# Interim Assessment Protocol for Forest Biodiversity in British Columbia

SEPTEMBER 2020

VERSION 1.0

## Standards for Assessing the Condition of Forest Biodiversity under British Columbia's Cumulative Effects Framework

**PREPARED BY:** Provincial Forest Biodiversity Technical Working Group – Ministry of Environment and Climate Change Strategy & Ministry of Forests, Lands, Natural Resource Operations and Rural Development

BRITISH COLUMBIA

CEF Cumulative Effects Framework

FREP Forest&Range Evaluation Program

## *Disclaimer*

The Interim Assessment Protocol (the Protocol) provides an initial standard method for assessing the current condition of the value selected for cumulative effects assessment across the Province of British Columbia. The Protocol is designed to use a multi-scaled approach to depict data at a broader (provincial) scale and to allow for refinements in data at a finer (regional) scale.

The assessment results based on this Protocol indicate the modelled condition of the value. Results are intended to inform strategic and tactical decision making and may also provide relevant context for operational decision making. Engaging local value experts to identify additional regional scale information – if applicable – and to support interpretation and application of results is encouraged.

The Protocol outlined in this document is subject to a) periodic review to support continuous improvement and b) regionally specific modifications, consistent with criteria for enabling regional variability. Where regional modifications are approved, they will be documented in this protocol, and become the standard for assessment in that area. If applicable, regional modifications are listed in the appendices of this document.

## *Document Control*

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# 1 Introduction

As forests cover almost two-thirds of British Columbia, forested ecosystems and the diversity of life within these forests, or 'forest biodiversity' is integral to the quality of life in B.C. (BC MF & BC MELP, 1995). Biodiversity[1] plays an important role in altering ecosystem processes and ecosystem functions such as rates of nutrient cycling, material flows and energy fluxes, and primary production (Cardinale et al., 2012; Diaz et al., 2006). Biodiversity is recognized at global (MEA 2005, IPBES 2018), national[2], provincial[3] and regional levels[4], biodiversity provides ecosystem functions and services that are important to human well-being (Figure 1). Not only does biodiversity sustain basic supporting and regulating services for the ecosystem and human existence, it also supports provisioning services and cultural services – all of which must be balanced to prevent the loss of biodiversity and to sustain human well-being. Maintaining or conserving biodiversity within forest ecosystems is therefore an important management objective for British Columbians, and throughout B.C.'s forest legislation, policy objectives and land use plans, the term 'Conserve biodiversity' is commonly referred to as a broad over-arching management objective.

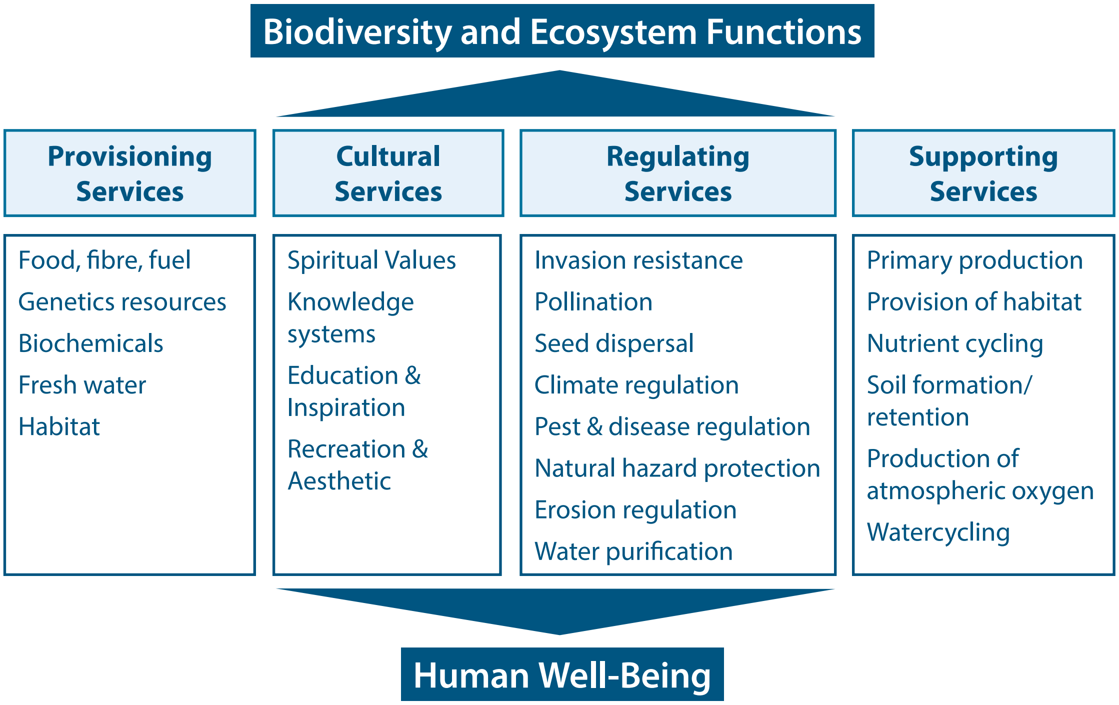

***Figure 1.*** *The relationship between biodiversity and ecosystem functions, ecosystem services and human well-being. Reproduced from Vold. T., and D.A. Buffett (eds.) 2008. Ecological Concepts. Principles and Applications to Conservation, B.C. 36pp.*

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[1] Biological diversity or 'biodiversity' is defined as the diversity of plants, animals and other living organisms in all their forms and levels of organization, and includes the diversity of genes, species and ecosystems, as well as the evolutionary and functional processes that link them

[2] See Canadian Biodiversity Strategy http://www.biodivcanada.ca

[3] See Biodiversity BC www.biodiversitybc.org and legal objectives and regulation developed under the *Forest Practices Code Act of BC*, and *Forest and Range Practices Act*.

[4] See Land and Resource Management Plans https://www2.gov.bc.ca/gov/content?id=FF718B3F8C5B421C90B156F4F3 4BA916

However, as biodiversity continues to be lost across all levels due to human and natural disturbances, the associated changes may threaten ecosystem processes and services that humans rely on for well-being (Chapin et al., 2000). To help evaluate whether the balance of efforts to conserve biodiversity are being met, governments, stakeholders, natural resource decision-makers and the public require information on the combined effects of land uses activities and natural disturbances on forest biodiversity.

## 1.1 Biodiversity Objectives

Recognizing the importance of biodiversity, British Columbian's have expressed the desire to 'maintain' or 'conserve' biodiversity through objectives developed under land use planning processes and legislation since the early 1990's.[5] Meeting society's objective to conserve biodiversity in British Columbia is accomplished through a comprehensive federal and provincial policy and regulatory framework (hereafter referred to as the 'biodiversity conservation framework'). The framework includes:

1. A provincial Protected Area Strategy (Province of B.C., 1995) committed to protect 12% of the land-base through a system of protected areas and reserves (Federal and provincial parks, protected areas, ecological reserves),
2. Strategic land use planning processes (e.g. Land and Resource Management Plans (LRMPs) that decide the appropriate use of the land,
3. Federal and Provincial legislation that provides for a variety of habitats at the landscape, as well as setting broad objectives (e.g. *Species at Risk Act*, *Migratory Bird Act*, *Forest and Range Practices Act (FRPA)* or *Land Act*),
4. Regulations that apply to sector-specific practices to provide important attributes at the landscape and stand scale, for example: FRPA Forest Planning and Practices Regulation (FPPR), Government Action Regulation (GAR), Higher Level Plans (HLP) established under the Forest Practices Code (FPC) and continued under FRPA, or Land Use Order Regulations (LUOR) under the *Land Act*; and
5. Forest Policy for Forest Biodiversity – FPC Biodiversity Guidebook (B.C. Ministry of Environment, 1995) and subsequent Landscape Unit Planning Guide (LUPG).

In the case of forest biodiversity, the implementation of the biodiversity conservation framework is founded on the conceptual framework outlined in the Biodiversity Guidebook whereby:

- All native species and ecological process are more likely to be maintained if managed forests are made to resemble those forest created by natural disturbance agents such as wildfire, wind and disease.
- Biodiversity management in B.C. recognizes that intensive forestry and other resource development are compatible with the maintenance of biodiversity.
- Recommended targets incorporate trade-offs to integrate society's desire to both derive economic benefits from the forest and to conserve biodiversity on the landscape.

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[5] All land use plans completed in the province to date include biodiversity objectives, legal objectives are included in FRPA (Section 9 FPPR) and conserving biodiversity more recently expressed as part of the vision for sustainable forest management under the provincial timber management goals objectives ad targets.

Thus, efforts to conserve[6] biodiversity on the land-base involve a 'balance' between what is perceived to be ecologically appropriate to conserve biodiversity and what is socially desirable in terms of economic benefits from the forest (Eng, 1998). Implementation of this biodiversity conservation framework, as an attempt to achieve a balance between commercial use and development of the forest with biodiversity conservation through spatially zoning the landscape, began in the early 1990's with the introduction of the *Forest Practices Code of B.C. Act* and land use planning processes (e.g. Commission on Resources and the Environment (CORE) and Land and Resource Management Plans (LRMPS)). Implementation required that various levels of biodiversity emphasis (Biodiversity Emphasis Options; BEOs) are assigned on the landscape to guide spatial Implementation of old growth management areas (OGMAs) and wildlife tree retention targets were prioritized following direction in the Landscape Unit Planning Guidebook.

## 1.2 Assessing Forest Biodiversity

To assess where the 'balance' of biodiversity conservation and socio-economic development lies, a key principle underlying this assessment approach is to clearly separate the assessment into two parts:

1. A science-based assessment of the ability of the land-base to maintain forest biodiversity under historic, current or projected future conditions, relative to relevant ecological benchmarks,
2. A management interpretation that evaluates:
   a. the observed forest condition relative to existing policy guidance[7], policy[8] or legal targets[9] where applicable, and
   b. the relative effectiveness of existing or proposed legal designations to mitigate impact and conserve forest biodiversity.

Version 1 of the Protocol (this document) describes an approach to estimate the effects of landscape change and modification on biodiversity (Bullet 1 above) and will provide indicators to help compare landscape condition to existing guidance, policy and legal targets (Bullet 2 above). Future versions of the Protocol are intended to include other aspects of risk assessment, including:

a. the effectiveness of existing or proposed legal designations to mitigate land use impacts and conserve forest biodiversity.

b. evaluation of the ecological and socio-economic consequences of land-base condition and related social/economic and cultural implications;

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[6] The term conserve is defined as "to keep", or "to protect from damage, loss, or waste".

[7] Includes documents such as the Biodiversity Guidebook or associated guidebooks that provide management recommendations around such measures as amounts of early, mature old seral forest.

[8] Including documents such as the Land Use Planning Guidebook that directed the implementation of legal designations such as Old Growth Management Areas (OGMAs).

[9] Such as mature or old forest targets established in Land Use Order Regulation (LUOR) under the *Land Act*, or under a Higher Level Plan (HLP) document.

In Version 1 of the protocol, the effects of landscape change are described as 'hazards' – or a source of harm or potential to cause harm – following a risk-based approach (CSA 1997, Wise et al. 2004, Vandine et al. 2004). The types of hazards associated with landscape change fall into three general categories of 'threatening processes' outlined in Lindenmayer and Fischer (2006,2007)[10]:

1. Habitat loss, alteration or degradation
2. Habitat sub-division and isolation
3. Changes in species behaviour, biology and interactions

Hazard ratings are used in the protocol to provide a measurement or expression of the likelihood of hazard occurrence. The terms Very Low, Low, Moderate, High, Very High are used to provide qualitative estimates of the likelihood of a hazard or effect occurring resulting from land change and/or modification (Table 1). Where possible, the ratings are associated with the probability of occurrence where that can be calculated.

***Table 1.*** *Terminology used to describe disturbance and hazard ratings using both a 3-class and 5-class rating approach.*

| 3-Class Rating | 5 –Class Rating | Definition | Probability % of Occurring |
|---|---|---|---|
| | Very Low | Highly Unlikely | <10% |
| Low | Low | Unlikely | <33% |
| Moderate | Moderate | May | 33-66% |
| High | High | Likely | >66% |
| | Very High | Very Likely | >90% |

In most cases, hazard ratings are based on the departure of measured or 'observed' condition from the 'expected' forest condition that would be found under the Historic Range and Variability (HRV)[11] of natural disturbances. Use of HRV as an ecological benchmark assumes the more likely that current forest conditions resemble those created historically by natural disturbances, the more likely biodiversity will be maintained. This approach is consistent with concepts outlined in existing guidance and policy and legislation.

### 1.2.1 Management Context

Results from the assessment protocol are intended to inform strategic-level decisions for the management and allocation of land and resources. These decisions can include:

- Annual Allowable Cut (AAC) determinations
- Establishing management targets through land use planning processes or regulatory procedures (e.g. GAR Order designation)
- Major projects

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[10] The term hazard is considered synonymous with the term 'threatening processes' used in Lindenmayer and Fischer (2007, 2006) and is used here to be consistent with the risk-based terminology applied elsewhere in the procedure. For ease of use, the hazard categories applied in the protocol were modified from Lindenmayer and Fischer's (2006) three original categories of threatening processes to; 1) Habitat Change, 2) Habitat Connectivity, and 3) Species Dynamics.

[11] Also referred to as the Range of Natural Variability (RoNV) and Natural Range of Variability (NRV) in the literature.

Results from this assessment are not intended to be used for permitting or 'transaction-level' decisions.

