The Frequency of Stand-replacing Natural Disturbance in the CIT Area

FINAL REPORT

Report to the Coastal Information Team

Karen Price and Dave Daust

October 31, 2003

Summary

Ecosystem-based management often uses the landscape patterns arising from natural disturbance regimes to inform management. This report estimates the natural disturbance frequency and proportion of old forest in various portions of BC's north and central coast.

Using forest age, disturbance history and ecosystem classification, we divided the study area into units experiencing similar disturbance frequencies, estimated the frequency for each unit using three different techniques, and translated the range of variation in disturbance frequency into a historical range of old forest in each unit. We examined available datasets (Forest Inventory and small-scale Predictive Ecosystem Mapping) and selected the latter for analysis. We used an independent dataset to check and refine logging activity data. We filtered suspicious data in an attempt to create a reliable dataset. In particular, data beyond 120 years ago likely contained errors. We aged logged stands prior to analysis and assumed that all remaining young stands were caused by natural disturbance.

We examined the appropriateness of two broad-scale (biogeoclimatic variants and hydroriparian sub-regions) and two fine-scale (Analysis Units and biogeoclimatic site series groups) classification systems for defining disturbance units. Timber Analysis Units were inappropriate. Cluster analysis identified combinations of hydroriparian sub-regions and site series with homogeneous disturbance frequencies and variation in disturbance frequency over the past 120 years. Disturbance units defined included Hypermaritime, Outer Coast North, Outer Coast South and Inner Coast physiographic regions and upland, fluvial, ocean spray and avalanche track ecosystems within these regions. Alternatively, biogeoclimatic variants clustered into four groups.

The three estimation techniques provided similar estimates of the historical disturbance frequency experienced over the past 120 years for each disturbance unit. Disturbance frequency, and variation in disturbance frequency, increased with increasing distance from the coast. Within regions, upland ecosystems (excluding avalanche tracks) experienced less frequent disturbance (and less variable disturbance frequency) than fluvial or ocean spray ecosystems.

Although the entire coast is dominated by old forest, estimates of the percent of forest over 250 years based on estimated disturbance frequencies for the past 120 years range from 46 – 73% in fluvial Inner Coast ecosystems to 95 – 99% in upland Hypermaritime ecosystems. These estimates can be used to inform management in the CIT area, but should be considered as hypotheses.

Introduction

Ecosystem-based management often uses the frequency and patterns of natural disturbance to inform management (e.g. Morgan et al. 1994, Province of BC 1995, Haynes et al. 1996, Cissel et al. 1999, Landres et al. 1999, Swetnam et al. 1999). In central and northern coastal BC, specifically the CIT (Coastal Information Team) planning area, several planning guides assess ecological risk by comparing features of anthropogenic and naturally-disturbed landscapes (e.g. the natural amount of old forest). In this report, we estimate the frequency of stand-replacing natural disturbances in the CIT area for use in these and other planning projects.

Dorner and Wong (2003) comprehensively review natural disturbance characteristics for the CIT area. They summarise the region's disturbances as follows:

"*Over the majority of the coastal landscape, stand-replacing disturbances are rare and stands are very old. Death and reestablishment of trees primarily occurs in small canopy gaps of ten trees or fewer. These gaps are typically created by a combination of wind and pathogens, and make up around 10 to 30 percent of the area in old-growth stands. Geomorphic disturbances are the most important naturally occurring high-severity, stand-replacing events in the area. Wind and fire may also occasionally create larger canopy openings, but return intervals for these larger events are on the scale of millennia throughout the majority of the area. Flooding is a key element of forest dynamics in floodplains and estuaries. Other agents that may occasionally injure or kill trees include snow, ice, frost, and drought, as well as insects and mammals, most notably porcupines, beavers, and deer. The different types of disturbances do not occur homogeneously across the forest landscape. Rather, most of the agents are confined to, or occur predominantly in specific stand types and on specific site types or landscape positions*." (Dorner and Wong 2003).

Dorner and Wong (2003) recommend dividing the landscape into units that reflect the different susceptibility of specific stands, sites and positions to disturbance (their Table B). Delineation of appropriate disturbance units is the first task of this report.

Few studies estimate the frequency of natural disturbance in the CIT area (summarised in Dorner and Wong 2003). A single study in the Central Coast found an average disturbance return interval of 4,400 years (primarily geomorphic disturbance agents) with longer intervals in hypermaritime islands (Pearson 2003). In the North Coast, estimated wind return intervals were more than 3,000 years and fire return intervals more than 1,000 years (Dorner and Wong 2002). The North Coast LRMP technical team used the limited data in Dorner and Wong (2003), and estimates of return interval based on the age-class distribution of forests (including harvested stands) to predict disturbance intervals (Holt and Sutherland 2003). They were unable to use data in harvested regions and relied on expert opinion to define their final ranges. This report builds on the work completed for the North Coast by extending analyses to the Central Coast and Haida Gwaii, by attempting to remove logging disturbance from age-class data and by examining several classification systems to determine the most appropriate spatial units for analysis of disturbance.

Disturbance Units Considered

Selecting an appropriate scale for any analysis of the range of natural variability is crucial (Morgan et al. 1994, Landres et al. 1999, Wimberly et al. 2000, Holt 2001). Choosing too small an area for analysis will result in variability so high as to be meaningless. For example, over several centuries, from 0 to 100% of a single stand could be young if a single disturbance replaces the entire stand. In areas of Oregon dominated by large, infrequent fires, even 40,000-ha watersheds proved too small to use the full range of amount of old forest to guide management (Wimberly et al. 2000). Conversely, choosing a too-large area, containing regions with different conditions and disturbance regimes, will also result in high variation. The largest area with relatively homogeneous disturbance dynamics should provide the most appropriate estimate.

Natural disturbance regimes vary with climate and physiography over broad scales (see Wong et al. 2002 for a review of disturbance regimes in British Columbia). For example, fires are bigger in drier areas and landslides are more common in wetter, mountainous areas. Within climatically and physiographically similar sub-regions, disturbance regimes vary with landform and substrate (Swanston et al. 1988, Swanson et al. 1993, Montgomery 1999). This finer-scale variation is more obvious in some areas than others. In interior sub-regions with low relief, natural disturbances (usually due to fire or insects) may be more or less randomly distributed over the landscape (e.g. Andison and McCleary 2002). Within the mountainous CIT area, however, disturbances are neither randomly nor uniformly distributed over sub-regions: geomorphic disturbance agents (avalanches, debris slides, debris flows, etc.) strip ribbons of forest from steep slopes; floods inundate valley bottoms and wind blows down patches in areas exposed to cyclonic storms or outflow winds (Dorner and Wong 2003, Pearson 2003). Thus, in the CIT area, appropriately homogeneous units for estimating a range in the variability of natural disturbances likely include both broad- and fine-scale divisions. We compare disturbance frequency in combinations of two broad-scale and two fine-scale classification systems to determine the most homogeneous units for analysis.

Broad Scale

The CIT area includes four very broad climatic/physiographic regions from west to east: the insular mountains on Haida Gwaii, the lowlands of the coastal trough, the maritime outer coast and submaritime inner coast mountains. The lowlands form narrow, low-lying, boggy strips along the coast and islands. The insular, outer coast and inner coast mountains feature steep, rugged mountains, large watersheds and ocean fjords, and are distinguished primarily by climate. Geomorphic disturbances (avalanches, debris flows and landslides) and flooding are common in the mountainous regions; fire is significant only in the inner coast mountains; wind is a minor disturbance agent except in exposed portions of the insular mountains (Pearson 2003). This classification was first proposed for the Central Coast by Pojar et al. (1999) and was confirmed as hydrologically appropriate by Trainor (2001).

Within these regions, three broad-scale classification systems attempt to delineate areas with relatively homogeneous conditions: Biogeoclimatic Ecosystem Classification and Ecoregion Classification are well established in British Columbia; hydroriparian sub-region classification has been recently developed specifically for the CIT area. Biogeoclimatic subzones and variants define areas with similar climate and focal plant communities (Banner et al. 1993). Ecosections are based on climate and landform and focus on wildlife habitat (Meidinger and Pojar 1991).

Hydroriparian sub-regions incorporate elements of both established classification systems and delineate groups of watersheds with relatively consistent hydrological conditions (Figure 1; Hydroriparian Planning Guide 2003). Ecoregion boundaries match some hydroriparian sub-region boundaries and hence do not need to be considered separately. The boundaries between biogeoclimatic subzones/variants and hydroriparian sub-regions often match, but biogeoclimatic subzones/variants change with elevation while hydroriparian sub-regions do not. We compared biogeoclimatic variants with hydroriparian sub-regions as possible broad-scale disturbance units. By grouping variants or sub-regions (based on disturbance frequency), we also investigated the appropriateness of the four regions defined by Pojar et al. (1999) for delineating areas with similar disturbance frequencies.