In applying the results of the protocol, it is imperative that users distinguish between the use of an ecological benchmark such as Historic Range and Variability (HRV) for the purposes of assessment, versus setting management targets. From an assessment perspective, comparisons with past conditions can be useful to understand the ecological change associated with disturbance processes (Safford et al., 2012). HRV remains relevant to understand departure from past conditions, as Safford et al. (2012) state "our knowledge and understanding of 'properly functioning' ecosystem processes is only definable with an understanding of past conditions". Human culture, social and economic systems (e.g. human settlements) are intricately linked to ecosystems, and human expectations for levels of ecosystem services necessary for basic human needs (i.e. regulating services) or that provide socio-economic benefits (i.e. provisioning services) are based on historical levels (Safford et al., 2012). However, the HRV concept has limited utility as a target for resource management, most notably because under rapidly changing climate and human influence future conditions will not be able to replicate the past, nor may we want them to (Safford et al., 2012). As a short-term interim target, HRV may still be applicable as using the past to guide the future still has the least amount of uncertainty compared to some forward-looking climate projections (Keane et al., 2009). Also, mitigating the effects of threats associated with ongoing land use is recommended as one of the top climate adaptation options (Heller and Zavaleta, 2009) as, in the near-term, land use, not climate change, is still considered the biggest threats to biodiversity (IPBES, 2018).

From a management perspective, comparisons between 'observed' forest conditions and levels recommended in existing guidance, policy or designated as legal targets also need to be interpreted in the appropriate historical context. Various circumstances and factors beyond the control of current land managers affect forest condition; when interpreting results users should consider the following:

1. Legacy impacts resulting from historic disturbances including both through natural processes (e.g. historic wildfires and anthropogenic disturbance (e.g. historic logging B.C.'s coast or forest clearing for agriculture on private land) may affect the ability of the land-base to achieve recommended guidance or policy targets;

2. Existing guidance, policy and legal targets incorporated trade-offs to balance biodiversity conservation and socio-economic interests, and may vary from HRV and, in some cases, may exceed guidance recommendations; and,

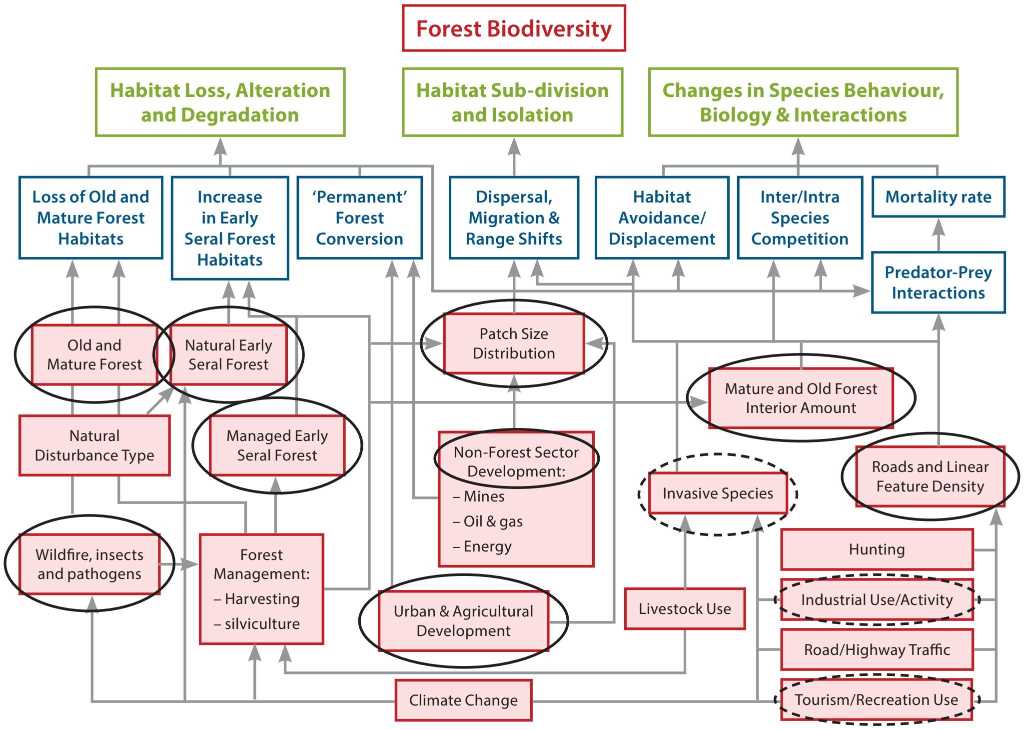
3. Recent management direction in the form of either policy (e.g. post-disturbance salvage) or new legal designations or legal targets (e.g. GAR orders) put in place since the original implementation of the biodiversity conservation framework may have shifted land-base conditions from those originally intended.

# 2 Protocol Overview

## 2.1 Background and Conceptual Model

This Forest Biodiversity Protocol applies new concepts that go beyond the initial conceptual model of the Biodiversity Guidebook. The Guidebook was focused on managing the landscape by Natural Disturbance Type (NDT), but there are other forms of disturbance that affect species. This protocol thus applies a conceptual framework developed by Lindenmayer and Fischer (2007, 2006) to identify hazards[12] associated with landscape change and/or modifications that can affect species diversity. The hazard categories correspond to the three main Components in Figure 2 and are as follows:

- **Habitat Change** – direct loss of forest habitats through conversion to alternate land uses (e.g. agriculture), or alteration or degradation of forest structural conditions resulting in disruption in habitat use.
- **Habitat Connectivity** – breaking apart of continuous habitat into multiple patches (habitat sub-division) and isolating remaining habitat patches affecting species day-to day movements, dispersal, seasonal migration or range shifts (habitat isolation).
- **Species Dynamics** – refers to changes in species behaviour, biology or interactions – habitat avoidance, increases in inter-species competition, predation, parasitism or disruption in mutualistic relationships between species.



**Conceptual Models** for values described how components and indicators influence or interact to affect the condition of a value.

**Components (Green)** are features and attributes of a value that should be measured and managed to meet objectives associated with values.

**Functions and processes (Blue)** describe mechanisms through which factors affect a component, that if compromised changes the state or condition of that component.

**Factors (Red)** are influential processes or states.

***Figure 2.*** *Conceptual model for Forest Biodiversity to provide a high-level summary of the system and of the assessment. The black circles identify the indicators that are used in the assessment. The thick black circle identifies the main indicator used in the assessment, the dashed lines identify additional indicators under consideration.*

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[12] The term hazard is considered synonymous with the term 'threatening processes' used in Lindenmayer and Fischer (2007, 2006)

## 2.2 Assessment Units

The Forest Biodiversity Assessment Protocol uses a multi-scale assessment and reporting structure of overlapping ecosystem units and administrative boundaries (Figure 3). Ecosystem units consist of Landform facets and Biogeoclimatic Subzones Variants (Figure 3, A and B). Ecosystem units follow the Biogeoclimatic Ecosystem Classification (BEC) system (Meidinger and Pojar 1991) that classifies ecosystems based on relatively homogeneous climate and 'climax' vegetation cover Administrative units use provincial Landscape Unit (LU) boundaries (Figure 3, C). The multi-scale approach allows for 'rolling up' assessment results from one spatial scale to other scales. For example, ecosystem units can be reported at the LU scale, or at the scale of the Biogeoclimatic (BGC) Subzone Variant across multiple LU's at the scale of a Resource District or Region

The BGC Variant is the smallest, provincially available scale of BEC Unit mapping used in the assessment procedure. BGC Subzone Variants are part of the zonal (climatic) classification and are used to represent slight differences in regional climate (drier, wetter, colder) that result in corresponding differences in vegetation, soil and ecosystem productivity. Landform facets are the smallest scale of ecosystem unit used in the assessment protocol. Landform facets are intended to represent potential Site Units – groups of sites or ecosystems that, regardless of present vegetation, have the same, or equivalent environmental properties and potential vegetation. To represent landform facets, the assessment protocol uses 'Topofacets' from Michalak et al. (2015) available at https://adaptwest.databasin.org/pages/adaptwest-landfacets. Topofacets are based on a Topographic Position Index (TPI) model[13] to partition the landscape into nine discrete landforms and three aspect classes (warm, neutral, cool) based on a Heat Loading Index.

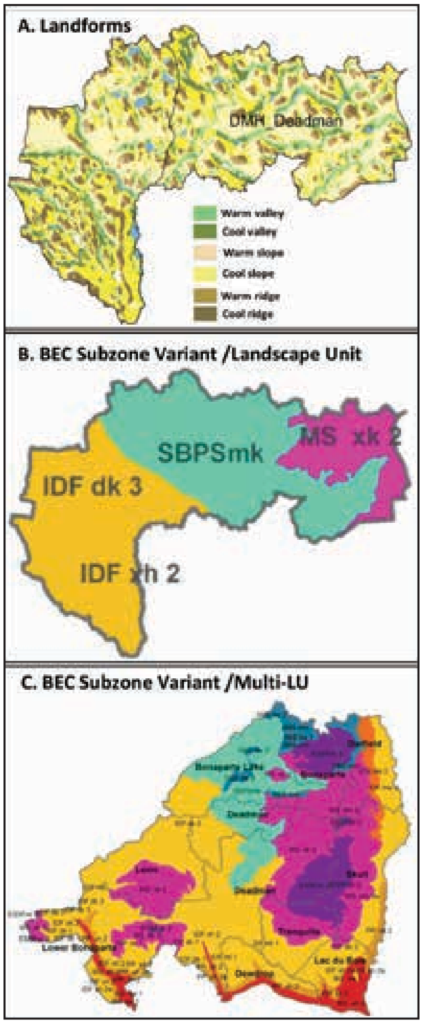
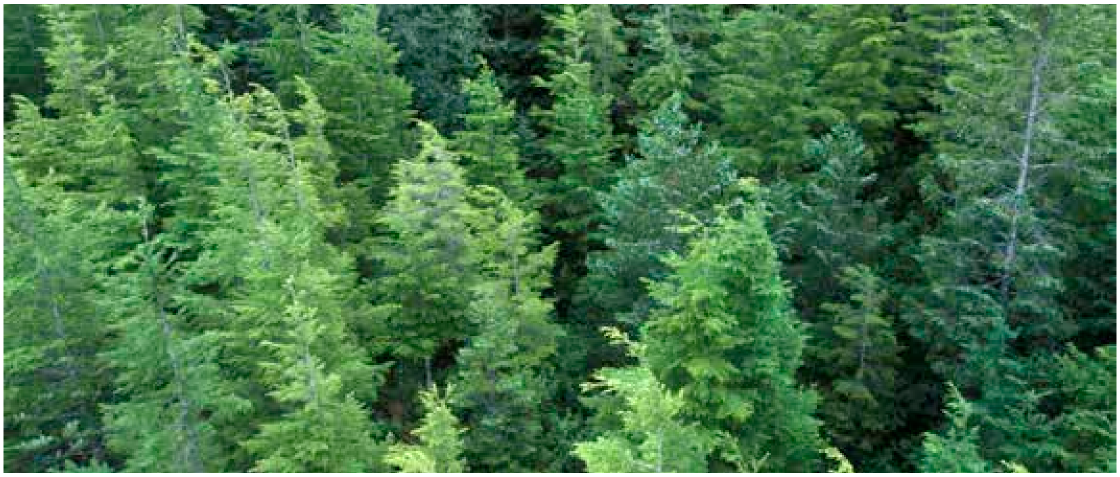


***Figure 3.*** *Example of the multi-scale reporting units for the Deadman Landscape Unit, 100 Mile Resource District.*



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[13] For more information, see Topographic Position Index Online Manual, http://www.jennessent.com/arcview/tpi.htm

# 3 Forest Biodiversity Indicators and Ratings

Within each hazard category (Habitat Change, Habitat Connectivity and Species Dynamics) indicators were selected that characterize both the state of forested habitat conditions (e.g. old forest amount, urban and agricultural settlement), and pressure indicators that measure the extent and severity of factors that modify forested habitats, or that exert influences on species in forest habitats (e.g. disturbance from roads or recreation) (Figure 4).