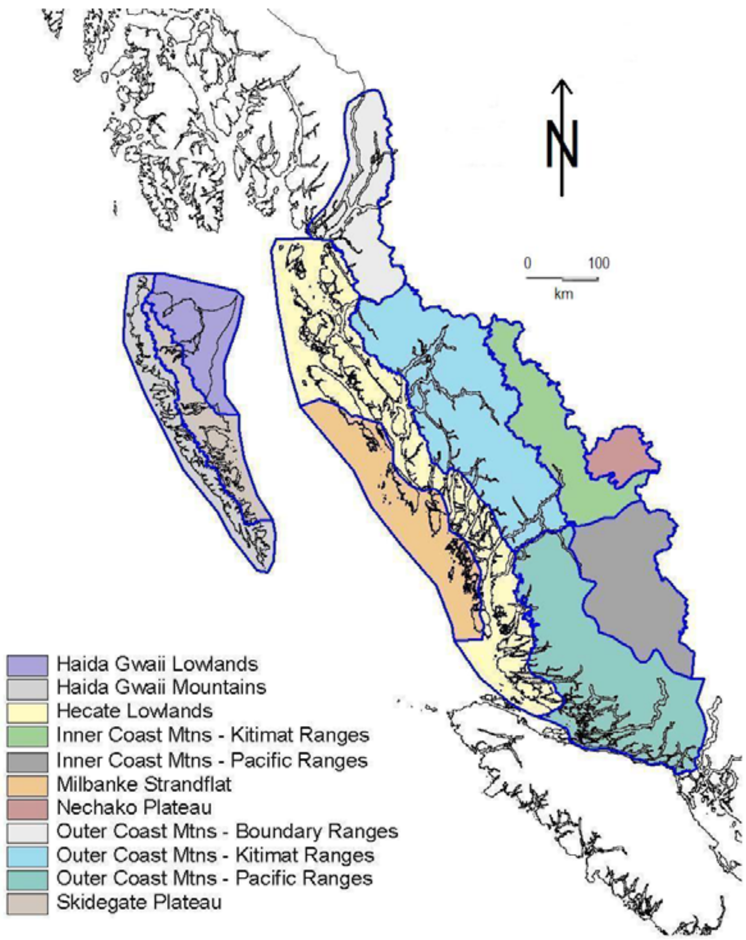

Figure 1. Hydroriparian subregions in the CIT Planning area.

Within the CIT area, there are 23 biogeoclimatic subzones and 29 variants (Table 1), and eleven hydroriparian sub-regions (Table 2).

Table 1. Area of each biogeoclimatic subzone within the CIT area (excluding Gwaii Haanis Park).

Subzone	Variants	Area (x 1,000 ha)
AT		1,276
CWH[1]v[2]h[3]	vh1[4], vh2	1,729
CWHwh	wh1, wh2	600
CWHvm	vm1, vm2	1,633
CWHwm		114
CWHmm	mm1	8
CWHdm		21
CWHxm	xm2	28
CWHws	ws1, ws2	208
CWHms	ms2	133
CWHds	ds2	82
MHwh		152
MHmm	mm1, mm2	885
MHmmp	mmp1, mmp2	163
ESSFmw		83
ESSFmc		65
ESSFmk		1
ESSFxv		2
IDFww		33
IDFdw		<1
MSdc	dc2	9
SBSmc	mc2	85
SBPSmc		55
Total		7,365

[1] CWH = Coastal Western Hemlock; MH = Mountain Hemlock, ESSF = Engelmann Spruce – Subalpine Fir, IDF = Interior Douglas-Fir, MS = Montane Spruce, SBS = Sub-Boreal Spruce, SBPS = Sub-Boreal Pine – Spruce ;
[2] v = very wet, w = wet, m = moist, d = dry, x = very dry
[3] h = hypermaritime, m = maritime, s = submaritime, w = warm, c = cold, p = parkland
[4] variants represent differences in latitude (CWHvh1 = central; vh2 = north), altitude (CWHwh1 and vm1 = submontane; wh2, vm2 = montane) and aspect (MHmm1 = windward; mm2 = leeward)

Table 2. Area of each hydroriparian sub-region within the CIT area (excluding Gwaii Haanis Park).

Sub-region	Abbreviation	Climatic Region	Physiographic Region	Area (x 1,000 ha)
Haida Gwaii Mountains	HGM	Hypermaritime	Insular Mountains	238
Skidegate Plateau	SP	Hypermaritime	Insular Mountains	293
Haida Gwaii Lowlands	HGL	Hypermaritime	Coastal trough	327
Milbanke Strandflat	MS	Hypermaritime	Coastal trough	194
Hecate Lowlands	HL	Hypermaritime	Coastal trough	1,350
Outer Coast Mountains – Boundary/ Skeena Ranges	OCB	Maritime	Coast Mountains	645
Outer Coast Mountains – Kitimat Ranges	OCK	Maritime	Coast Mountains	1,035
Outer Coast Mountains – Pacific Ranges	OCP	Maritime	Coast Mountains	1,681
Inner Coast Mountains – Kitimat Ranges	ICK	Submaritime	Coast Mountains	404
Inner Coast Mountains – Pacific Ranges	ICP	Submaritime	Coast Mountains	979
Nechako Plateau	NP	Continental	Interior Plateau	205
Unclassified				15
Total				7,365

Fine Scale

Neither biogeoclimatic variants nor hydroriparian sub-regions capture the variation in landforms (e.g. floodplains, steep uplands, wetlands) that is related to disturbance type on the coast (Dorner and Wong 2003). Two fine-scale classification systems define ecosystems within the broader sub-regions. Timber analysis units (AUs), developed for analyses of timber potential, classify forested ecosystems based on predominant tree species and tree growth rate (Ministry of Forests 1999a). Biogeoclimatic site series classify forested and, to some extent, non-forested ecosystems based on plant community, soil moisture and nutrient regimes, and landscape position (Banner et al. 1993).

As macroclimate changes, plant communities shift to different landforms. Within similar macroclimates, biogeoclimatic site series tend to be associated with particular landforms and can be grouped accordingly. Similarly, within relatively homogeneous areas, it is possible to correlate timber AUs with site series and, consequently, with landforms. The North Coast LRMP takes this approach and combines AUs into high, moderate and low disturbance classes (Holt and Sutherland 2003). AUs across larger regions than the North Coast, however, do not represent the same ecosystems or landforms. For example, “spruce” units on the coast are dominated by Sitka spruce and associated with riparian or shoreline ecosystems whereas “spruce” units further inland are dominated by hybrid white spruce and occur in upland as well as riparian ecosystems. Similarly, “pine” units on the outer coast are typically rarely-disturbed bog/forest mosaic ecosystems, while “pine” units further inland can be young seral stages of several ecosystems or dry ecosystems. For this reason, AUs, as well as site series, should only be considered within sub-regions or biogeoclimatic variants. We compared groups of site series with AUs as possible fine-scale units.

Over half of the forested area within the CIT area is covered by low productivity stands dominated by Western redcedar or yellow cedar (Table 3).

We predicted that, within wet and very wet broad-scale units, high productivity AUs would experience more frequent disturbance because they often occur on fluvial or steep colluvial landforms. We predicted that, near the coast, spruce-leading AUs would have relatively frequent disturbances due to flooding and that inland, Douglas-fir stands would experience most frequent and most variable disturbance due to fire.

Table 3. Area of each AU within the CIT area.

Dominant Tree[1]	Productivity[2]	Area (x 1,000 ha)
Cedar	High	76
	Medium	267
	Low	897
	Very Low	1,287
Hemlock	High	133
	Medium	287
	Low	370
	Very Low	519
Spruce	High	41
	Medium	56
	Low	34
	Very Low	97
Douglas-fir	High	12
	Medium	31
	Low	35
	Very Low	7
Pine	All	235
Alder	All	55
Cottonwood	All	11
Maple	All	< 1
Deciduous	All	14
Undefined	All	2,900
		7,365

[1] Leading species classes are based on inventory type groups: Douglas fir = 1 to 8; Cedar = 9 to 11, 14; Hemlock = 12, 13, 15 to 20; Spruce = 21 to 26; Pine = 27 to 34; Alder = 37, 38; Maple = 39; Cottonwood = 35, 36; Other deciduous = 40 to 42.

[2] Productivity class are based on site index (estimated tree height at age 50; SI): For Douglas-fir leading, good = (SI > 27), medium = (20 < SI ≤ 27), low = (10 < SI ≤ 20) and very low = (SI ≤ 10); For other leading species, good = (SI > 22), medium = (15 < SI ≤ 22), low = (10 < SI ≤ 15) and very low = (SI ≤ 10).

Maps showing groups of site series (small-scale predictive ecosystem mapping or “ssPEM”) list over 200 aggregated site series within biogeoclimatic variants for the CIT area—far too many for analysis. Hence, we combined site series into groups having similar landscape positions that we hypothesised would experience similar disturbances (Table 4). We retained ssPEM categories for estuarine, fluvial and ocean spray ecosystems and combined several wetland ecosystems into a single category. We also created a fan category, consisting of ecosystems that often occur on fluvial fans. In the upland, we retained the avalanche track category and divided the remaining aggregated site series into a “colluvial” class with steep, productive ecosystems and a general “upland” class (based on Banner et al. 1993). We predicted that, within a broad sub-region, disturbance would be relatively frequent in fluvial ecosystems due to flooding, on fans due to hydrogeomorphic processes, in ocean spray forests due to exposure to wind, and on colluvial slopes due to landslides. Avalanche tracks are defined by repeated disturbance. We predicted that disturbance would be less frequent in wetlands and general upland ecosystems.

Table 4. Area of each group of site series within the CIT area[*].

Site series group	Area (x 1,000 ha)
Avalanche	87
Colluvial	1,033
Estuary	<1
Fluvial	62
Fan	452
Ocean spray	27
Upland	1,922
Wetland	345
Other	31
Total	3,960

[*] Areas are lower in this table because we did not divide the area into site series until after filtering the data (see below).

In their review of natural disturbances in the CIT area, Dorner and Wong (2003) suggest creating disturbance units based on site characteristics. They divide the area into floodplains and fans, bog wetlands, gullies, estuaries, saltspray forest, subalpine forest, avalanche tracks and productive and less productive upland forest. Our classification by site series should capture this suite of units. Dorner and Wong (2003) then divide upland forest by steepness and exposure to storms. Hydroriparian sub-regions and, to some extent, biogeoclimatic variants represent areas of different steepness at a broad scale. We did not explicitly include measurement of steepness in our analyses. Measurement of exposure to wind is complicated by the fractured coastal topography and could not be captured using existing classification systems.

Methods

Data

Dave Leversee (spatial analyst, Sierra Club) compiled datasets, performed overlays and assessed the quality of information available.

This study is based on existing forest-age data and assumes that stand age approximates time since the disturbance. Two available databases describe forested land in the CIT area. Forest inventory data ("seamless forest cover") distinguish forested from non-forested cover and record selected attributes of forested areas including predominant tree species, site productivity (based on estimated tree height), stand age and disturbance history. Attributes for old or naturally-disturbed forests are estimated from air photo interpretation (about 1:15,000 scale) and field sampling; information about logged sites comes from activity reports. Small-scale predictive ecosystem mapping (ssPEM), based on satellite imaging, forest inventory data and terrain modelling, divides vegetation into biogeoclimatic variants and site series (EBA Engineering Consultants 2003). SsPEM also records attributes for each ecological unit, including stand age and disturbance history.

The content and quality of forest inventory data vary across the CIT planning area. Forest inventory databases are developed and maintained by both government agencies and private industry, depending upon the land-use agreements in specific areas. Creating a complete coverage of the CIT area requires combining data of differing quality and sometimes extrapolating from inferior formats (e.g., more general species classes). SsPEM data should be more consistent across the CIT planning area than forest inventory data, because they rely partly on satellite images of the CIT area. The forest inventory database has been used for many purposes; its errors are well-known. SsPEM is a relatively new database with unknown errors.

Inspection of both ssPEM and forest inventory databases revealed gaps, errors and inconsistencies (Dave Leversee, personal communication). Logging information, in particular, posed interpretative problems. Forest inventory data misclassify a large proportion of old logging as naturally disturbed (e.g. over 30% misclassified in parts of the Central Coast, Pearson 2003). Conversely, ssPEM classifies some natural areas as logged (Dave Leversee personal communication) as well as the reverse (Price 2003). Difficulties with the available version of the seamless forest cover and a better logging layer in ssPEM led us to rely on ssPEM for most attributes.

Data extracted from ssPEM include biogeoclimatic variant, site series, projected stand age and disturbance history. Hydroriparian sub-regions were based on a small-scale map and description given in the Hydroriparian Planning Guide (2003 draft). We created AUs by combining inventory type groups (groups of tree species) with site productivity classes recorded in ssPEM. AU definitions were based on recent timber supply reviews in the North Coast, Central Coast and Queen Charlotte Island Forest Districts, but were modified to provide consistent definitions across the entire CIT planning area (see Table 3 footnote).

We combined stand age into 20-year age classes up to 140 years and combined all forest over 140 years into a single class. Age data for old forests, based on air photo interpretation, are notoriously problematic (Pollack et al. 1997). Using age classes reduces the errors in individual estimates but does not remove biased errors. In coastal forests, age is often underestimated, particularly on low-productivity sites that are difficult to interpret remotely and generally outside the harvesting landbase (Holt and Sutherland 2003). In the conventional 9-class grouping (seven 20-year classes up to 140 years, class 8 = 140 – 250 years, class 9 = 250+ years), age-classes 7, 8 and 9 most likely contain errors for some forest types.

Information on disturbance history lists stand-replacing disturbance agents including logging, fume kill, natural agents and unknown. We considered disturbance of unknown origin to be natural because many natural disturbances cannot be easily identified without field verification—hence most remain unclassified. Fume-killed stands died when they were exposed to smoke from a mine.

We checked disturbance history as mapped by ssPEM with an independent source (disturbance history maps based on 1998 Landsat imagery, forest cover age class, some air photo interpretation and flights; Sierra Club of Canada, BC Chapter), and subsequently modified the database. SsPEM appeared to overestimate logging, identifying some apparent natural disturbances on the satellite image as logged (Dave Leversee, personal communication). This overestimate may be due to relying partly on structural stage to classify logging (EBA Engineering Consultants 2003). An overlay of the satellite-image on the ssPEM maps made it possible to flag “logged” ssPEM polygons covered by more than 25% of satellite image logging as “probably logged” and those covered by less as “probably natural” (25% was chosen subjectively as half of 50%; visual inspection of the overlay suggested that logged polygons usually overlapped by only 50% because of differences in the resolution and position of the polygons). Visual inspection also showed relatively few cases where the satellite data suggested that naturally-disturbed ssPEM polygons should be classified as logging (Dave Leversee, personal communication), thus we did not alter the ssPEM natural classification. Final disturbance classes hence include natural disturbance (327,091 ha)[1] and fume kill (15,965 ha) listed in ssPEM, and "probably natural" (44,630 ha) and "probably logged" (485,393 ha).

To estimate the amount of naturally-disturbed young forest, we reversed the effects of anthropogenic disturbance in the data by aging "probably logged" and fume-killed stands. We assumed that the remaining young forest was natural, although it includes "probably natural" and unknown-origin stands as well as stands with defined natural disturbances. Because the period of reliable data for analysis was 120 years (see below), we assumed that anthropogenically-disturbed stands were at least 120 years old before logging or fume kill, and did not need to consider how logging was distributed in older stands. This assumption seems reasonable on the coast, generally, given the ubiquity of old forest, and for logging particularly, given that mature and older stands are targeted. Aging, rather than removing, anthropogenic disturbance allows logged stands to contribute to the estimate of original old forest and thus affects the estimated proportion of young, naturally-disturbed forest. Removing logged areas from the database results in an overestimate of disturbance frequency (Pollack et al. 1997).

We did not know the pre-harvest leading tree species, and consequently AU, of logged stands. During the aging process, we retained the recorded AU for harvested stands, assuming that AU remained unaltered. This assumption is unrealistic, but necessary in the absence of a succession model. Biogeoclimatic site series are based on potential plant community in old stands and do not pose the same challenge.

Data Filtering

Analyses in this report are based on existing data, many of them sensed remotely (air photos or satellite image) or copied from old activity records. Misclassification of anthropogenic disturbance, of forest age or of ecosystem characteristics increase error in analyses. Hence, we assessed patterns for suspicious classification and removed some areas or classes from the database in an attempt to create a reliable area and period for analysis (Table 5).

We excluded Gwaii Haanis Park from analyses because visual inspection suggested that forest cover data (and consequently ssPEM) there were particularly unreliable (Dave Leversee, personal communication). We removed the Nechako Plateau because it is relatively small and climatically very different from the rest of the region, composed of subzones with interior climates. We subsequently removed several other interior biogeoclimatic subzones because they included less than 5,000 ha within the remaining area.

We removed large non-forested areas (parkland or alpine biogeoclimatic subzones) and smaller areas within the remaining landbase without forest cover (undefined AUs). We also removed a

[1] Areas of each disturbance class only include age classes 1 to 7.

small area classified as age-class 0. Age-class 0 does not represent a 20-year period (unlike age-classes 1 to 6) and sometimes occurs by default when information is missing.

Table 5. Areas removed from the database.

Type of Unit	Unit	Reason for removal	Net Area removed
Hydroriparian subregion	Undefined	questionable data	15,092
Hydroriparian subregion	Nechako Plateau	interior climate	205,153
Biogeoclimatic subzone	ESSFmc, mk, xv, IDFdw	too small to analyse (< 5,000 ha)	4,628
Biogeoclimatic zone	AT	non-forest	1,259,663
Biogeoclimatic subzone	MHmmp, MHwhp	non-forest	190,360
AU	unclassified AUs	non-forest	1,490,652
Age class	age class zero	misclassified ecosystem?	3,442
Subzone within hydroriparian subregion	CWHwm, ws and MHmm in Outer Coast Mountains-Boundary Ranges	misclassified fume kill?	162,588
AU within hydroriparian subregion	pine AUs in the HGL and HL	misclassified age?	74,926
			3,406,504

To assess errors related to misclassification of disturbance origin, we plotted the proportion of naturally-disturbed area in each age class on top of anthropogenic disturbance for different combinations of hydroriparian subregion, biogeoclimatic variant and AU. We found an increase in disturbance classified as natural that correlated with the location and timing of known fume kill (Figure 2). Suspecting misclassification of fume kill as "natural", we removed the entire region affected (removal of specific age classes complicates analyses). After removing the fume-killed region, the CWHws1 variant was reduced to an area too small to warrant analysis; we removed it entirely. Several high productivity AUs had increases in natural disturbance that correlated with the onset of harvesting in an area (Figure 3). We suspect that some early logging has been misclassified as natural, but the pattern was not sufficiently consistent to warrant their removal.

Figure 2. Proportion of study area in each age class (midpoint) in stands classified as naturally disturbed and fume killed.

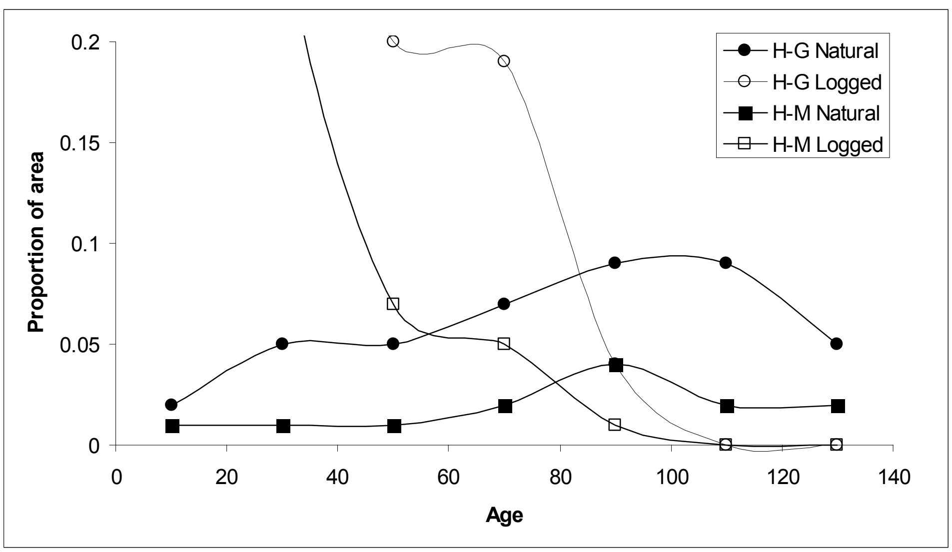

Figure 3. Proportion of study area in each age class (midpoint) for hemlock-good (H-G) and hemlock-medium (H-M) analysis units classified as naturally disturbed and logged.