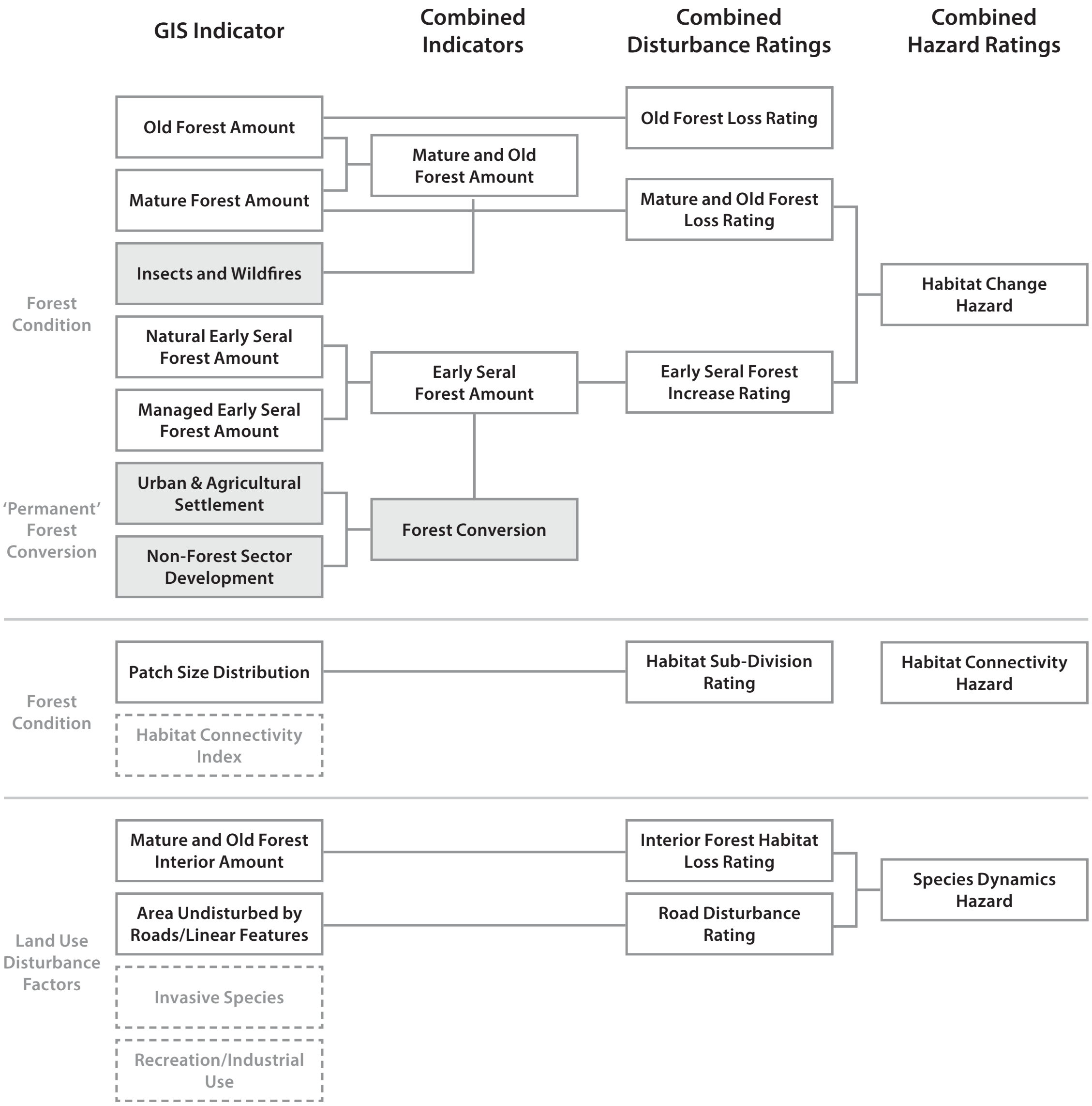

***Figure 4.*** *Conceptual representation illustrating the relationship between indicators and ratings used in the assessment protocol. Shaded boxes indicate supplementary indicators that provide additional information factors affecting the amount of early, mature and old seral forest, but that do not directly affect the ratings. Boxes with dashed lines identify potential future indicators*

# 3.1 Habitat Change

## 3.1.1 Scientific Context

Habitat Change refers to the direct loss of forest habitats through relatively permanent conversion to alternate land uses (e.g. agriculture) or interim loss, alteration or degradation of important forest habitat requisites such as structural attributes (e.g. standing dead and live trees, downed wood) or micro-climatic conditions.

The term "habitat loss" in this protocol refers to the loss of habitat diversity – the full range of habitats that would be expected to occur naturally. This definition is consistent with B.C.'s current biodiversity conservation approach of using habitat diversity as a surrogate for maintaining species and genetic diversity.

The full range of habitats that would be expected to occur naturally is generated by producing the "expected" forest age distribution (seral stage distribution). This can be calculated based on estimates of historic stand-replacing disturbance return intervals (Section 3.1.5). Habitat loss can be estimated by the extent that the observed range of forest habitat conditions deviate from that expected to 'historically' occur on the landscape. Habitat loss is estimated through the following steps;

- Defining the Historic Forest Land-base (HFLB), or that area that would have historically provided forest habitats,
- Defining forest habitats, and describing ways to characterize different habitat conditions,
- Estimating the expected amount of different forest habitats based on estimates of historic stand-replacing disturbance return intervals,
- Estimating the likelihood that habitat loss, degradation or alteration has occurred based on departure of existing forest habitat conditions from expected historic conditions.

## 3.1.2 Defining the Historic Forested Land-Base

A key piece underlying any assessment of forest habitat loss or change is defining the area of the land-base that is, or would have been, covered by forest. Defining what is a 'forest', or what was historically forested, can be a subjective interpretation in some cases.[14] Defining the forest can be particularly challenging on ecotones between grassland and alpine areas that are sparsely forested, and where tree density can shift over time given climatic changes and natural disturbances that modify forest structure in these ecotones. The CEF assessment protocol uses an approach developed by Eng (2016) to define the Historic Forest Land-Base (HFLB), or the area that was likely historically covered by forest, based on best available information (Appendix 1). The HFLB is derived using three existing GIS datasets:

1. British Columbia Land Classification (BCLC; https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/landcover-02.pdf Scheme within the provincial Vegetation Resources Inventory layer)

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[14] The term 'forest biodiversity' used in this Protocol refers to biodiversity of terrestrial, forested ecosystems. For practical reasons, the assessment is restricted to the forested land-base that includes both Crown and private land and more sparsely forested areas that border alpine and grassland habitats. Assessments of biodiversity within grassland, alpine ecosystems can be completed separately. Assessment of aquatic ecosystems is proposed under the CEF aquatic ecosystems assessment protocol.

2. Baseline Thematic Mapping layer (BTM; https://catalogue.data.gov.bc.ca/dataset/baseline-thematic-mapping-present-land-use-version-1-spatial-layer )
3. Biogeoclimatic Ecosystem Classification (BEC; https://www.for.gov.bc.ca/hre/becweb/)

The B.C. Land Classification in the provincial VRI is the primary dataset for defining the HFLB based on BCLC Class 1 (Vegetated 'V' or non-vegetated 'N') and Class 2 (Treed 'T' or non-treed 'N'). In areas where VRI data is missing (e.g. Tree Farm Licences (TFLs)), the BTM and BEC datasets are used to fill in those gaps (Eng, 2016).

The purpose of defining the HFLB is to remove non-forest (lakes, wetlands, large rivers, rock outcrops, alpine and grassland) from the gross area that is used to calculate the forest. Defining the HFLB also identifies areas of the land-base that have been previously converted to non-forest conditions, often long ago (i.e. urban, agricultural, railway lines, highways, mines), and that would have historically been considered forested. The HFLB is used as the 'denominator' in all the indicator and ratings calculations applied in the protocol (Figure 5). For reporting purposes the total HFLB is reported as well as the Crown Land portion of the HFLB (excluding private land).

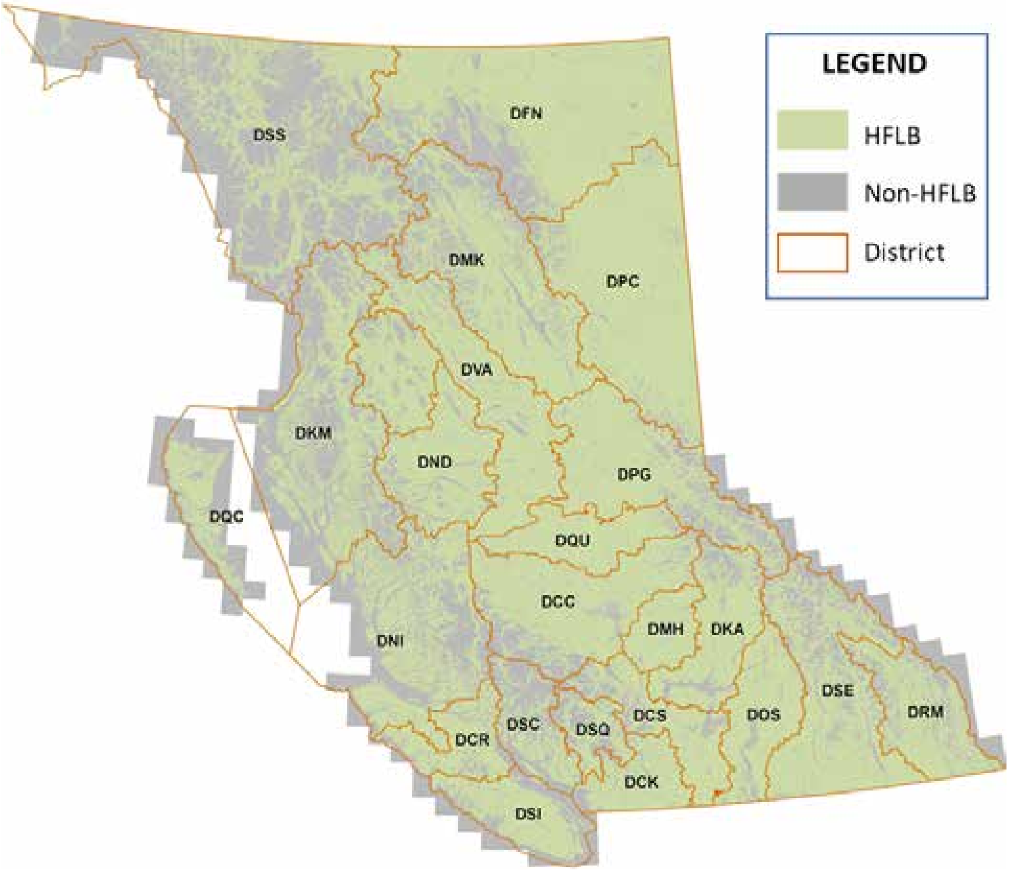

*__Figure 5.__ A representation of the Historic Forest Land-Base (HFLB) in BC.*

### 3.1.3 Defining Forest Habitats

Forest habitats are often characterized using 'seral stages' which correspond to distinctive steps or stages in a series of biotic communities, or 'sere', that form through the process forest ecosystem development called succession (Oliver 1981; Oliver and Larson 1990; Spies 1996). Forest development phases are described largely based on differences in forest structure, composition and environmental conditions that occur as a forest ages following stand initiating or replacing natural disturbance events such as wildfire (Table 2). The relationship between seral stages, phases in forest development and forest age following a stand replacing disturbance event can be generalized as follows (After Oliver and Larson 1990; Spies 1996):

***Table 2.*** *Definitions of the different Seral Stages*

| Seral Stage* | Forest Age* | Description |
|---|---|---|
| Early | 0-40 years | The stand establishment phase, characterized by pioneer species. |
| Mid-seral | 41-100 years | Often referred to as the 'thinning', 'stem exclusion' or 'pole/sapling' stage. Characterized by the closing together of tree canopies, shading of the understory that excludes shrubs, herbs and trees intolerant of shade. |
| Mature | 81-140 years | Transition phase in stand development. Characterized by the breaking up of the original cohort of trees from the stand establishment phase, canopy gaps infill with new trees and understory shrubs and herbs. |
| Old | >100- >250 years | Referred to as the 'shifting mosaic' phase characterized by a shifting pattern of relatively small and patchy disturbances that promotes development of understory shrubs and trees |
| Ancient | >500 years[a] | (escaped disturbance for long periods, often forest older than trees) |

* Seral stage and forest age categories follow those referred to in the Biodiversity Guidebook. Mature and old forest age definitions overlap in this table as the age varies by ecosystem type (Appendix 2). The Ancient seral stage has been added to reflect stands with long-lived trees species.

[a] 500 years is used as a general estimate and can vary by forest ecosystem.

### 3.1.4 Measuring Forest Habitats

In this assessment protocol, forest habitats measured at any given point in time, or the 'observed' forest condition are characterized as 'early', 'mid', 'mature' or 'old' forest seral or successional stages according to age-based definitions in the Biodiversity Guidebook (Appendix 2). Age-based definitions generally assign seral categories to the following ages; early seral forest = <40 yrs. old, mid seral forest ranges from >40yrs to up to 120 yrs., mature forest ranges from as low as 80 yrs. to up to 250 yrs., and old forest = >141 or >250 yrs.). In applying the forest-age based definitions, forest age is used as a surrogate for forest structure and function. However, the limitations of using forest age, particularly considering intermediate-severity disturbances (e.g. insects and wildfires) that affect the structure and function of forests, but not necessarily the age, is acknowledged. Additional supplementary indicators are included that describe the amount of mature and old forest that is affected by intermediate-severity disturbances such as insects and wildfire (See section 3.1.7 – supplementary indicators related to insect and wildfire disturbance). Future work is also required to develop alternative approaches and datasets that better account for the variation in forest structure associated with a range of disturbance severity.

To measure the 'observed' forest age distribution on the HFLB, the methods described by Eng (2016) were followed to assign forest age using a combination of VRI and BTM datasets. The total area in each forest seral stage can be calculated by first classifying VRI polygons into each forest seral category according to the 'Projected Age' attribute, and then summing the total area of each category that falls within the HFLB. Where VRI is not available, such as on some private land and Tree Farm Licence areas, BTM is used where a 'BTM age' is assigned to each BTM class (i.e. forested or non-forested land cover classification) to align with a seral category and fill in gaps. All alienated forest land is assigned an age of '0', such that these land cover classes fall within the early seral forest category. Alienated forest lands were all categorized as early seral forest because some alienated land cover classes likely represent a source of persistent early seral habitat that is non-forested but vegetated by native species ( e.g. transmission lines, seismic lines), while other forms provide less or little habitat value for native species as these are highly modified or may be overtaken by non-native species (e.g. urban or agricultural land). Section 3.1.8 provides a further description of alienated forest classes that are included in the early seral forest category, but that are also reported as supplementary indicators to understand land uses that contribute to early seral forest area.

### 3.1.5 Estimating Expected Forest Conditions under Natural Disturbance

The area of forest that can be expected to occur in any given forest age class is based on the natural disturbance regime. Essentially, the area of forest in different age classes in a landscape at a given time (the forest age class distribution) is related to the return interval[15] of forest stand-replacing disturbances that 'reset' the forest age to zero (Van Wagner 1978, Johnson and van Wagner 1985). The negative exponential equation can be used to calculate the expected amount (% of forested land-base) for early seral, mature and old where the expected amount of forest greater than a certain age is calculated as:

$$t = \exp(-[t/b]),$$

Where;
t = age (time since last stand-replacing disturbance) and
b = the average stand-replacing disturbance return interval.