To assess errors related to misclassification of age, we plotted age class for each AU in each biogeoclimatic variant and hydroriparian sub-region. We found an increase in the area recorded in age-class 7 in several AUs in several regions, relative to the areas in age-classes 1 – 6 (Figure 4). We suspect that this pattern arises from a small proportion of age-class 8 being misclassified as 7. Because of the much greater area of age class 8 relative to age class 7 in old coastal forests, misclassification of the same small proportion of each age class would lead to an large overestimate of the area in age-class 7. We combined age-class 7 with older forest for all analyses because we suspect that misclassified age-class-7 data occur sporadically throughout the CIT planning area. Hence, our reliable time period for analysis is the most recent 120 years.

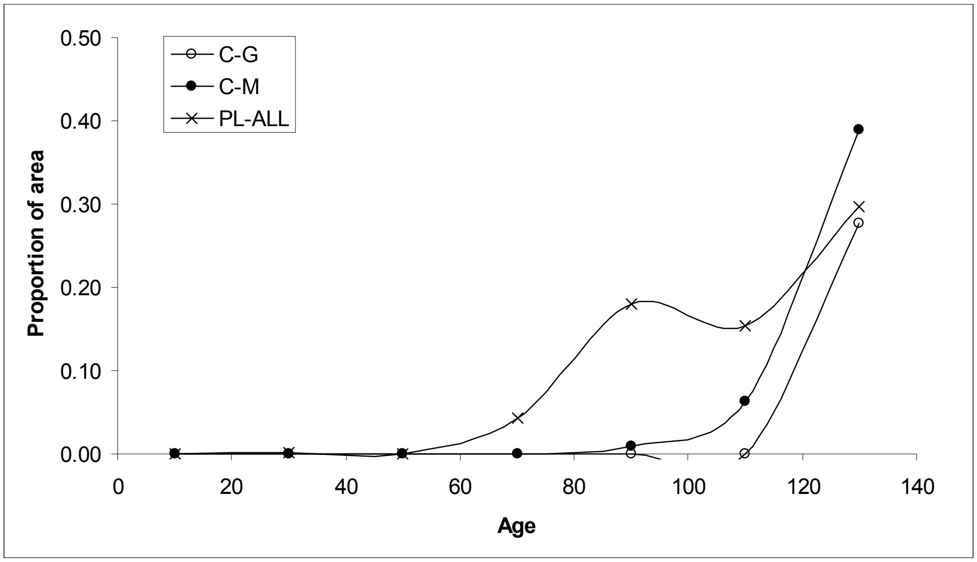

Figure 4. Proportion of study area in each age class (midpoint) for the cedar-good (C-G), cedar-medium (C-M) and pine (PL-ALL) AUs in the Haida Gwaii Lowlands following reclassification of logged stands as age-class 9.

The pine AU (all site productivity classes) appeared to be misclassified in several age classes in two sub-regions. The Haida Gwaii Lowlands and Hecate Lowlands were classified as having very little area in age classes 1 – 4 and a much higher area in classes 5 – 7 (see Figure 4). Coastal pine occurs in boggy, poor-growing sites that have not been targeted by logging, nor should they be particularly predisposed to stand-replacing disturbance. We suspect that pine bogs are difficult to age during air photo interpretation because tree height may reflect both site quality and tree age. In addition, because pine bogs do not undergo succession to another tree species and because pine have a relatively short life span, tree age may be a poor reflection of stand age, particularly when healthier, probably younger, trees are selected for age samples. Thus, we removed the pine AU from the Haida Gwaii Lowlands and Hecate Lowlands.

Selection of Disturbance Units

We used a simple measurement of disturbance frequency (based on the proportion of area in each age class, method 1 below) to discriminate among combinations of the two broad-scale (biogeoclimatic variant and hydroriparian sub-region) and two fine-scale (AUs and groups of site series) disturbance units. We plotted mean and standard deviation (based on age classes 1 – 6; i.e., up to 120 years) for each combination of units and used these plots and cluster analysis (non-hierarchical clustering using Kmeans; SYSTAT 5.03) to define a minimum number of relatively homogeneous disturbance units (based on means and standard deviations). We compared the results among the four combinations of broad and fine-scale units (variant x site series, variant x AU, sub-region x site series, sub-region x AU) and selected the best combination for subsequent analyses and estimates.

Estimating Natural Disturbance Frequency

Many techniques exist to estimate natural disturbance regimes (described in Wong et al. 2002). Appropriate methods depend upon the available data and on assumptions about disturbance characteristics. Because existing data rarely match the requirements and assumptions of any one method, it is prudent to try several techniques and compare the results (Wong et al. 2002). This study uses stand age as a surrogate for the time since disturbance and is based on existing databases (e.g. Johnson and Gutsell 1994). Hence, we use a map of forest age placed over a map of disturbance units to infer the disturbance history of the CIT area for the past 120 years. Such analyses have been used, primarily in fire-dominated landscapes, for at least two decades (review in Boychuck et al. 1997).

No one method is ideal for the coastal situation, although the rarity and small size of disturbances facilitate analyses somewhat. We examine natural disturbance frequency in three ways, using a simple ratio approach based on the proportion of young forest in each age class, calculating the probability of survival by age class and fitting a negative exponential function to stand-age distribution data (Wong et al. 2002).

<u>Method 1</u>

We first analysed the data using the proportion of forest area in each age class. For each disturbance unit, we calculated the mean and standard deviation of the proportion of area in each age class included in the 120-year reliable dataset (disturbance frequency estimates) and then divided by 20 to estimate the annual disturbance frequency (Equation 1).

$$f_i = \frac{A_i \Big/ \sum_{1}^{n} A_i}{Yr_i} \qquad (1)$$

where

f = disturbance frequency per year
A_i = area in age class i
Yr_i = years in age class i
i = age class
n = number of age classes

We used this method primarily to partition the CIT area into units with homogeneous disturbance frequencies. This method is formally applicable only when the dates of all disturbances, including repeated disturbances in the same area, are known. Forest age cannot provide these data because the traces of old disturbances can be obliterated by more recent disturbances. Hence, disturbance frequency will be underestimated for areas susceptible to repeated disturbance. Because disturbances are infrequent in the CIT area, and because our reliable sample period is short (120 years), we considered the potential error due to hidden disturbances low enough, and the benefits of a simple analysis high enough to warrant trying the technique. In a study of disturbance using recent and old air photos, Pearson (2003) did not find evidence for any significant obliteration of old disturbances. We aimed to reduce the overall error due to repeat disturbances by examining areas susceptible to frequent disturbances (e.g. avalanche tracks, fluvial ecosystems) separately from those areas less susceptible to repeat events. Hence, these estimates should be relatively trustworthy for the areas less susceptible to repeated disturbance, but questionable for the small units with repeated disturbance.

<u>Method 2</u>

Our remaining methods are based on the negative exponential model and account for repeated disturbances in older age classes. In the second method, based on Reed's saturated model (Reed 1997, Reed et al. 1998), we calculated the proportion surviving from one age class to another based on the cumulative area in all older age classes (Equation 2a) and then calculated a disturbance frequency using a negative exponential equation (2b).

$$P = \frac{CA_{i+1}}{CA_i} \qquad (2a)$$

and

$$f_i = \frac{Ln(P)}{-t} \qquad (2b)$$

where

P = proportion of area surviving from one age class to another (also proportion greater than age t)
CA = cumulative area (all area in focal and older age classes)
i = focal age class
f = disturbance frequency
t = years in age class i

This method again produces a value for each age class, available for calculating means and standard deviation. As a variation on this method, we "rolled-back" age classes, proportionally distributing each age class into older age classes (Dorner 2002).

<u>Method 3</u>

In the third, widely-used, method, we fitted a negative exponential function to the entire distribution of age-class data. It is not possible to calculate a mean or standard deviation for this method.

<u>Assumptions</u>

Use of the negative exponential assumes that disturbances follow a Poisson process. All three approaches assume that the disturbance regime does not change over time or across the landscape and that susceptibility to disturbance is not age-dependent.

We assume that natural disturbance frequency has not changed over the analysis period. With harvesting disturbance aged, there is no a priori reason to consider separate disturbance history epochs. In the wet, sparsely populated, CIT area, neither an increase in fires associated with early settlement nor more recent fire suppression pose the interpretative difficulties that they do elsewhere (e.g. Wong et al. 2002). Our reliable period of data is short relative to moderate or long-term climatic fluctuations. The validity of this assumption depends upon our ability to identify harvested areas correctly.

On the coast, we cannot assume that all stands face the same probability of disturbance. Indeed, differential susceptibility is one of the characterising features of disturbance regimes in coastal forests (Dorner and Wong 2003). However, we can divide the CIT area into disturbance units based on landforms with different susceptibility to disturbance (see Disturbance Units, above). We then assume that disturbance does not vary within units. This assumption is more reasonable for some units than others.

We assume that, within a particular disturbance unit, natural disturbance is not age-dependent. In coastal forests, in the absence of logging, young forests may be disturbed more often than old forests, not because younger forests are more susceptible (as, for example, old forest are more susceptible to beetles in other areas), but because they are more likely to be growing on susceptible landforms. Avalanche chutes are the most extreme example, where forests rarely have time to re-establish before disturbance (data in Dorner and Wong 2003). Our site-series groups are intended to separate out avalanche chutes and other landforms with high susceptibility to disturbance.

Finally, we assume that disturbances are small, relative to the study area, and evenly spread over time. This assumption is generally, but not entirely valid (Dorner and Wong 2003, Pearson 2003). Periods of heavy rainfall and major storms are linked with episodic flooding events over large areas (e.g. Hogan and Schwab 1991); a single fire in the Central Coast accounted for all fire disturbances in the study area over the past 140 years (Pearson 2003).

Provided that disturbances are small relative to the study area and that disturbance frequency does not change over time or space, the negative exponential method is relatively robust to departures from assumptions when tested on fire-driven systems (Lertzman et al. 1998). No experiments have tested assumption in coastal disturbance dynamics.

Results

Disturbance Units Selected

<u>Fine Scale</u>

We selected site series groups over AUs as a fine-scale disturbance units for both theoretical and empirical reasons.

1. Site series are more directly related to disturbance regimes than AUs. In particular, it was possible to combine site series into groups relevant to disturbance (e.g. floodplains, wetlands, steep upland ecosystems), but much less feasible to combine AUs. The inability to group AUs resulted in too many units with small areas, leading to very high standard deviations and non-normal distributions.
2. Different seral stages of a given ecosystem are often classified as different AUs, but the same site series. Many ecosystems have a deciduous seral stage (usually alder or

cottonwood in the CIT area). When young, these ecosystems are classified as deciduous AUs. This classification system made estimation of a disturbance frequency for an ecosystem with a deciduous stage virtually impossible. Without a succession model there was no way of knowing what a deciduous stand was before disturbance or what it could become over time. In some cases, disturbance will still be recorded after a time delay, as the young conifers grow amongst deciduous trees (e.g. age class 3 spruce may actually represent 150 rather than 50 years post-disturbance), but errors are unknown and incalculable.

3. SsPEM aggregated site series are useful for delineating and separating areas with different disturbance regimes or questionable data. As an example of the first case, avalanche chutes experience more frequent disturbances, are not randomly located over upland forest and should not be included in upland estimates. As an example of the second case, data in ocean-spray forests suggested that large amounts of old A-frame logging were misclassified as natural. The ocean-spray data can be considered separately from other estimates using site series, but not using AUs.
4. Separation by groups of site series resulted in a lower mean coefficient of variation than separation by AUs, suggesting that groups of sites series were more homogeneous (variant x AU: CV = 1.5; hydroriparian sub-region x AU: CV = 1.2; variant x site series: CV = 1.0; hydroriparian sub-region x AU = 1.0).

<u>Broad Scale</u>

It was more difficult to choose between the two broad-scale classification systems. Biogeoclimatic subzones and hydroriparian sub-regions overlap but do not match perfectly (Table 6). The hypermaritime subzones are found primarily in the insular mountains and lowlands; the maritime subzones are chiefly within the outer coast mountains and the sub-maritime and inland subzones are mostly within the inner coast mountains. Five subzones are limited to a single hydroriparian sub-region. The high elevation mountain hemlock zone is divided into fewer groups than the coastal western hemlock zone, and hence is spread over more sub-regions. This correspondence between classification systems is not unexpected given that biogeoclimatic divisions were considered during development of the hydroriparian sub-regions.

Table 6. Overlap between biogeoclimatic subzones and hydroriparian sub-regions. Combinations of hydroriparian sub-region and biogeoclimatic subzones with at least 5,000 ha contain a check mark.

		Hydroriparian sub-region									
		Insular mountains		Lowlands			Outer Coast Mountains			Inner Coast Mountains	
	Biogeoclimatic subzone	HGM*	SP	HGL	MS	HL	OCB	OCK	OCP	ICK	ICP
Hyper-maritime	CWHvh	✓			✓	✓	✓	✓			
	CWHwh		✓	✓							
	MHwh	✓	✓			✓	✓				
Maritime	CWHvm					✓	✓	✓	✓		
	CWHmm								✓		
	CWHdm								✓		
	CWHxm								✓		
	MHmm					✓	✓	✓	✓	✓	✓
Sub-maritime	CWHws								✓	✓	✓
	CWSms							✓	✓	✓	✓
	CWHds									✓	✓
Inland	ESSFmw									✓	✓
	IDFww										✓
	MSdc										✓

* See Tables 1 and 2 for acronyms.

Analyses did not suggest that one broad system provided more homogeneous disturbance units than the other based on similar coefficients of variation.

Analyses showed a strong effect of distance from the coast, but no obvious effect of elevation on disturbance frequency. The elevation gradients represented by biogeoclimatic variants, although representing different overall ecosystems, may not represent different disturbance frequencies (acknowledging the obvious difference that there are fewer floods, but more avalanches, at higher elevation).

Because we had no clear reason to select one broad-scale unit over the other, we analysed the data using both biogeoclimatic variant and hydroriparian sub-region.

Final Disturbance Units

Cluster analysis of hydroriparian sub-regions and site series groups, based on mean and standard deviation of disturbance frequency, created four broad-scale units (Table 7) and three fine-scale units (Table 8). The clustering of hydroriparian sub-regions closely match the broad climatic/physiographic regions suggested by Pojar et al. (1999) and will subsequently be referred to as physiographic regions.

Table 7. Clustered hydroriparian sub-regions.

Cluster (region)	Hydroriparian sub-regions
Hypermaritime	HGM, SP, HGL, MS, HL
Outer Coast North	OCK, OCB
Outer Coast South	OCP
Inner Coast	ICK, ICP

Table 8. Clustered site series.

Cluster	Site series groups
Upland	Upland, colluvial, fan, wetland
Fluvial	Fluvial
Ocean spray	Ocean spray
Avalanche	Avalanche

We had predicted that ecosystems on steep colluvial slopes and fans would experience more disturbance than ecosystems in other upland areas. The data did not discriminate among these ecosystems. Neither could we discern any difference in the disturbance frequencies in wetland and upland ecosystems. As predicted, fluvial and ocean spray ecosystems experienced more frequent, and more variable frequency, disturbance. We removed avalanche tracks from further analyses because of their extremely high levels of disturbance, susceptibility to repeated disturbance events within the analysis period and low relevance to forest management. Hence each broad-scale unit included three fine-scale groups: upland forested (except for avalanche tracks), fluvial and ocean spray ecosystems (ocean spray ecosystems covered too small an area for analysis except in the Lowland unit).

A similar cluster analysis of biogeoclimatic variants and site series groups created four broad-scale units (Table 9).

Table 9. Clustered biogeoclimatic variants.

Cluster	Biogeoclimatic variants
Hypermaritime plus others	CWHvh1, vh2, wh1, wh2, mm1, MHwh, mm2, MSdc2
Very wet maritime	CWHvm1, vm2
Dry maritime and wet sub-maritime	CWHdm, xm, ws, MHmm1, ESSFmw
Dry sub-maritime	CWHms, ds, IDFww

Within biogeoclimatic variants, we could not detect any differences among site series groups, possibly because biogeoclimatic variants, to some extent, capture variation expressed by site series groups. For example, high elevation variants had no fluvial ecosystems. Hence, fine-scale units did not add much to the explanatory power of the broad group. Conversely, because hydroriparian sub-regions include entire watersheds and all elevations, site series groups were a useful addition.

Frequency of Natural Disturbance in the CIT Area

As expected in a region dominated by gap disturbances, by far most of the unlogged forest in the CIT area is old (Figure 5).

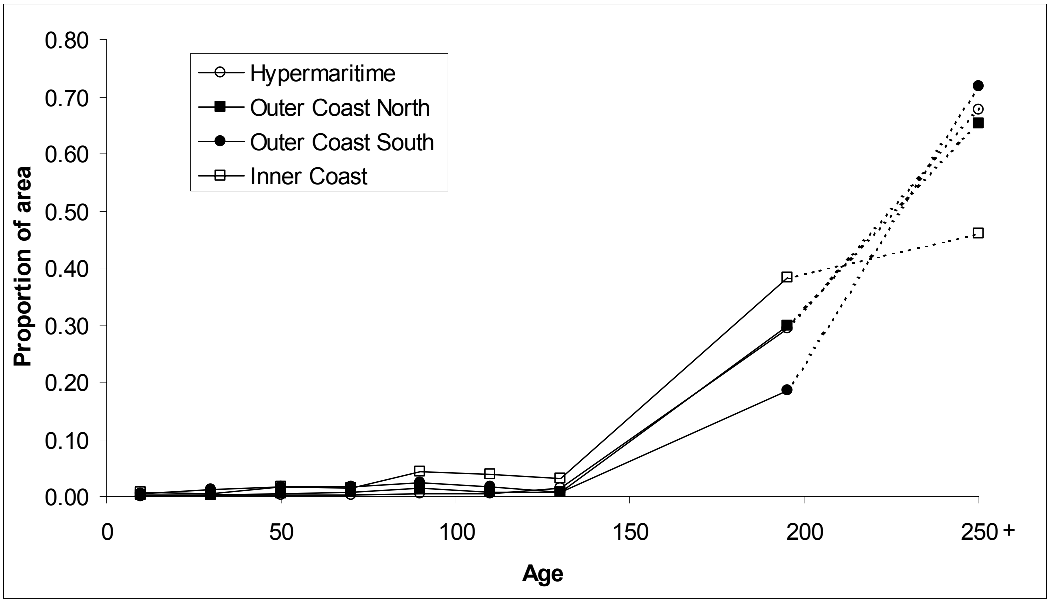

Figure 5. Proportion of study area in each age class (midpoint except for last class) in physiographic regions.