The negative exponential equation results in a non-linear relationship between expected area of forest above or below a certain age and fire return interval (Figure. 6). In general, as the return interval of stand-replacing disturbances becomes greater, the area of mature and old forest is expected to increase.

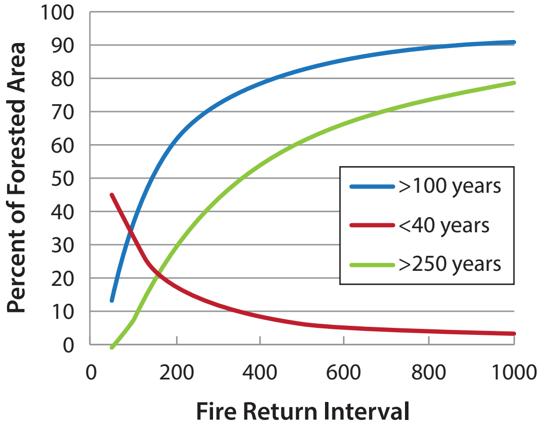

***Figure 6.*** *Illustration showing the relationship between mean expected amounts of old (>250 yrs.), mature and old (>100 yrs.) and early seral (<40 yrs.) forest and stand-replacing disturbance return interval using the negative exponential model.*

Preliminary estimates for the disturbance return interval of stand-replacing wildfires were developed in the Biodiversity Guidebook. The Biodiversity Guidebook assigned stand-replacing disturbance return intervals by Biogeoclimatic (BGC) subzone and categorized each BGC unit into one of 5 Natural Disturbance Types (NDTs). Each BGC unit has a mean return interval (or disturbance return interval) of stand-initiating disturbance, ranging from 100 years in the NDT3 to 350 years in the NDT 1. Since the Biodiversity Guidebook was published, further research has been conducted to describe the disturbance dynamics of several forest ecosystems in the province. For example, in Northeastern B.C., return intervals of 100 to 900 years have been used based on the work of Delong (2011) and return

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[15] The terms 'fire return interval' and the 'fire cycle' are synonymous and refer to the period of time for the total area of a landscape or equivalent assessment area to be burned. This does not mean every point within the area is burned as some areas will escape fire and others may burn twice or more within the time period.

intervals of 1,000 to 3,000 or more years for coastal B.C. (Price and Daust, 2003). In this assessment protocol, disturbance return intervals for each BGC Subzone Variant are based on Biodiversity Guidebook estimates, or where more recent information on return intervals has been accepted (Appendix 3).

Initial estimates from the biodiversity Guidebook applied the negative exponential equation to estimated fire return intervals to provide an average amount of forest expected for each BGC subzone group. The outcome of applying the negative exponential model is a single expected mean estimate for each forest age class rather than a range. This outcome occurs when using the negative exponential equation because it assumes a constant disturbance rate and size, equal probability of disturbance regardless of forest age, and randomly located disturbance events (Van Wagner, 1978). Changes in any of these assumptions will vary the expected age distribution associated with any single disturbance return interval (Van Wagner, 1978; Johnson and Van Wagner, 1985). The expected amount of forest in any given part of a landscape can vary given the spatial and temporal variability in disturbances on the landscape due to “top down” such as climatic influences or “bottom-up” controls such as fuel, slope, aspect (Lertzman and Fall, 1998) that affect disturbance dynamics. Thus, an expected distribution of forest in any given age class, rather than an average amount of forest, is used as a benchmark for comparing the observed forest condition to capture the expected variability in the spatial and temporal variability of natural disturbances. A synthesis of existing studies was completed to provide an estimate of the historic variability around the expected amount of forest in different forest age/seral stages (Appendix 4). The synthesis includes results from modelled studies that simulate disturbance dynamics, studies that estimate return intervals and forest age class distributions from forest inventory maps to estimate fire frequency.

Based on the results of the review of variability in expected amounts of different-aged forests, three ratings were derived to estimate the likelihood that observed forest habitats have deviated form expected historic levels;

- The *Early Forest Increase* rating is used to estimate the likelihood that the amount of early seral habitats has increased beyond historic *levels*.
- The *Mature and Old Forest Loss Ratings* are used to estimate the likelihood that the amount of mature and old forest habitats have decrease beyond historic levels, and
- *Old Forest Loss Ratings* are used to estimate the likelihood that the amount of old forest habitats has decrease beyond historic levels.[16]

To measure the difference between the observed amount of forest at a given time and the distribution of an expected amount of forest in any seral category, a ‘Z-score’ is calculated as;

*Z-score = (observed% -mean expected%)/standard deviation of expected%*

The Z-score provides a relative measure of the number of ‘standard deviations’ that an observed amount falls outside of an expected distribution (Figure 7). Use of the Z-score assumes that the expected amounts of forest in each forest age category is randomly distributed about the mean and can be approximated using a normal distribution. Based on the deviation between the observed and expected amounts, a likelihood rating (Very Low, Low, Moderate, High, Very High) is assigned as a qualitative estimate of the likelihood that observed conditions would have been expected to occur historically.

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[16] Mature and old forest are combined in one rating assuming that; a) many forests classified as mature or old may have similar attributes and that function as similar habitats for many species , and 2) the ability of forest inventory to distinguish forest age beyond 140 years since stand-replacing disturbance is limited.

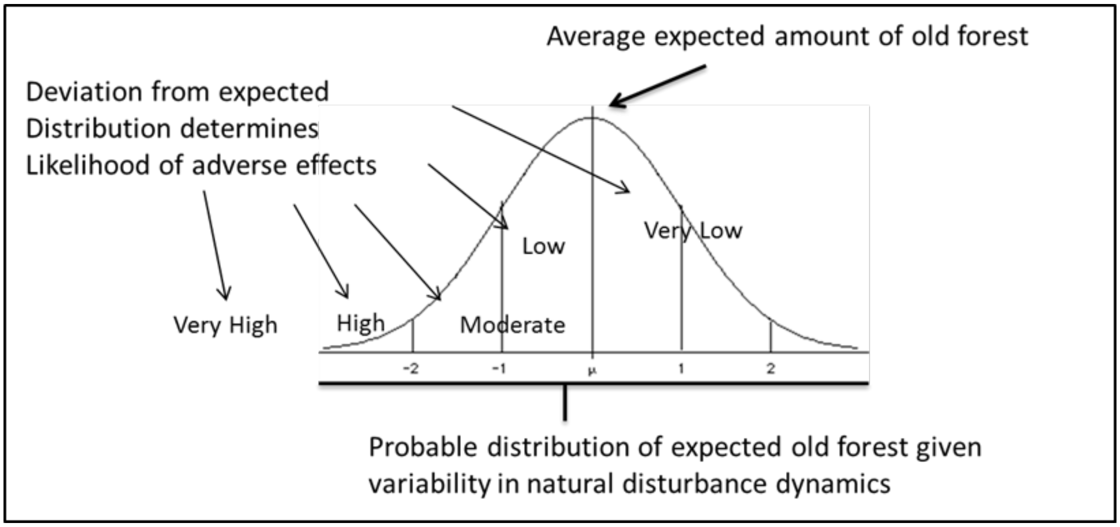

***Figure 7.*** *Relationship between likelihood ratings for Old Forest loss and the expected mean amount and distribution of old forest under the historic range of variability.*

### 3.1.6 The Habitat Change Hazard Rating

The *Habitat Change Hazard Rating* is a qualitative expression of the likelihood that the range of habitat conditions departs from amounts that occurred historically- or a loss of habitat diversity. The *Habitat Change Hazard Rating* is based on the deviation of observed from expected amounts of both early seral forest, and mature and old forest. The rating is derived by combining the *Early Seral Forest Increase* and *Mature and Old Forest Loss* ratings in the following matrix (Table 3).

***Table 3.*** *The Habitat Change Hazard Rating matrix based on the early Seral Forest Increase and Mature and Old Forest Loss ratings.*

| | | **Mature and Old Forest Loss Rating** | | |
|---|---|---|---|---|
| | | **Low** | **Moderate** | **High** |
| **Early Seral Forest Increase Rating** | **Low** | Very Low | Low | Moderate |
| | **Moderate** | Low | Moderate | High |
| | **High** | Moderate | High | Very High |

### 3.1.7 Supplementary Indicators of Insect and Wildfire Disturbance Severity

Intermediate-severity forest disturbances are described as the range of forest disturbance that falls between canopy gap-scale disturbances, that are caused by removal of a single canopy tree, cluster of trees or even a large branch, and stand initiating or 'catastrophic' forest disturbances that remove most or all the overstory vegetation (Hart and Kleinman, 2018).

The current approach to classifying seral stages based on forest age, as a means of capturing forest structure and function (Section 3.1.3 and 3.1.4), is challenged to consider intermediate-severity disturbances. The challenge occurs for two reasons; 1) difficulty in assigning an age to a forest where a portion of the forest overstory is killed or various tree layers (sapling, poles, dominant, co-dominant or veteran trees) remain alive and intact, and 2) As updates to the forest inventory (VRI) occur, forest age is projected forward from the last photo interpretation. As a result, disturbances do not update the forest age but are captured in the forest inventory as disturbance type and severity using information sources such as aerial overview surveys[17] for insect damage, or satellite-derived tools such as Burned Area Reflectance Classification (BARC) mapping[18] to classify burn severity.[19]

To provide information on the extent of mature and old forest affected by various intermediate-severity disturbances indicators for insect attack severity and wildfire burn severity are included in the assessment protocol (Table 4). The amount of mature and old forest in each disturbance type and severity class is broken down allowing for reporting at a Landscape Unit (LU) or Biogeoclimatic subzone variant scale. Further interpretation is required to determine if mature or old forests at different levels of insect or wildfire (Section 4).

***Table 4.*** *Natural disturbance types severity classes and data sources used to characterize insect and wildfire disturbance to mature and old forest on the Historic Forest Land-Base (HFLB).*

| Disturbance Type | Severity (% Mortality) | Data Source |
|---|---|---|
| Insect<br>IBM (mountain pine beetle)<br>IBS (spruce beetle)<br>IBD (Douglas-fir beetle) | 0-30%<br>31-70%<br>>70% | Vegetation Resource Inventory (VRI) |
| Wildfire | Unburned (10%)<br>Low (20%)<br>Moderate (50%)<br>High (90%) | Vegetation Resource Inventory (VRI) |

### 3.1.8 Supplementary Indicators of Land Use that Contributes Early Seral Forest Area

Land use activities that convert forest land to a non-forested or semi-forested condition are amongst the biggest contributors to biodiversity loss. Conversion of forest habitats to urban and agricultural land uses is considered one of the largest threats to biodiversity worldwide (IPBEs, 2018; Ricketts and Imhoff 2003; Wilcove et al., 1998). Of the threats facing endangered species in Canada, urbanization and agriculture were cited in 50% and 41.2% of cases respectively (Venter et al., 2006). Industrial uses such as mines, oil and gas developments, transmission and pipeline corridors, highways and infrastructure are other contributors to biodiversity loss that result in relatively permanent conversion of forests to a non-forested condition. These 'non-forest sector developments' typically delay the forest re-growth, maintain conditions in vegetated, but non-forested condition (e.g. transmission corridors or pipelines) or result in longer term delays in forest re-growth (e.g. mines, oil and gas pads, windfarm developments). Even where forests are re-established following forest harvest, post-harvest forest stands often do not contain the structural attributes of naturally disturbed forests. Young complex forest habitats that are created after stand-replacing or more severe partial natural disturbances are an often-overlooked aspect of managing for forest biodiversity (Swanson et al., 2011).

Portions of the HFLB that have been converted or alienated from the forested land-base are captured as early seral forest when classifying forest habitats by age (Section 3.1.2). Distinguishing

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[17] For more information an Aerial Surveys, visit https://www2.gov.bc.ca/gov/content?id=D61D47FA25DB4D5DA9A19AB1806C34DB

[18] For more information on BARC mapping, visit https://fsapps.nwcg.gov/baer/home

[19] For more information on burn severity and forest inventory data, visit https://www2.gov.bc.ca/gov/content?id=DFC310185BA74B768DEAC09F3C741D31

between the various land use categories that contribute to early seral forest area is imperative to understand the combined effects of all land use activities on biodiversity. Each land use creates very different post-disturbance habitats that vary in their contribution to conserving biodiversity on the land-base. In addition, each type of land use also has different regulatory regimes and authorization processes whereby various options to mitigate impacts to biodiversity can be incorporated.