Disturbance frequency was lowest in the Hypermaritime region, low in the northern portions of the Outer Coast Mountains, higher in the southern portions of the Outer Coast Mountains and highest in the Inner Coast Mountains (Figure 6). Variation in disturbance frequency increased similarly. Fluvial and ocean-spray ecosystems appear to have been disturbed more frequently than upland ecosystems (region effect: $F_{3,43} = 10.1$, $p < 0.001$; site series effect: $F_{1,43} = 16.9$, $p < 0.001$; no significant interaction; two-way analysis of variance based on results from method one). Each hydroriparian group differed from at least one other (Bonferroni-corrected pairwise comparisons).

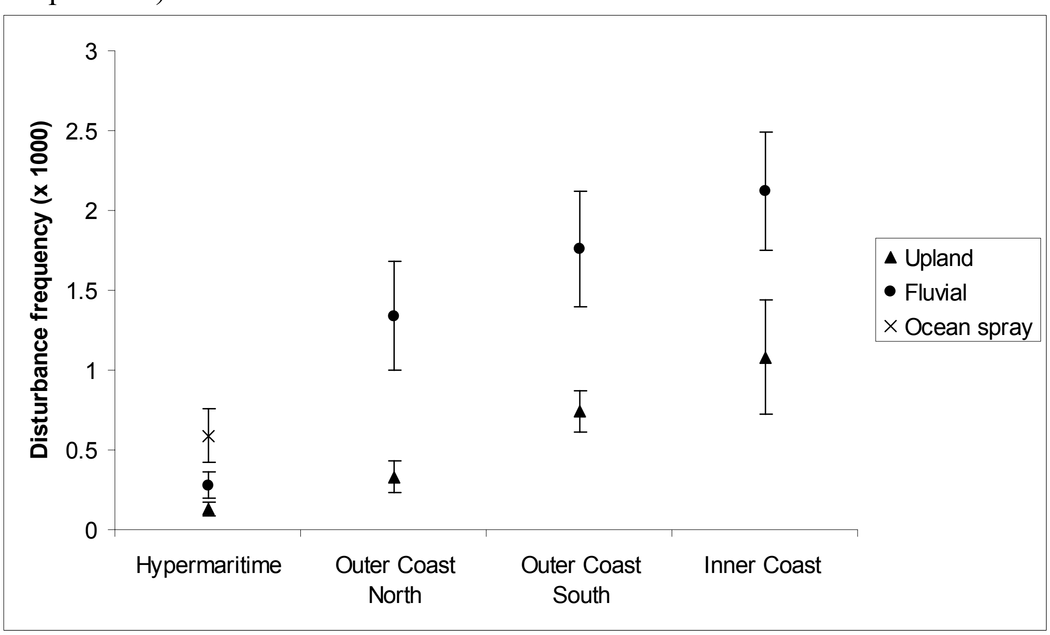

Figure 6. Mean disturbance frequency (proportion of area disturbed per year x 1,000) estimated by method 2 for upland, fluvial and ocean spray units in the four physiographic regions of the CIT area. Bars are standard errors.

Within the final disturbance units, the three methods for estimating natural disturbance gave similar results (Table 10). The roll-back technique gave estimates equivalent to those estimated by method 2 without roll-back. This similarity is because, with the assumption of equal hazard of disturbance across all age groups, the roll-back technique is essentially equivalent to Reed's (1997, Reed et al. 1998) method except under high disturbance frequencies.

Table 10. Mean disturbance frequency (proportion of area disturbed per year x 1,000) calculated by three methods for upland and fluvial disturbance units in four physiographic regions of the CIT area. Methods 1 and 2 are shown ± standard deviation; no valid range is calculable for Method 3.

	Upland			Fluvial		
Region	Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
Hypermaritime	0.13 ± 0.10	0.13 ± 0.10	0.10	0.28 ± 0.19	0.28 ± 0.19	0.23
Outer Coast North	0.33 ± 0.23	0.33 ± 0.23	0.29	1.24 ± 0.76	1.31 ± 0.81	1.40
Outer Coast South	0.71 ± 0.31	0.74 ± 0.33	0.67	1.59 ± 0.85	1.73 ± 0.87	1.82
Inner Coast	1.02 ± 0.82	1.07 ± 0.88	0.82	1.87 ± 0.73	2.07 ± 0.86	1.96

Closer examination of ocean spray and fluvial data revealed complications in interpretation. The ocean-spray data, particularly on Haida Gwaii, recorded extremely high disturbance levels 80 – 120 years ago and very low disturbance levels more recently (Figure 7). We suspect that a considerable amount of old A-frame logging may be misclassified as natural disturbance in this ecosystem. This old logging creates small patches that are very difficult to identify remotely. The disturbance frequency and variation in frequency may be unreliable for this unit.

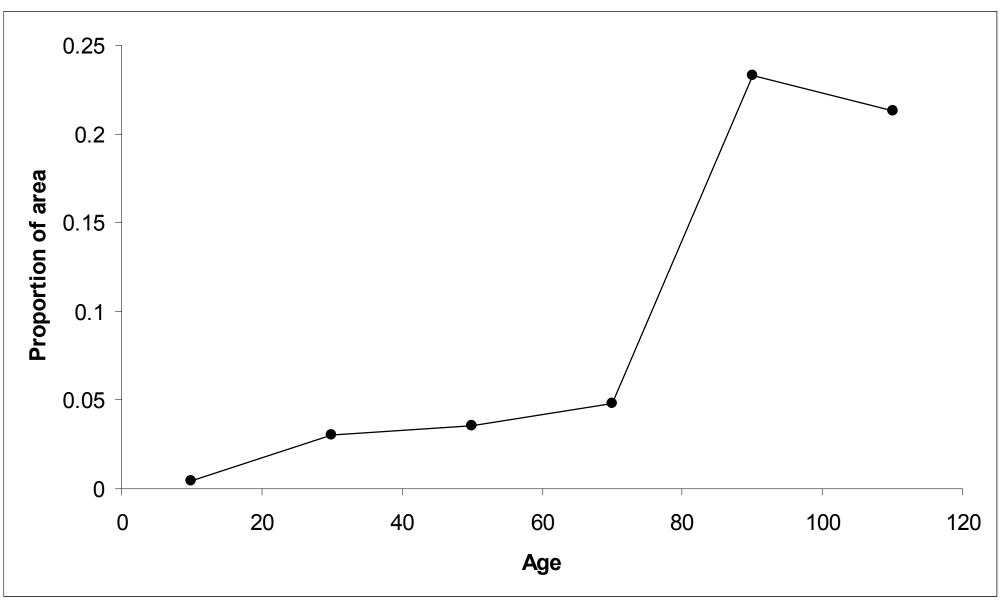

Figure 7. Proportion of ocean spray forest in each age class (midpoint).

Grouping low, mid and high bench floodplains into a single "fluvial" ecosystem (in ssPEM) also created difficulties in interpretation. Including all deciduous forest within fluvial ecosystems overestimates disturbance on high-bench floodplain as some low-bench floodplains will always remain deciduous; i.e. the assumption that all stands face the same probability of disturbance is violated. This overestimation poses a difficulty in providing management guidelines as the high-bench floodplain contains the only forests subject to harvest. We could not separate the high and low-bench floodplains with existing data, but instead provide upper and lower bounds to the disturbance in the high-bench floodplains. The estimates provided above (that include low-bench floodplains) set the upper bound for fluvial disturbance levels. To provide a lower bound for fluvial disturbance, we estimated disturbance frequency in non-deciduous AUs within the fluvial ecosystems. These estimates are remarkably similar to those for upland areas (compare Table 11 with Table 10 method 1). The actual level of fluvial disturbance will lie somewhere between the two extremes—but there is no way of determining exactly, or even approximately, where.

Table 11. Mean disturbance frequency (proportion of area disturbed per year x 1,000) for non-deciduous fluvial ecosystems (± SD).

Region	Disturbance frequency (x 1,000)
Hypermaritime	0.20 ± 0.20
Outer Coast North	0.35 ± 0.35
Outer Coast South	0.75 ± 0.40
Inner Coast	1.10 ± 0.90

Because all methods gave similar results, we used the simplest method for looking at biogeoclimatic variants. Analysis of the final groups of biogeoclimatic variants revealed a similar pattern to that found in hydroriparian sub-regions (Figure 8; $F_{3,20} = 6.6$, $p < 0.003$, one-way analysis of variance), although some variants had disturbance frequencies more similar to those from distant sub-regions. In particular, the hypermaritime disturbance unit included the CWHmm1, MHmm2 and MSdc2—all existing further inland. Of these variants, the CWHmm1 and MSdc2 cover very small portions of the CIT area (about 7,000 ha each); the disturbance frequencies calculated may not be truly representative of these variants. Variants did not all combine into subzones as might be expected. Although variants of the CWHvh, CWHwh and CWHvm subzones experience similar disturbance frequencies, the MHmm variants differ. The windward variant (MHmm1) has considerably more frequent and more variable disturbance than the leeward (inland) MHmm2. In general, mean disturbance frequency and variation in disturbance frequency increased with distance from the coast.