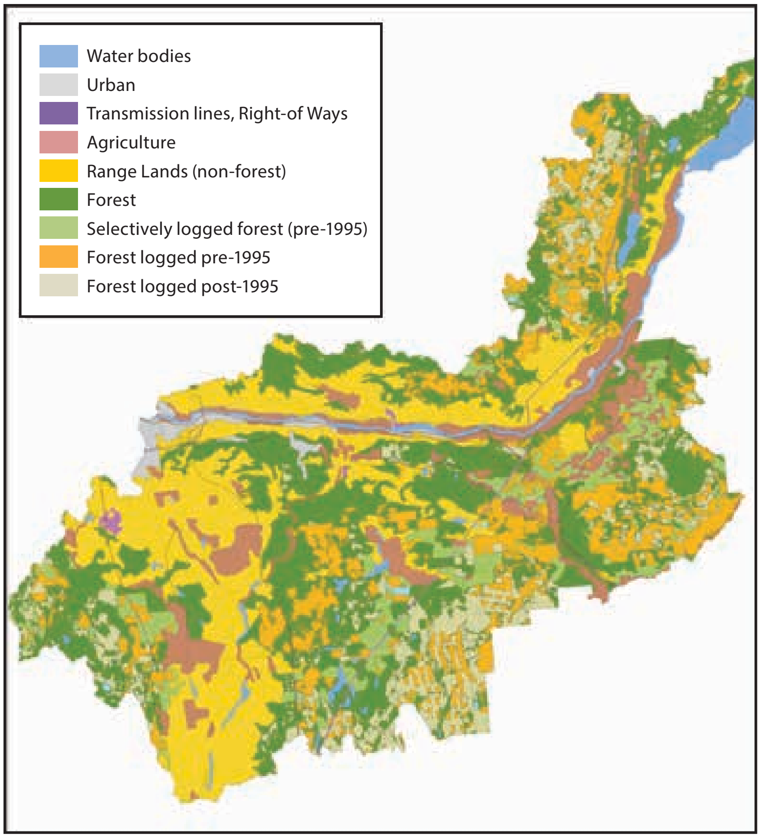

***Figure 8.*** *Land cover classes based on the Cumulative Effects Framework (CEF) Development Layer for the Campbell Landscape Unit, Thompson Rivers Resource District.*

Land uses that convert or alienate forest lands to a non-forested condition are distinguished using a Provincial CEF Development Layer to update the Baseline Thematic mapping (BTM) Layer that was originally created in 1995. The CEF Development Layer combines various provincial tenure datasets available in the British Columbia Geographic Warehouse (BCGW) and the BTM layer in a hierarchal manner to provide a 'snapshot' of the extent of area covered by each land cover category (Figure 8; Table 5). Non-forest sector development including; transmission lines, rights-of-way (i.e. railways and highways), oil and gas developments, seismic lines and mining are accounted for individually,[20] and then combined in a *Non-Forest Sector Development* indicator. The area of urban, agricultural or urban-agricultural mixed areas are calculated individually and summed into the *Urban and Agricultural Development* indicator. Early seral forest that falls within forested landscape is separated into managed and un-managed forest indicators to distinguish between early seral forest created following natural disturbance or forest management.[21]

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[20] Summaries of area affected by individual non-forest sector development categories will be available in summary data provided by the CEF Forest Biodiversity assessment outputs.

[21] Recent forest disturbances such as the 2017 wildfires or MPB insect attack does not affect forest age in VRI

***Table 5.*** *Land Cover category, Indicators and data sources used to characterize types of land Cover classified as early seral forest on the Historic Forest Land-Base(HFLB).*

| Forest Condition | Indicator | Data Source |
|---|---|---|
| Forested early seral | Managed Forest | Vegetation Resource Inventory (VRI) , Projected Age <40 Yrs, Harvested = 'Yes' |
| | Un-managed Forest | Vegetation Resource Inventory (VRI) , Projected Age <40 Yrs, Harvested = 'No' |
| Converted or alienated early seral Forest | Urban and Agricultural | **CEF Development layer:**<br>Agriculture, Urban, Urban Mixed |
| | Non-Forest Sector Development | **CEF Development layer:**<br>Transmission Lines<br>Railway<br>Oil and Gas lines<br>Right of Way<br>Seismic Lines<br>Mining |

## 3.2 Habitat Connectivity

### 3.2.1 Scientific Context

Habitat Connectivity refers to the connectedness of habitat patches for individual species (Lindenmayer and Fisher, 2006). Habitat connectivity is the opposite of habitat isolation, and connectivity between habitats is reduced the more that habitat patches are sub-divided and isolated from one another. Both habitat subdivision and isolation are considered important threatening processes that interact with habitat loss to contribute to species decline (Lindenmayer and Fisher, 2006). Habitat subdivision and isolation affect individual species differently, and the effects can vary substantially between species depending on factors such as the natural distribution of species and their mobility and mode of travel. Many other species-specific traits affect the extent to which habitat sub-division and isolation may impact species. For plants, the effects of habitat isolation are largely restricted to the dispersal of propagules (seeds, spores, etc.). For animals, the effects of habitat isolation are more complex, affecting species at different spatial and temporal scales including, (after Lindenmayer and Fisher, 2006):

- Day to day movements – such as moving between different types of habitats (e.g. foraging, nesting, denning, etc.);
- Dispersal movements – such as dispersing juveniles moving from natal areas to nearby suitable habitats;
- Movements of individuals in meta-populations; and,
- Seasonal migration and range shifts.

The use of *Habitat Connectivity Hazard* in this assessment protocol refers to the likelihood that habitats are more sub-divided and isolated than what would have occurred historically. In this current version of the protocol, *Patch Size Distribution* is used to estimate the proportion of total area of similarly-aged forests that occur on a landscape in different sized patches. The divergence between the observed and an expected Patch Size Distribution is used to derive a *Habitat Subdivision Rating* as a qualitative estimate of the likelihood that mature and old forest habitats are sub-divided and broken up into smaller patches than would have occurred historically. Further work is required to develop the *Habitat Connectivity Hazard Rating* to incorporate both measures of habitat subdivision and a characterization of habitat isolation as it affects habitat connectivity for individuals or groups of species, and their ability to move or disperse between habitats (e.g. a Habitat Connectivity Index). As described earlier, 'habitat' is species-specific, and the ability of individual species to move or disperse between adjacent habitats in a modified, fragmented landscape is also species specific as different organisms have different dispersal ability.

#### *Patch Size Distribution*

The spatial patterns created by landscape changes such as forest harvesting can have different influences on landscape patterns over time (McIntyre and Hobbs, 1999). Initially, small dispersed harvest openings tend to perforate large contiguous tracts of mature or old forests, this pattern creates large amounts of edge, but harvested patches fall within a matrix of older forest that is still largely connected for most organisms. However, as the amount of young forests increase, and size of young forest patches increase (either due to large single openings or coalescing of many small openings into a larger aggregate opening), the area and size of old and mature forest remnants typically decrease in size, inter-patch distance increases, and mature and old forest habitats become more isolated and less connected.

The conservation concern arising from dispersed forest harvesting and coalescing of small openings into large aggregate openings is related to the size of remnant mature and old forest patches. Particularly, in disturbance-prone landscapes, remnant mature, and old forest patches provide important refuges that allow species that require forest structural characteristics to survive and then eventually disperse and recolonize disturbed areas once the forest regenerates (Robinson et al., 2013). Smaller forest habitat patches can lead to species decline (Bender et al., 1998), and smaller patches may be unable to support viable populations over time (Shaffer, 1981).

### 3.2.2 Patch Size Distribution Indicator

The *Patch Size Distribution Indicator* is used to estimate the proportion of total area of similarly-aged forests that occur on a landscape in different sized patches. Patch Size distribution is defined as the proportion of total area of similarly-aged (within 20 years) forests that occur on a landscape in different sized patches.[22] Considering both the influence of early seral forest patch size on spatial landscape pattern, and the conservation concerns arising from the size distribution of remnant mature and old forest, the amount of forest in early, mature and old forest patches is tracked as part of the Patch Size Distribution indicator. The Patch Size Distribution Rating is used to derive the Habitat Sub-Division Rating in 3 steps considering;

- Defining distinctive forest patches using the age and spatial proximity of adjacent forest types,
- Estimating forest patch size distribution of early and mature and old forest patches based on historic estimates derived from historic forest inventory maps and modelling studies.
- Comparing the divergence of the observed amounts of early, mature and old forest patch size distributions to an expected forest patch size distribution

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[22] This should not be confused with the frequency distribution of different sized event patches. A single large (>1,000 ha) early seral patch contains more proportion of total area than 100 small 10 ha patches.

### *Defining Forest Patches*

To define forest patches, VRI and BTM information was first used to distinguish between non-forest and forest types following the approach to define the HFLB described in section *'Defining the Forested Land-base'*. Unique forest patches were defined by combining adjacent forest polygons with similar age classes using the age class groupings outlined in Table 6. Unique patches are formed if similarly-aged forest polygons are separated >100m, such that small residual patches <1ha in size and 'peninsulas' or corridors (e.g. riparian corridors) of different aged forest <100m wide within a larger similarly aged forest patch are included as part of that singular patch.

***Table 6.*** *Forest Patch Types and definitions*[23]

| Patch Type | Definition |
|---|---|
| *Older Forest patches* | |
| Old patches | Old seral stage forest |
| Mature + Old patches | Mature and/or old seral stage |
| *Mature patches* | Mature seral stage |
| Early mature Patches | Mature seral stage ≤140 years in NDT/BEC units where mature seral stage includes forests up to 250 years |
| Late Mature patches | Mature seral stage >140 years in NDT/BEC units where mature seral stage includes forests up to 250 years |
| Younger (Recruitment) Forest Patches | Includes six patch types:<br>• 0-20 yr. old forest patches<br>• 21-40 yr. old forest patches<br>• 41-60 yr. old forest patches<br>• 61-80 yr. old forest patches<br>• 81-100 yr. old forest patches<br>• 101-120 yr. old forest patches (In NDT/BEC types where forest of this age are classified as mature, they are included as part of mature and mature + old patches and not as younger(recruitment) patches) |

### *Historic Estimates for Mature and Old Forest Patches*

Historic estimates for early seral, mature and old seral forest were summarized based on a review of the available published literature (Appendix 5). Based on that summary Table 7 provides initial estimates of historic benchmarks for mature and old forest patch size distributions. These results can provide a reasonable first approximation for other subzones in the province, at least as a preliminary estimate until further information is available.

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[23] Cariboo Chilcotin Land Use Plan Regional Biodiversity Conservation Strategy Update Note #4: An Approach for patch size assessments in the Cariboo Forest Region. https://www.for.gov.bc.ca/hfd/library/RBCS.htm

***Table 7.*** *Estimated proportions for mature and old forest by patch size class*

| | **Patch Size (ha)** | | | | |
|---|---|---|---|---|---|
| Estimated for NDT3* | **<40** | **41-250** | **251-1,000** | **>1,000** | **>5,000** |
| | Proportion of total old or mature forest area | | | | |
| | 10-30 | 10-30 | 20-40 | 20-40 | <5 |

| | **Patch Size (ha)** | | | | |
|---|---|---|---|---|---|
| Estimated for NDT1,2 and 4* | **<40** | **41-250** | **251-1,000** | **>1,000** | **>5,000** |
| | Proportion of total old or mature forest area | | | | |
| | 5-15 | 5-15 | 20-40 | 30-70<br>(30-50) | 5-15 |

* Cumulative frequency distributions were derived from results reported for each study to standardize the proportion of area in each patch size class.

### 3.2.3 The Habitat Sub-Division Rating

The *Habitat Sub-Division Rating* provides an estimate of the likelihood that mature and old forest habitats are sub-divided into smaller patches than would have occurred historically. The emphasis of this rating is on mature and old forest habitats as these become the most limiting in landscapes subject to modification through human use and natural disturbances. The *Habitat Sub-Division Rating* is derived by first calculating the 'observed' patch size distribution (percent of mature and old forest in each patch size class):

*% Area Mature and Old Forest in Patch Size (x) = Total Area Interior Mature + Old forest in Patch Size (x) / Total Mature + Old Forest Area*

Where;

- Mature and old forest is defined for each BGC subzone using age-based criteria
- Patch size classes include 0-40, 41-250, 251-1000, and >1000 hectares

The rating is then derived by comparing the difference between the observed distribution of mature and old patch sizes from an expected distribution based on HRV estimates. The difference between the observed from expected distribution is calculated by using a measure of divergence (D) between the observed and expected distributions (Appendix 6). Where the observed mature and old patch distribution = expected distribution, then D =0, and D increases as the observed distribution diverges from an expected distribution (Figure 9).

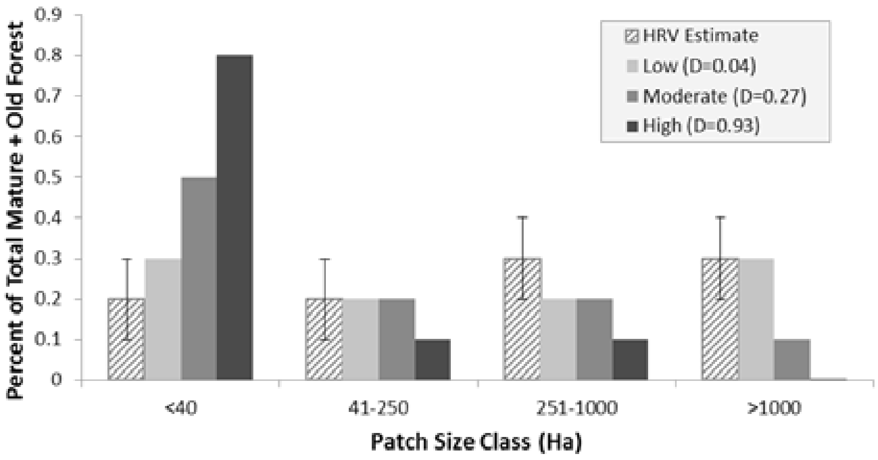

***Figure 9.*** *Percent area of mature and old forest in various patch size classes representing the 'expected' patch size distribution for mature and old forests for NDT3 ecosystems based on historic range and variability (HRV) estimates (hatched) compared to three hypothetical 'observed' distributions representing increased subdivision of mature and old forest patches into smaller patch sizes (deviation from the expected.*

In general, measures of divergence (D) <0.1 fall within the estimated HRV of patch sizes. Measures of (D) from 0.11- 0.3 fall within HRV in at least two patch size categories, while divergence (D) beyond 0.3 falls outside of HRV in all patch size classes (Table 8).