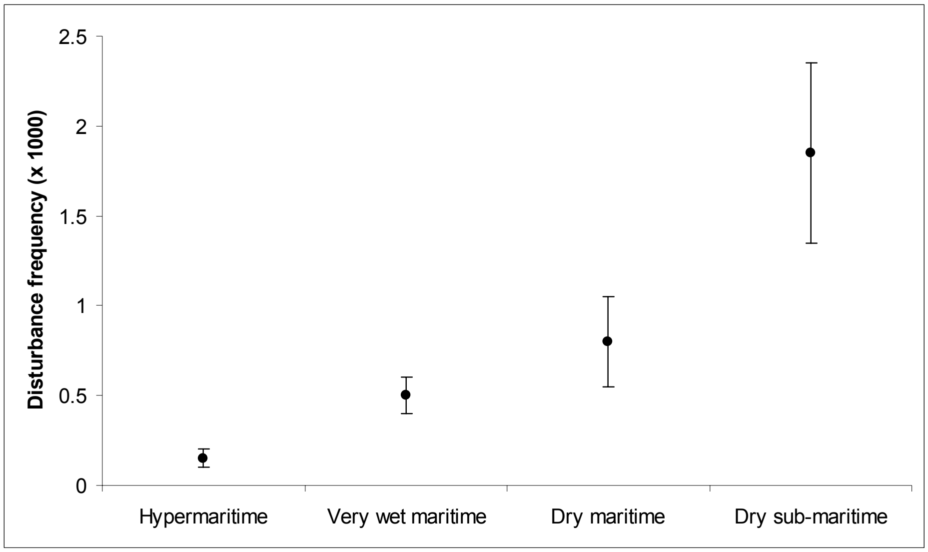

Figure 8. Mean disturbance frequency (proportion of area disturbed per year x 1,000) estimated by method 1 for upland, fluvial and ocean spray units in the four biogeoclimatic groups within the CIT area. Bars are standard errors.

Estimated Proportion of Old Forest

Tables 12 and 13 show the range of return intervals and natural old forest estimated for each natural disturbance unit. The intervals are based on the standard deviation for each disturbance unit for the method 2 with roll-back (see Table 10). The proportion of old forest is calculated using a negative exponential equation (Equation 3). Because a negative exponential curve levels out at the long return intervals found on the coast, the resulting proportion of old forest is relatively insensitive to small changes in estimated disturbance frequency.

$$P = e^{-(f \times t)} \qquad (3)$$

where

P = proportion greater than age t
t = stand age
f = disturbance frequency

Table 12. Estimated return intervals and natural proportion of old forest in different disturbance units as defined by physiographic region and site series group.

Region	Site series group	Return interval*	Proportion of forest > 250 years (%)
Hypermaritime	upland	4,500 – 10,000	95 – 98
	fluvial	2,200 – 10,000	89 – 98
	ocean spray	1,000 – 5,600	78 – 96
Outer Coast North	upland	1,800 – 10,000	87 – 98
	fluvial	500 – 2,000	61 – 88
Outer Coast South	upland	900 – 2,500	76 – 90
	fluvial	400 – 1,200	54 – 81
Inner Coast	upland	500 – 5,600	61 – 96
	fluvial	300 – 900	43 – 73

* To nearest 100 years; truncated at 10,000 years.

Table 13. Estimated return intervals and natural proportion of old forest in different disturbance units as defined by biogeoclimatic variant.

Variant	Return interval*	Proportion of forest > 250 years (%)
Hypermaritime plus others	4,000 – 20,000	94 – 99
Very wet maritime	1,400 – 3,300	84 – 93
Dry maritime and wet sub-maritime	700 – 5,000	70 – 95
Dry sub-maritime	400 – 1,500	53 – 85

* To nearest 100 years

Discussion

Disturbance Units

Our analyses suggest that the most homogeneous disturbance units in the CIT area are a combination of broad physiographic regions and a limited number of site series groups. Within these disturbance units, using a "reliable" dataset over the most recent 120 years, three analysis techniques produced similar estimates of natural disturbance frequency. Among the four regions, disturbance frequency, and variation in disturbance frequency, experienced over the last 120 years increased further from the coast. Within the regions, disturbance frequency, and variation in disturbance frequency, was higher on ocean-spray and fluvial ecosystems compared with upland ecosystems (excluding avalanche tracks).

The four physiographic regions (Haida Gwaii and lowlands, Outer Coast North, Outer Coast South, Inner Coast) are similar to those proposed by Pojar et al. (1999) for the Central Coast (Lowlands, Outer Coast, Inner Coast) except that the Haida Gwaii Mountains cluster with the Lowlands and the Outer Coast Mountains fall into two groups. That conditions are different in the southern portion of the Outer Coast Mountains is corroborated by the presence of a number of unique biogeoclimatic variants (see Table 7). The low disturbance frequency in the Haida Gwaii Mountains was somewhat surprising—we had expected a higher disturbance frequency due to exposure to oceanic storms (Pearson 2003). Instead, the Haida Gwaii Mountains had the lowest amount of young forest of any of the eleven sub-regions. Logging began most recently in the Haida Gwaii Mountains. Even with the improved logging information, old logging may remain misclassified in other regions. Alternatively, disturbance agents other than wind could be lower in the Haida Gwaii Mountains leading to an overall lower disturbance frequency. The eleven sub-regions identified by the Hydroriparian Planning Guide (2003 draft) seem unnecessarily fine for analyses of natural disturbance frequency with existing data. They might be more useful in detailed analyses considering disturbance type and pattern.

We recommend physiographic regions (created by clustering hydroriparian sub-regions) rather than biogeoclimatic variants as broad disturbance units. Physiographic regions allow separation of landforms and ecosystems within the broad units, as suggested by Dorner and Wong (2003). Biogeoclimatic areas, conversely, overlap with site series and prevent discrimination among landforms and ecosystems.

We were surprised by the small number of groups of site series with detectably different disturbance frequencies. Although avalanche tracks, fluvial ecosystems and ocean spray ecosystems all had higher disturbance frequencies, disturbance frequencies in ecosystems usually found on fans, colluvial slopes and wetlands were not distinguishable from those on other upland ecosystems. The predominance of geomorphic disturbances in the CIT area had led us to expect more disturbance on colluvial slopes and fans (Dorner and Wong 2003, Pearson 2003). Suspecting that Method 1 was not sensitive to units with high disturbance frequency, we tried using Method 2 on a subset of the data to no avail. Errors in ssPEM, errors in grouping site series and a lack of explicit consideration of slope may have obscured existing patterns. Future analyses should include slope classes because sufficiently steep terrain is necessary for most types of slides to occur.

We found that AUs designed to model timber supply were inappropriate for analyses of natural disturbance frequency in the CIT area for the variety of theoretical and empirical reasons listed in the results. In particular, the lack of a succession model makes estimates based on AU extremely suspect. Unfortunately, current assessment of ecological risk in the area relies on both AUs and disturbance estimates. Using site series with physiographic regions as ecological units in future risk assessment would increase confidence in the disturbance estimates for each unit. In the interim, it is possible to take the numbers provided in this report and to apply them to appropriate AUs after consultation with ecologists. To assist with this task, the relationship among site series groups and AUs in the database used for analysis is shown in Appendix 1.

Disturbance Frequency

This study examined the frequency of stand-replacing disturbances—a single element of disturbance regime. Disturbance type, size and intensity are also important features for understanding the dynamics of landscape pattern. Disturbance type likely varies among the defined disturbance units (e.g. flooding in fluvial ecosystems, more fire inland), but it is not possible to test hypotheses about the types of disturbance from frequency data. Careful examination of air photos in conjunction with GIS databases, in the manner of Pearson (2003), are necessary to examine these hypotheses. Most disturbances in the CIT area do not kill entire stands, but instead open small gaps in the canopy (Dorner and Wong 2003). Our analyses could not include these disturbances.

The estimates provided in this report can guide management by facilitating risk assessments based on the amount of old forest in the CIT area. The small size of natural disturbances on the coast means that estimates of natural disturbance frequency are probably more useful for guiding management than are estimates in regions with large infrequent disturbance (e.g. Wimberly et al. 2000 in Oregon). We used standard deviation around the mean of the six age classes to represent the historical range of variability in disturbance frequency in the CIT area, using 20-year age classes as samples. We then translated this range of disturbance frequency into a range of return intervals and finally amount of old forest. These standard deviations represent the uncertainty around the mean. We caution that while we have reasonable confidence in the mean historical disturbance frequency presented, we have much less confidence in the range. A better estimate of the range of old forest might sample a series of watershed or landscape units within each region to describe the actual historical range of old forest (Brigitte Dorner, personal communication).

Over any 120-year period, the mean is the best estimate of the historical disturbance frequency. We do not suggest that all areas should be managed to the mean proportion of old forest, however. Disturbance events are stochastic; many different landscapes are theoretically possible at any time. The past 120 years are only one of many potential realities (i.e. this study sampled a single 120-year disturbance sequence). Simulation experiments, based on estimated disturbance parameters, would improve understanding of the full range of natural landscape conditions (e.g. Steventon 2002). This limitation is perhaps less important in the CIT area with its infrequent and small disturbances than in areas with higher disturbance frequency or larger disturbances.

Our estimates for disturbance return interval are somewhat longer than those used in the risk assessment performed for the North Coast LRMP (Holt and Sutherland 2003). In the North Coast, estimates of return interval ranged from 400 – 1,000 years for AUs with frequent disturbance, 1,000 – 2,000 years for AUs with moderate disturbance and over 2,000 years for AUs with infrequent disturbance. For the regions within the North Coast (Hypermaritime and Outer Coast North), we only estimated return intervals of less than 1,000 years in the fluvial ecosystems of the Outer Coast Mountains.

Because of questionable data, especially in older stands, we were unable to use the entire spectrum of forest age classes for analysis. Some analysis techniques provide better estimates with a complete array of ages. However, our estimates of disturbance frequency were very sensitive to using older age-class data and relatively insensitive to the method of analysis. Given a choice between using reliable data and a better analysis technique, we chose the former, based on sensitivity analyses.

We were fortunate in having access to two independent sources of information about the location of logging. Previous estimates for the North Coast were unable to separate logging from natural disturbance. Forest inventory data misclassify a large proportion of logging as natural (particularly beyond 60 years ago; Pearson 2003). SsPEM seems to capture logging, but misclassify some natural areas as logged. We believe that the correction via Sierra Club satellite imagery improved our estimate of logging, but cannot estimate the accuracy of disturbance history without interpreting air photos.

Our estimates of natural disturbance assume that the probability of disturbance is independent of age. Although we have attempted to divide the CIT area into homogeneous disturbance units, some units (e.g. fluvial units) may still contain portions that are more prone to disturbance. As a result, younger stands may be affected. If disturbances primarily affect younger forest, we have overestimated the disturbance frequency for the remainder of these units but underestimated the overall disturbance frequency for these units. In addition, because we have based our analyses entirely on young forests, we could be sampling those areas most susceptible to disturbance, again overestimating disturbance frequency for older forest types. For example, if we assume that stands less than 120 years old are twice as likely to be disturbed as older stands, then our estimates of disturbance frequency are almost twice as high as they should be for the older forest.

Due to the limitations of our study, the estimates provided in this report should be considered as hypotheses. They should be included in adaptive management experiments and modified as data improve and analysis opportunities allow.

Acknowledgements

We thank Brigitte Dorner for her patient help throughout and advice with analysis techniques. We used a primer designed by Joseph Fall to learn about various techniques. We thank Debbie Narver (MSRM) for providing the databases and Dave Leversee for compiling and overlaying databases and for assessing the validity of logging activity data. We thank Brigitte Dorner and Doug Steventon for reviewing an earlier draft of the report. We thank the Coastal Information Team for funding work on natural disturbance frequency.

References

Andison D.W. and McCleary K. 2002. Disturbance in riparian zones on foothills and mountain landscapes of Alberta. Alberta Foothills Disturbance Ecology Research Series Report #3. Foothills Model Forest.

Banner, A., W. MacKenzie, S. Haeussler, S. Thompson, J. Pojar, and R. Trowbridge. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. Ministry of Forests Land Management Handbook 26, Victoria, BC.

Boychuk, D., Perera, A.H., Ter-Mikaelian, M.T., Martell, D.L., and Li, C. 1997. Modeling the effect of spatial scale and correlated fire disturbances on forest age distribution. Ecological Modeling 95:145-164.

Cissel, J.H, Swanson, F.J., and Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications 9:1217-1231.

Dorner, B. 2002. Forest management and natural variability: the dynamics of landscape pattern in mountainous terrain. PhD thesis. Simon Fraser University, Burnaby, BC.

Dorner, B., and Wong, C. 2003. Natural disturbance dynamics in the CIT area. Report for the CIT.

Dorner, B., and C. M. Wong. 2002. Natural Disturbance Dynamics on the North Coast. Background Report prepared for the North Coast LRMP, Prince Rupert, BC.

EBA Engineering Consultants. 2003. Small-scale predictive ecosystem mapping for the Central Coast, Queen Charlotte Islands and North Coast LRMP areas. 64 pp.

Haynes, R.W., Graham, R.T., and Quigley, T.M. 1996. A framework for ecosystem management in the Interior Columbia Basin and portions of the Columbia Basin. USDA FS PNW-GTR-405.

Hogan, D.L., and Schwab, J.W. 1991. Stream channel response to landslides in the Queen Charlotte Islands, BC: changes affecting pink and chum salmon habitat. Proceedings of the 15th Northeast pink and chum salmon workshop. Pp 222 – 236. Pacific Salmon Commission, Department of Fisheries and Oceans.

Holt, R. 2001. An ecosystem-based management planning framework for the North Coast LRMP. Background Report to the North Coast LRMP.

Holt, R. F., and G. Sutherland. 2003. Environmental risk assessment: base case. Coarse filter biodiversity. Final report to the North Coast LRMP.

Hydroriparian Planning Guide. 2003. Draft guide prepared by the Coastal Information Team.

Johnson, E.A., and Gutsell, S.L. 1994. Fire frequency models, methods and interpretations. Advances in Ecological Research 15:214-220.

Landres, P.B., Morgan, P., and Swanson, J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

Lertzman, K., Fall, J., and Dorner, B. 1998. Three kinds of heterogeneity in fire regimes: at the crossroads of fire history and landscape ecology. Northwest Science 72:4-23.

Meidinger, D. and Pojar, J. 1991. Ecosystems of British Columbia. BC Ministry of Forests, Victoria BC, Special Report Series 6.

Ministry of Forests. 1999a. Mid Coast timber supply area analysis report. 114pp.

Ministry of Forests. 1999b. North Coast timber supply area analysis report. 101pp.

Ministry of Forests. 2000. Queen Charlotte timber supply area analysis report. 143pp.

Montgomery, D.R. 1999. Process domains of the river continuum. Journal of the Water Resources Association 35:1-14.

Morgan, P., Alpet, G.H., Haufler, J.B., Humphries, H.C., Moore, M.M., and Wilson, W.D. 1994. Historical role of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2:87-111.

Pearson, A. 2003. Natural and logging disturbances in the temperate rain forests of the Central Coast, British Columbia. Report to the Ministry of Sustainable Resource Management, Victoria BC.

Pollack, J.C., Quesnel, H. Hauk, C., and MacLean, H.1997. A quantitative evaluation of natural age class distributions and stand replacement intervals in the Nelson Forest Region. BC Ministry of Forests, Nelson BC.

Price, K. 2003. Testing the Hydroriparian Planning Guide. Report to the Coastal Information Team and North Coast LRMP.

Province of BC. 1995. Biodiversity Guidebook. Queens Printer, Victoria, BC.

Pojar, J., C. Rowan, A. MacKinnon, D. Coates, and P. LePage. 1999. Silvicultural options in the Central Coast. Report for the Central Coast LCRMP.

Reed, W.J. 1997. Estimating historical forest-fire frequencies from time-since-last-fire-sample data. IMA Journal of Mathematics Applied in Medicine and Biology 14:71-83.

Reed, W.J., C.P.S. Larsen, E.A. Johnson and G.M. MacDonald. 1998. Estimation of temporal variations in historical fire frequency from time-since-fire map data. Forest Science 44:465-475.

Sierra Club of Canada, BC Chapter. Logging layer based on Landsat information from 1998.

Steventon, J.D. 2002. Historic disturbance regimes of the Morice and Lakes timber supply areas. Draft discussion paper for the Morice LRMP.

Swanson, F.J., Jones, J.A., Wallin, D.O. and Cissel, J.H. 1993. Natural Variability - Implications for Ecosystem Management. USDA FS PNW-GTR-318.

Swanston, D.F., Kratz, T.K., Caine, N. and Woodmansee, R.G. 1988. Landform effects on ecosystem patterns and processes. BioScience 38:92-98.

Swetnam, T.W., Allen, C.D., and Betancourt, J.L. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9:1189-1206.

SYSTAT 5.03. SYSTAT Inc., Evanston IL, US.

Trainor, K. 2001. Geomorphological/hydrological assessment of the Central Coast plan area. Background Report #1 for the CIT Hydroriparian Planning Guide.

Wimberly, M.C., Spies, T.A., Long, C.J., and Whitlock, C. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. Conservation Biology 14:167-180.

Wong, C., Sandmann, H., and Dorner, B. 2002. Estimating historical variability of natural disturbances in B.C. Report to the BC Ministry of Forests.

Appendix 1.

Percent of each AU falling in combinations of physiographic regions and site series groups. Physiographic regions include the following hydroriparian subregions: Hypermaritime includes Haida Gwaii Lowlands, Haida Gwaii Mountains, Hecate Lowlands, Milbanke Strandflat and Skidegate Plateau; Outer Coast North includes the Boundary Ranges and the Kitimat Ranges; Outer Coast South includes the Pacific Ranges; Inner Coast includes the Kitimat and Pacific Ranges. Fluvial and ocean spray site series match the groups listed in ssPEM. Upland site series includes a variety of wetland and forested upland site series. “Other” site series includes area classified as avalanche tracks, estuaries and other marginally-forested ecosystems.

	Physiographic region and site series groups													
	Hypermaritime				Outer Coast North			Outer Coast South			Inner Coast			Total
Analysis Unit	Fluvial	Ocean spray	Upland	Other	Fluvial	Upland	Other	Fluvial	Upland	Other	Fluvial	Upland	Other	
C-G	2	1	16	0	0	9	0	0	65	1	0	5	0	100
C-M	1	0	40	1	0	13	0	0	40	0	0	5	0	100
C-L	1	1	57	2	0	14	0	0	23	0	0	1	0	100
C-VL	0	0	68	4	0	13	1	0	13	1	0	1	0	100
FD-G	0	0	0	0	0	0	0	2	84	1	1	12	0	100
FD-M	0	0	0	0	0	1	0	1	57	2	2	37	0	100
FD-L	0	0	0	0	0	4	0	0	25	1	1	68	1	100
FD-VL	0	0	0	0	0	0	0	0	56	7	0	34	2	100
H-G	0	1	30	0	1	10	1	1	53	0	0	3	0	100
H-M	0	1	30	0	1	20	1	1	33	0	0	14	0	100
H-L	0	1	24	0	0	28	0	0	22	0	0	24	0	100
H-VL	0	0	16	0	0	18	0	0	26	1	0	37	0	100
S-G	3	5	66	0	2	7	0	6	7	0	1	2	0	100
S-M	4	4	52	0	3	17	1	4	6	0	1	8	0	100
S-L	4	6	66	1	1	15	1	1	2	0	0	3	0	100
S-VL	3	5	57	1	0	4	0	1	4	0	0	24	0	100
PL-ALL	0	0	36	0	0	15	1	0	7	1	0	38	1	100
AC-ALL	0	0	0	0	1	9	0	16	12	0	30	32	0	100
DR-ALL	2	4	22	0	4	6	1	16	36	2	2	4	0	100
M-ALL	0	0	1	0	0	0	0	0	84	15	0	0	0	100
DEC-ALL	0	0	0	0	0	8	0	0	0	0	8	84	0	100
Total	1	1	47	2	0	15	0	1	23	1	0	10	0	100