***Table 8.*** *The Habitat Sub-Division Rating based on the measure of divergence (D) of the observed mature and old forest patch distribution from an expected distribution based on the historic range and variability.*

| | **Habitat Sub-Division Rating** | | |
|---|---|---|---|
| **Divergence (D) of observed mature and old forest patches** | **Low** | **Moderate** | **High** |
| | <0.10 | Hig 0.11-0.30 h | V. Hig >0.30 h |

## 3.3 Species Dynamics

The term "Species dynamics' refers to the relationships between a species and its environment (i.e. behavior and biology) and its interactions with other species. The use 'Species dynamics' is intended to be analogous to the threatening process identified by Lindenmayer and Fisher (2006) referred to as 'Changes in species behavior, biology and interactions with other species' that result from landscape change and modification. Types of changes that can result in species decline include:

- Habitat avoidance and displacement
- Increased inter-species competition
- Increased predation or parasitism
- Disruption of mutualistic relationships between species

The *Species Dynamics Hazard* refers to the likelihood that species have altered their behaviour, biology or interactions due to increased forest edges and roads and linear features effects into forested environments. The *Species Dynamics Hazard* relies on two GIS-based indicators that can be readily calculated from available datasets and include the *Mature and Old Interior Forest Amount* and *Area Undisturbed by Roads and Linear Features*. Responses to human-caused disruptions are species-specific and will vary depending on a multitude of factors within any local context, thus it is important to note is that these two indicators likely do not account for some factors (e.g. recreational/industrial use) that affect species biology, behavior, or interactions, and further interpretation will be required to describe consequences to individual or groups of species.

### 3.3.1 Scientific Context

#### *The Importance of Interior Forest Habitats*

Natural edges are a relatively common feature in most forested landscapes (Von Sacken, 1998; Harper et al., 2015). Edges occur naturally between forested and non-forested openings (e.g. wetlands, lakes), or sparsely forested areas (e.g. sub-alpine parkland, sparsely forested meadows), or are created by natural disturbances, such as wildfires, particularly in landscapes prone to more frequent, severe natural disturbance (Parkins et al., 2017; Harper et al., 2015, 2005). Where forests adjoin naturally non-forested features (e.g. wetlands, lakes, rocky outcrops) natural edges can often be long-term or permanent features on the landscape, and the transition between the forest and opening is often gradual (Harper et al., 2005). These edges create a natural transition or 'ecotone' between forest and natural openings that provide important habitats for many species; particularly in disturbance-prone landscapes many species are well suited to utilizing edge environments (Harper et al., 2015).

As landscapes are modified by human activity, edges created through severe natural or human-caused events can result in abrupt boundaries (such as between on old forest and clearcut) that impose changes in adjacent forests, perforate or dissect large tracts of interior forest (Esseen et al., 2016; Harper et al., 2015). Human caused edges can occur more frequently where the rate of disturbance exceeds that of natural disturbance cycles (Harper et al., 2015). Human-caused edges may also persist for longer periods, particularly where forests are converted to other land uses (e.g. urban or agricultural) or maintained in a perpetually de-forested condition for extended periods (such as along transmission right of ways).

The increase in forest edge and resulting loss of interior forest habitat[24] has emerged as an area of conservation concern as landscape change and modification fragments areas of contiguous forest into smaller isolated remnants, (Esseen et al., 2016; Haddad et al., 2015; Lindenmayer and Fischer, 2006; Von Sacken, 1998). Much of the concern over loss of interior forest habitats is related to the effects on forest-dwelling species due to changes in biological and physical processes that occur along human-caused edges. The term 'edge effects' (Voller, 1998; Angelstam, 1992) is used to refer to ecological phenomenon that occur between the boundary of two adjacent patches. Types of edge effects can include:

- abiotic influences such as changes in light, wind and other microclimate variables, and physical changes in forest structure, and
- changes in biotic processes such as inter-species competition (e.g. invasive species), predation or parasitism directly associated with the edge environment.

The extent that edge effects from an adjacent area extend into a forest, or the depth of edge influence (Chen et al., 1992), can vary depending on the 'edge contrast' – the degree to which

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[24] Interior habitat is defined as the portion of a species' habitat that does not experience edge effects and maintains its functional viability for plant and animal communities (Von Sacken, 1998). Interior habitats can refer to any forested, grassland or other habitat that is not affected by edges (Von Sacken, 1998).

two adjacent patches differ. For abiotic processes such as those described by forest microclimatic variables, factors such as the types of adjacent forest vegetation (shrubs/trees), forest structure (height of adjacent trees), edge type (abrupt or gradual) and edge orientation and daily weather can all influence edge effects (Chen et al., 1990). The edge influence can vary between forest biomes (e.g. boreal forest vs. temperate or rainforest) based on forest productivity and extent of inherent natural edges (Esseen et al., 2016). In general, most edge effects occur within 1-2 tree heights. Changes in microclimatic gradients and other physical processes that affect forest structure generally occur within the first 50-100m and maximum edge effects are expected to occur up to a distance of approximately 200 metres (Chen et al., 1992; Harper et al., 2015).

### *Effects of Roads and Linear Features*

The effects of roads (highways, resource roads) and linear features (railways, seismic lines, transmission lines) on biodiversity have been relatively well documented in the literature (See Benitez-Lopez et al., 2010; Robinson et al., 2010; Fahrig and Rytwinski, 2009; Trombulak and Frissel, 2000; Forman and Alexander, 1998, for reviews). In a review of empirical literature, Fahrig and Rytwinski (2009) found strong evidence for negative effects of roads at the population level. In general, the effects of roads were predominantly negative, and varied by taxa; amphibians and reptiles, birds, mid-sized and large mammals tended to show negative effects, while small mammals and some small birds and vultures showed neutral or positive effects. Many of the negative effects of roads and linear features relate directly to changes in species behaviour (i.e. avoidance of roads) and threaten species in ways not directly associated with loss of habitat associated with road construction, and can include:

- Increased mortality due to increased predator efficiency;
- Increased direct mortality (hunting, killing, vehicle collisions);
- Animal displacement and/or avoidance associated with traffic and noise,
- Stress on breeding individuals
- Intrusion of edge effects into adjacent forests,
- Soil and air pollution,
- Barriers to movement
- Increases in invasive species colonization.

The extent of negative from roads can be influenced by several factors related to; road and traffic characteristics (e.g. traffic volume), landscape topography, slope and adjacent vegetation (forest or non-forest). For example, Forman and Alexander (1998) and Seiler (2001) reported studies that show decreased bird abundance associated within the area around roads, but that effect was reduced with adjacent forest vegetation compared to grassland. The effects increased with traffic volume and traffic speed.

Many road-related effects often occur within the first 100-200m from a road. Mortality from vehicle collisions directly on roads can be a significant source of mortality for some species and main contributor to population decline (e.g. some birds, herpetofauna). Most noticeable road-related effects, especially for plants, occur within the first 10-15m of roads (Roever et al., 2008). Pollution effects from salt, heavy metals can persist within the first 100-200m of roads. Hunting or unintended killing of species such as Grizzly Bear has also been shown to be in close proximity to open roads (McLellan and Shakelton, 1988; Nielsen et al., 2004).

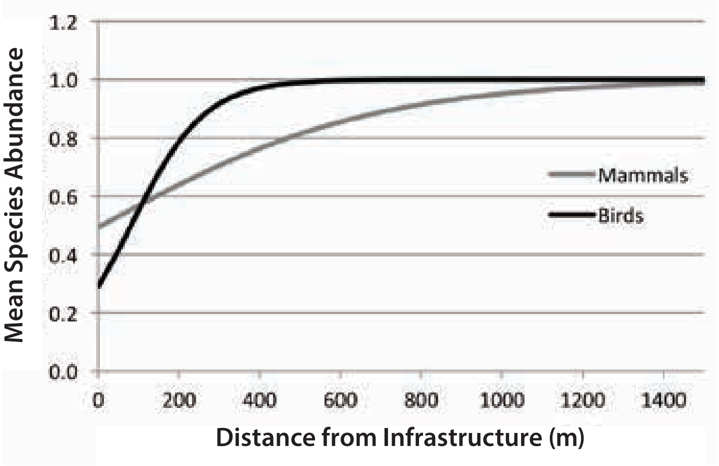

***Figure 10.*** *Average relationship between mean species abundance and distance from infrastructure for birds and mammals in forested biomes, based on pooled results of published studies from a meta-analysis completed by Benitez-Lopez et al. (2010).*

For some birds and large mammals, habitat displacement or avoidance of roads can extend much further. In a meta-analysis of relevant studies, Benitez-Lopez (2010) showed that mean bird species and mammal abundance in forested ecosystems was reduced within 500-1000m of infrastructure (roads, railways, powerlines, pipelines, hydroelectric developments oil wells, seismic lines and wind parks) (Figure 10.), but that most road-related were mitigated at 500m for bird species and 1-2000m for mammals in forested environments. Responses varied between mammals; rodent species were affected within the first few meters of a road whereas the effects on Artiodactyla (hoofed mammals) occur within 1000 metres. For species such as caribou (*Rangifer tarandus*), particularly in non-forest environments, avoidance of linear features can extend for several kilometres (Benitez-Lopez et al., 2010). Responses of bird taxa also varied; with species such as songbirds showing negative effects, while other taxa such as raptors (Falconiformes) were positively related to roads, likely responding to carrion resulting from vehicle collisions (Benitez-Lopez et al., 2010).

### 3.3.2 Old and Mature Forest Interior Indicator

The *Old and Mature Interior Forest Indicator* is used to estimate the amount of old and mature forested area that is not influenced by edge. The Old and Mature Forest Interior indicator is calculated as:

*% Area Interior Mature and Old Forest = Total Area Interior Mature +*
*Old forest/ Total Mature + Old Forest Area*

The indicator and associated rating are calculated in 3 steps that includes;

- Assigning edge buffer distances to approximate the edge influence into mature and old forest patches based on the contrast or difference in tree cover in the adjacent area,
- Estimating the historic range and variability of interior forest area, considering variability in the amount of naturally-formed edges associated with historic disturbance regimes,
- Comparing the observed amount of interior forest habitat to expected amounts.

#### *Assigning Edge Buffer Distances*

To assign edge buffer distances, distinct patches of different aged forests were identified following the criteria to form patches outlined in Section 3.2.1. Since many human-caused edges are relatively short-lived (e.g. harvested openings that are regenerated) as disturbed openings re-grow and the physical effects of the edge become less pronounced, the edge influence of one forest patch into the adjacent mature and old forest is ‘contrast-weighted’ considering the age or type adjacent forest or non-forested patch. For the mature and old forest patch types a contrast-weighted edge buffer distance extending into mature and old patches was used to represent the depth of edge influence, considering expected differences in tree height and forest continuity of adjacent different aged patches and non-forest types (Table 9 and Figure 3-11).

***Table 9.*** *Edge buffer distances used to represent the influence of edge effects into mature and old forests from adjacent patch types. Adapted from Table 2 of the CCLUP Regional Biodiversity Conservation Strategy.*

| Seral Stage or Patch | Adjacent Patch | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mature | 101-120 years | 41-100 years | 20-40 years | 0-20 years | Non-productive; Non forested* | Lakes, Wetlands and Large Rivers |
| **Old** | 10 | 25 | 50 | 100 | 200 | 100 | 100 |
| **Old and Mature** | 0 | 50 | 50 | 100 | 200 | 100 | 100 |

* This category includes naturally non-forested areas. Converted forest areas, including urban and agricultural lands and major linear corridors are included as patches 0-20 years old.

### *Estimating Expected Interior Forest Amount Based on Historic Disturbances*

The Biodiversity Guidebook provided preliminary estimates for the percent area of interior forest by Biodiversity Emphasis Option (BEO), recommending 10-25% of old forest area in interior habitat for Low BEO Landscapes, and 25-50% for Intermediate and High BEO landscapes. Low BEO implied a higher risk to biodiversity compared to Intermediate BEO (moderate risk) and High BEO (low risk) (Appendix 2 Biodiversity Guidebook).

The Cariboo-Chilcotin Biodiversity Conservation Strategy applied the Biodiversity Guidebook recommendations in the context of both BEO and NDT, such that NDTs that typically experience relatively infrequent stand replacing disturbances and smaller patch sizes (e.g. NDT 1 and 2) have greater forest interior area as a proportion of total old forest as compared to more disturbance prone ecosystems (e.g. NDT3)(Table 10).

***Table 10.*** *A comparison of recommended amounts of interior forest based on disturbance regime and Biodiversity Emphasis Option from the Biodiversity Guidebook to preliminary estimates of based on disturbance regimes.*

| NDT | Mean Event Interval* | Expected Forest Amount* | | | Recommended Interior Forest by BEO** | |
|---|---|---|---|---|---|---|
| | | Early | Old | Old + Mature | Low | Intermediate or Higher |
| 3 | 150yr | 23 | 39 | 51 | 10 | 25 |
| 2 | 200yr | 18 | 29 | 61 | 10 | 25 |
| 4 | 250yr | 15 | 37 | 67 | 25 | 50 |
| 1 | 350yr | 11 | 49 | 75 | 25 | 50 |

* An example Mean Event Interval and expected forest amount for each NDT are shown for reference only to illustrate differences in expected forest ages. Expected amounts of early seral includes forest <40 yrs. Mature forest >100yrs and Old forest >141 for NDT3 and >250yrs for other NDTs

**Note that values in the table are percentages of the total area of old forest that is interior old forest. Guidelines for forest interior area as outlined in table 4 of the CCLUP Regional Biodiversity Conservation Strategy.

## 3.3.3 The Interior Forest Habitat Loss Rating

The Interior Forest Habitat Loss Rating is used as an estimate of the likelihood of a loss of mature and old interior forest habitats and increased edge effects. To derive the ratings, the range of expected early seral forest amounts by stand-replacing disturbance return intervals (Table 10) was used to derive historic estimates for mature and old interior forest area based on the relationship between % early seral forest and interior forest area (Appendix 6) , In forested ecosystems with infrequent stand-replacing disturbances (NDT 1,2, 4), relatively low amounts of early seral and smaller patch sizes

HRV estimates of interior forest area is expected to be higher than the BG recommendations. Forest ecosystems that experience more frequent stand-replacing disturbance events (NDT3) typically have higher amounts of edge and lower amounts of interior forest area estimates are more consistent with the BG recommendations for Low BEO (Table 11).

***Table 11.*** *Interior Forest Habitat Loss ratings of Low, Moderate and High relative to stand-replacing disturbance return interval.*

| Stand-Replacing Disturbance Return Interval | Interior Forest Habitat Loss Rating | | |
|---|---|---|---|
| | Low | Moderate | High |
| | Percent (%) Interior Mature + Old Forest | | |
| <200yrs | >25 | 11-25 | <10 |
| 200-350yrs | >50 | 25-50 | <25 |
| 350+yrs | >70 | 51-70 | <50 |

## 3.3.4 Area Undisturbed by Roads and Linear Features Indicator

The *Area Undisturbed by Road and Linear Features* indicator is intended to estimate the proportion of the landscape potentially not affected by the negative effects associated with roads and linear features. Three buffers distances; 150m, 500m and 1000m are used to represent the 'zone of influence' of potential negative effects of roads and linear features into the surrounding forested land-base (Figure 11), corresponding with the responses of a variety of organisms to a range of road-related effects as reported in the literature (see previous section) .

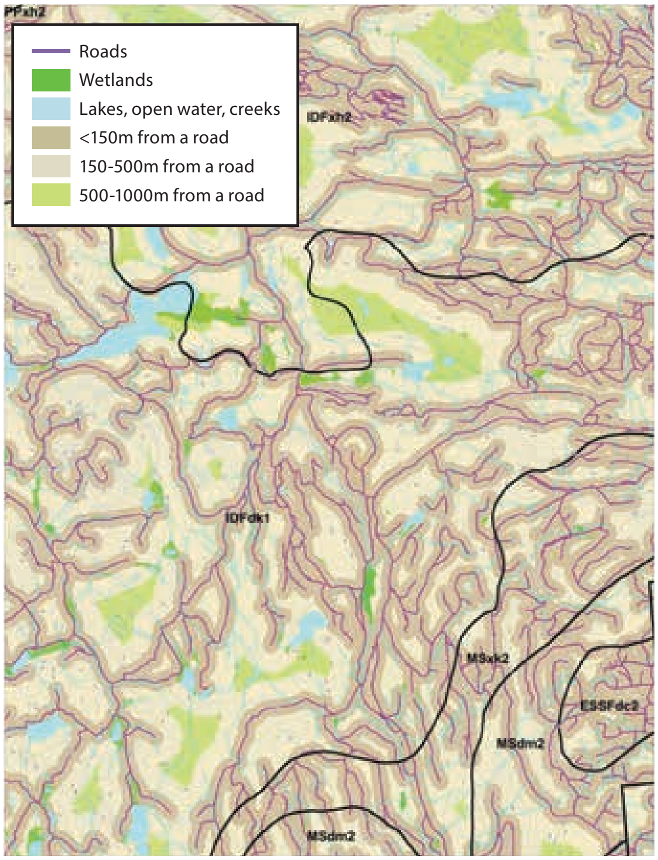

***Figure 11.*** *An example illustration of the area undisturbed by road indicator showing portions of the land-base <150, 150-500 and 500-1000m from a road.*

To calculate the indicator, roads and linear features were first identified using the provincial Cumulative Effects Framework (CEF) Integrated Road Layer created by consolidating various BCGW road sources in a hierarchal order including; the – Digital Road Atlas (DRA), Forest Tenures (FTEN) Roads and Mineral Tenure roads. The layer includes highways and resource roads as well as linear features such as power transmission and oil/gas pipelines. For all roads and linear features buffer distances of 150, 500 and 1000m into the surrounding HFLB were applied equally regardless of road classification (paved/gravel/railways/pipelines and undefined (forest roads)). The indicator reports the % of the HFLB that is > 150, 500 or 1000m from a road or linear feature as portions of the forest land-base potentially 'undisturbed' or unaffected by roads or linear features. Several important assumptions are required in applying the Integrated Roads layer in this indicator approach including:

1. No distinction was made between road classes as to traffic, amount and/or type of activity, all are assumed to have equal use.

2. All roads are assumed to be open and accessible (no gates, no deactivation/rehabilitation that would restrict access), and
3. All portions of roads are assumed to be used equally and have an equal probability of effect along their length.

Most of the assumptions noted above are likely violated based on known differences in traffic volumes, or accessibility affecting the amount of human use along different road types (e.g. highways, major resource roads or in-block roads). However, data on use or traffic volumes is not available at this time, so the use of the integrated roads layer in this way provides a reasonable first approximation of potential impacts of roads on biodiversity, but further work is required in the future to improve data (Section 3.3.5).

#### *Deriving the Indicator Rating*

The *Road/Linear Feature Disturbance Rating* is a qualitative estimate of the extent of roads and linear features effects in forested environments. Unlike other ratings where benchmarks are based on historic estimates, roads and linear features have no historic analogue. To derive ratings existing published literature on road-related effects was reviewed to determine preliminary benchmarks (Appendix 7). The existing literature does provide some evidence to suggest that relatively low road densities (<0.06km/km$^2$, approximately 60% area >500m from a road) in forested environments is required to maintain large carnivores such as wolves, mountain lion (*Felis concolor*), and functioning predator prey systems (Forman and Alexander 1998). Moderate to high road densities (>1.5 km/km$^2$; approximately <30% of the HFLB >500m and almost no area >1000m from a road) suggest that most of the landscape would experience relatively high level of road-related effects on almost all species and provides an upper benchmark between the moderate and high likelihood ratings (Table 12).

***Table 12.*** *The Road/Linear Feature Disturbance rating based on the percent (%) of the historic forest land-base >500m from a road or linear feature.*

| | **Road/Linear Feature Disturbance Rating** | | |
|---|---|---|---|
| | **Low** | **Moderate** | **High** |
| **Area >500m from a Road or Linear Feature** | >60% | 31-60% | <30% |

### 3.3.5 Changes in Species Behavior, Biology and Interactions Hazard

The *Species Dynamics Hazard Rating* is used to estimate the likelihood that species have altered their behaviour, biology or interactions due to increased forest edges and roads and linear features effects. The rating is derived by combining the *Interior Forest Amount Rating* and the *Roads/ Linear Features Disturbance Ratings* in the following matrix (Table 13).

***Table 13.*** *The Species Dynamics Hazard Rating matrix based on the Forest Interior Loss and Road/Linear Feature Disturbance Ratings.*

| | | **Road/Linear Feature Disturbance Rating** | | |
|---|---|---|---|---|
| | | **Low** | **Moderate** | **High** |
| **Forest Interior Loss Rating** | **Low** | Very Low | Low | Moderate |
| | **Moderate** | Low | Moderate | High |
| | **High** | Moderate | High | Very High |

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# 5 Appendices

## Appendix 1: Defining the Historic Forest Land-Base

### Background and Introduction

The Historic Forest Land-Base (HLFB) is an estimate of the area of British Columbia's land-base that is presently forested or was likely forested in the recent past.  The term 'historic' is used in a relatively recent context (i.e. last 100-150 years) and can generally be considered to include areas forested prior to European settlement and industrial development in BC. Thus, using the term 'historic' refers to areas of the land-base that is, or was, likely capable of supporting forest and assumes; 1) that currently forested areas represent areas that also likely historically supported forest and, 2) recent mapping and remotely sensed imagery can be used to identify currently non-forested areas (e.g. urban, agriculture, railways, highways, mines ) that likely supported forest prior to development.

The HFLB is also a 'snapshot' in time and there are several limitations that should be kept in mind when applying this information in any analysis. First, what is currently forested along ecotones between forest and grassland or forest and alpine areas likely shifted over time given climatic changes and natural disturbances (e.g. wildfires) and natural forest ingress that modify forest structure in these ecotones. Second, early agricultural settlements, such as in portions of the Kootenays, Okanagan, Cariboo Chilcotin and Peace Regions followed lower valley grassland and/or sparsely forested ecosystems where the level of forest clearing applied to develop agricultural land is largely unknown. Thus, the extent of those areas that were historically forested is difficult to estimate and so the HFLB definition can either over or under-estimate forested areas in these regions. Third, the extent of pre-contact First Nations forest management (e.g. burning) is mainly unknown, and the affect of these practices on modifying forest cover over time is not considered. Finally, human modifications to water bodies such as the creation of reservoirs through damning of rivers or channelization of rivers is not considered. These changes would require re-creation of the natural water courses and is beyond the current scope.

The purpose of defining the HFLB is to provide a benchmark for estimating change in forest land cover over time. For assessment purposes the benchmark can be used to:

1) Estimate the area of permanent or semi-permanent conversions of forest land to a non-forested condition (e.g. open pit mines, agriculture, urban or rural settlements)
2) Estimate the change in land cover between two or more time periods by providing a consistent baseline or 'denominator' when comparing differences in any land cover category (e.g. amount or percentage of young or old forest).

## Approach

### *Defining the Forest*

The approach described here follows and builds off the work of Eng (2018) titled "*Creating a Land Cover and Forest Age Map for British Columbia*".[1] Following that approach, an initial classification of the HFLB was defined using the British Columbia Land Cover (BCLC) Classification scheme https://www.for.gov.bc.ca/hfd/library/documents/bib107006_2002.pdf in the provincial VRI dataset.

- BCLC Level 1 distinguishes between 'V'= Vegetated, 'N' = Non-vegetated land and 'U' = Unreported (Map 1).
- BCLC Level 2 defines Land Cover Type including 'T'= Treed and 'N' = Non-treed for Vegetated land, and 'L' = Land or 'W' = Water for Non-vegetated land (Map 2).
- BCLC Level 3 describes landscape position; 'W'= Water, 'U' = Upland or 'A' = Alpine (Map 3).

Any portion of the land base that was classified as BCLC1 = 'Vegetated', BCLC2 = 'Treed' and BCLC3 'Upland' was initially classified as "HFLB" (Table 1). All other areas were assigned as "Non-HFLB" with Unreported areas initially classified as 'Unknown".

***Table 1.*** *BC Land Cover Classification Categories used to apply an initial classification of areas that are forested (HFLB? = Yes), non-forested (HFLB? = No) or Unreported (HFLB? = 'Unknown) and categories requiring further review.*

| BCLC Level 1 | BCLC Level 2 | BCLC Level3 | HFLB? | Further Review |
|---|---|---|---|---|
| 'V'= Vegetated | 'T' =Treed | 'U'= Upland | 'Yes' | |
| | | 'W'= Wetland | 'Yes' | |
| | | 'A'= Alpine | 'Yes' | |
| | 'N' = Non-Treed | 'U'= Upland | 'No' | Yes |
| | | 'W'= Wetland | 'No' | |
| | | 'A'= Alpine | 'No | |
| 'N'= Non-Vegetated | 'L' = Land | 'U'= Upland | 'No' | Yes |
| | | 'W'= Wetland | 'No' | |
| | | 'A'= Alpine | 'No' | |
| | 'W' = Water | 'W'= Wetland | 'No' | |
| | | 'A'= Alpine | 'No' | |
| | 'N'= Non-Treed | 'U'= Upland | 'No' | |
| 'U' = Unreported | | | Unknown | Yes |

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[1] Eng, M. 2018. Creating a Land Cover and Forest Age Map for British Columbia; the Forest Resource Evaluation Program Method. Unpublished report prepared for BC Ministry of Forests, Lands and Natural Resource Operations. 24 pages.

Further review of this initial classification is necessary as the BCLC classification is based on current land cover and does not necessarily distinguish well between areas that are naturally non-vegetated or non-forested, and those that may have been converted to non-forest conditions through land use. The initial classification results assisted in identifying three BCLC categories for further review (Table 1), including:

1. BCLC1= 'Vegetated', BCLC2= 'Non-Treed' and BCLC3 = 'Upland'. By definition "vegetated includes >5% cover by vegetation (trees, shrubs, herbs, graminoids, lichens) and "non-treed' areas include <10% crown cover of tree species of any size. Initial examination revealed that this classification was applied to naturally sparsely or non-forested areas as well as areas where trees have been cleared. Areas in this classification could therefore include recent cutblocks, right-of ways, or agricultural clearing in areas that may have been previously forested.
2. BCLC1= 'Non-vegetated', BCLC2 = 'Land', and BCLC3 = 'Upland'. By definition 'Non-vegetated' areas include <5% cover by vegetation. This classification included further classification levels (BCLC 4 and BCLC 5) that provided non-vegetated land definitions that could include both naturally non-vegetated areas (e.g. Exposed Land = Beach, Bedrock, Glaciers) and relatively permanent human developments (e.g. open pit mines, railways, gravel pit, airports, urban areas). The classification does not distinguish areas of human developments that may have been previously forested.
3. Unreported areas cover a relatively small portion of the land-base restricted to where inventory information is currently not available. Examples include some National or Provincial Parks, some Tree Farm Licenses (TFLs), and areas outside of British Columbia.

## Manual Review and Definition of the Historic Forest Land base

A two -step process was used to classify the land-base as "HFLB/Non-HFLB" for the three BCLC categories identified above as requiring further review and classification:

Step 1 involved manual identification of polygons that may have been mis-classified to "HFLB" or "Non-HFLB" categories under the initial HFLB classification based on the BCLC categories applied in the VRI. The initial HFLB classification layer was overlaid with both satellite imagery and the Baseline Thematic mapping (BTM) Layer https://catalogue.data.gov.bc.ca/dataset/baseline-thematic-mapping-present-land-use-version-1-spatial-layer to identify current and historic land cover , and the 1:50,000 map-sheet tile grid. Each map-sheet tile was individually visually scanned to identify areas obviously mis-classified as either HFLB or non-HFLB according to the initial HFLB classification. Types of mapping misclassifications included:

1. Where linear boundaries exist between HFLB and Non-HFLB polygons associated with linear corridors or agricultural/urban land (Fig 1.) and,
2. mapping irregularities such as large rectangular polygons in non-classified alpine areas or inconsistent classification particularly between individual mapsheets in grassland/forest ecotones (Fig. 2).

These polygons were copied into a separate feature layer in ArcGIS labelled "Manual Fix" for subsequent review and interpretation.

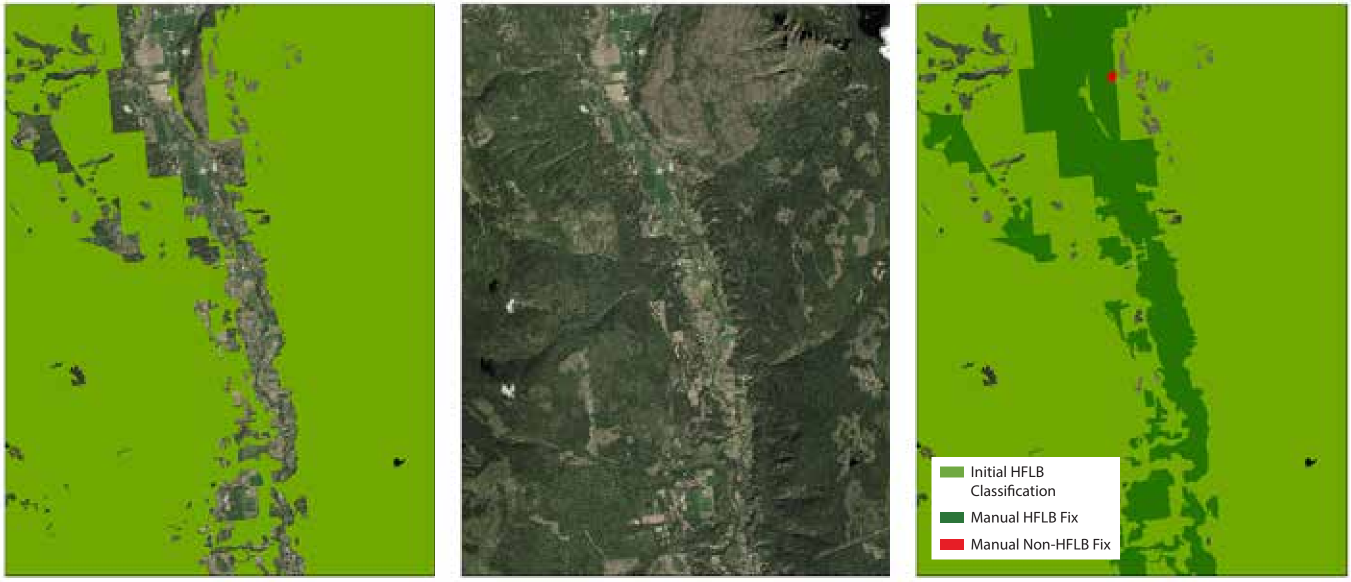


***Figure 1.*** *An example of initial HFLB classification using BCLC classification from VRI on the left (A) in an area of agricultural/ forest interface. The satellite imagery (B) shows clear linear edges between forested polygons and adjacent land (private land) that was cleared for agricultural uses. These areas were interpreted as previously forested based on adjacent forest stands and then manually "fixed" by interpreting and classifying as either 'HFLB' or 'Non-HFLB' (C) using satellite imagery and Baseline Thematic mapping (BTM).*

Step 2 involved assigning a HFLB or Non-HFLB label for each of the identified polygons in the "Manual Fix" layer. Areas that were clearly non-forested due to human causes (forest harvesting, land clearing or linear corridors) that clearly showed a sharp edge with an adjacent forested polygon, indicating the forest was cleared, were manually assigned as HFLB (Fig. 1). The remaining polygons largely consisted of alpine/forest or grassland/forest ecotones. The polygons were intersected with the BTM layer and non-forest polygons (BTM categories = 'Alpine', 'Glaciers and Snow', 'Barren Land', 'Wetland', 'Fresh Water', 'Range Land', 'Shrubs, 'Sub Aline Avalanche Chutes') were assigned as Non-HFLB and forested areas (BTM Category = 'Old Forest', 'Young Forest', 'Recently Logged', 'Recently Burned', 'Selectively Logged') assigned as HFLB.

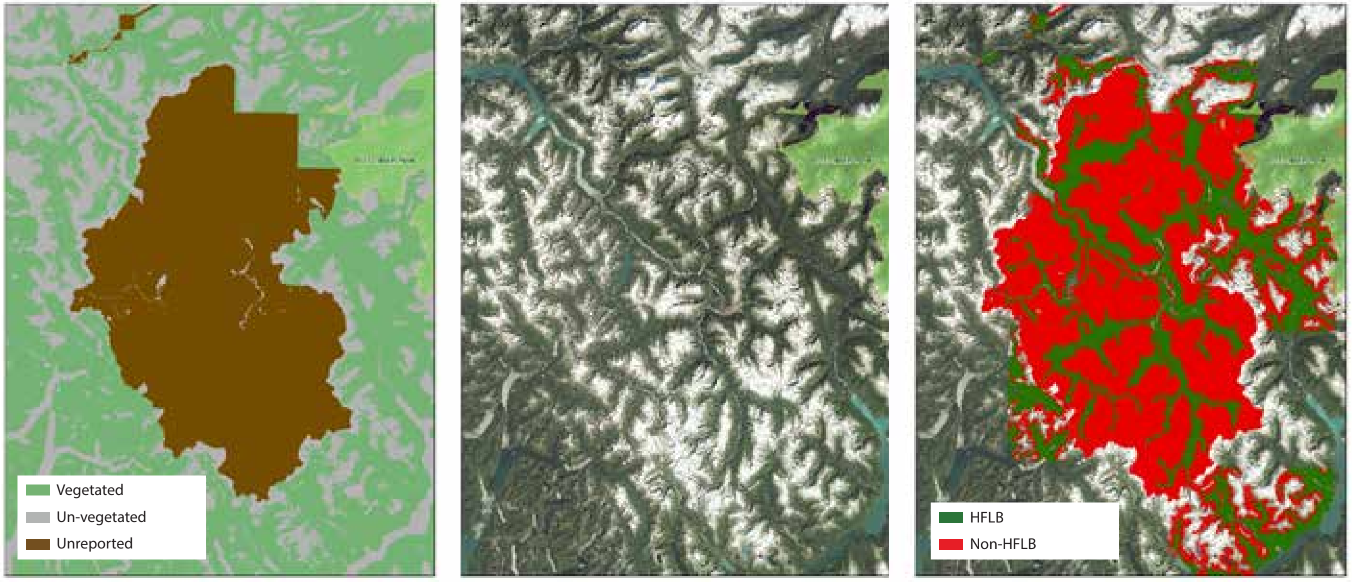
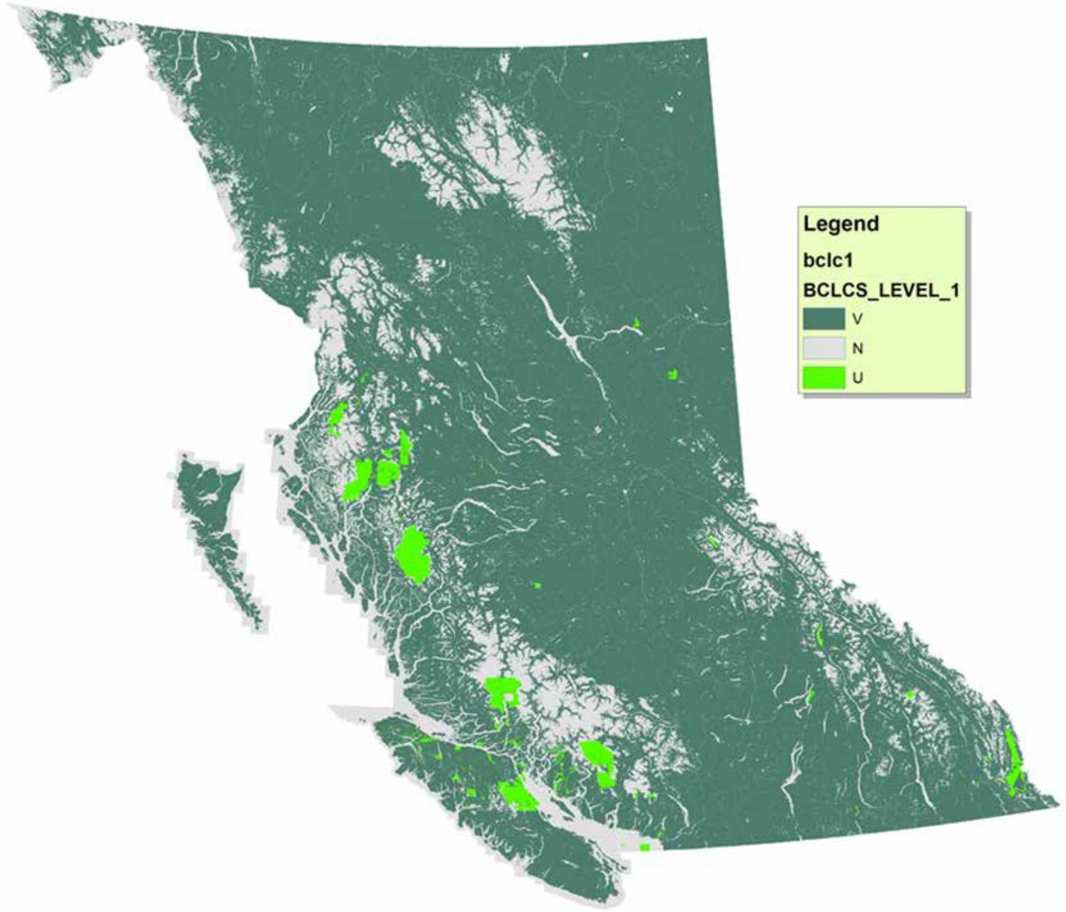
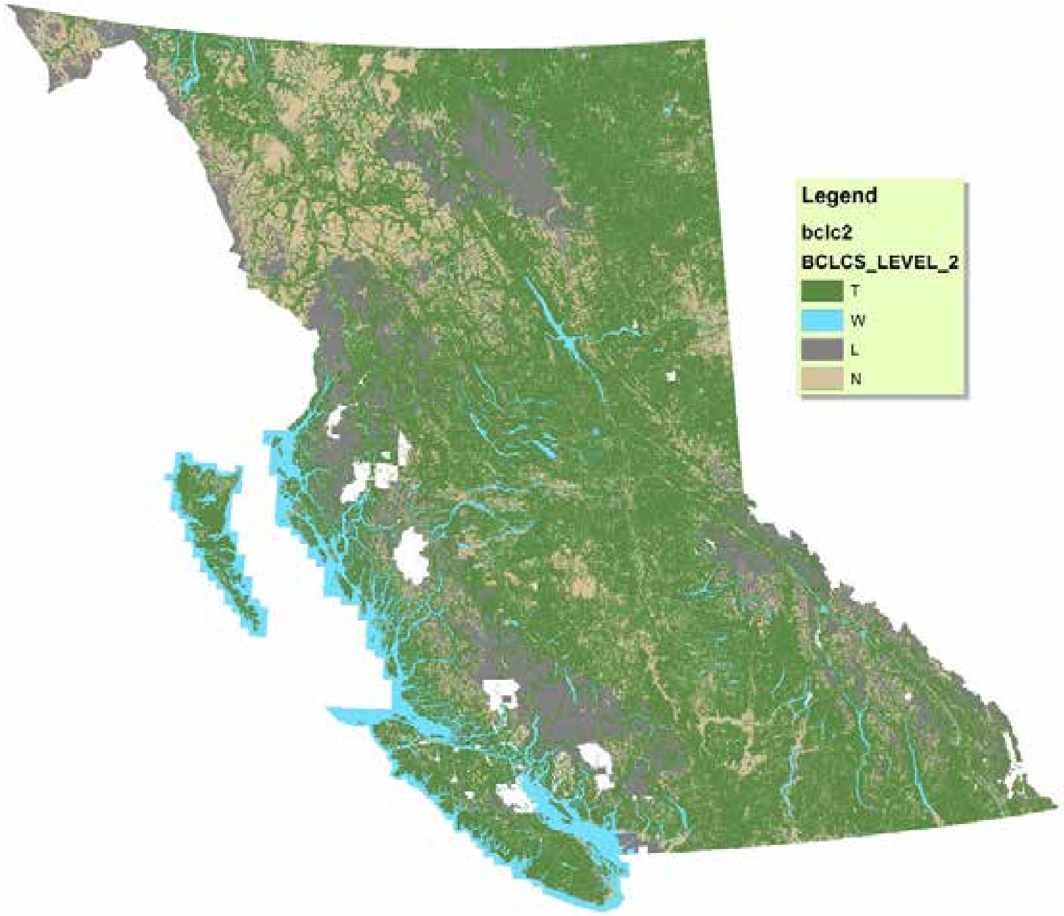


***Figure 2.*** *Map on the left showing an area west of Tweedsmuir provincial park classified as 'Unreported' under the BCLC classification in the VRI data. Under the initial HFLB classification the entire area would be assigned as "HFLB" despite significant non-forested areas as shown with satellite imagery (B). These polygons were identified and then manually classified using Baseline Thematic Mapping (BTM) to distinguish forest and non-forest areas (C).*

## Map 1. BC Land Cover Classification Level 1

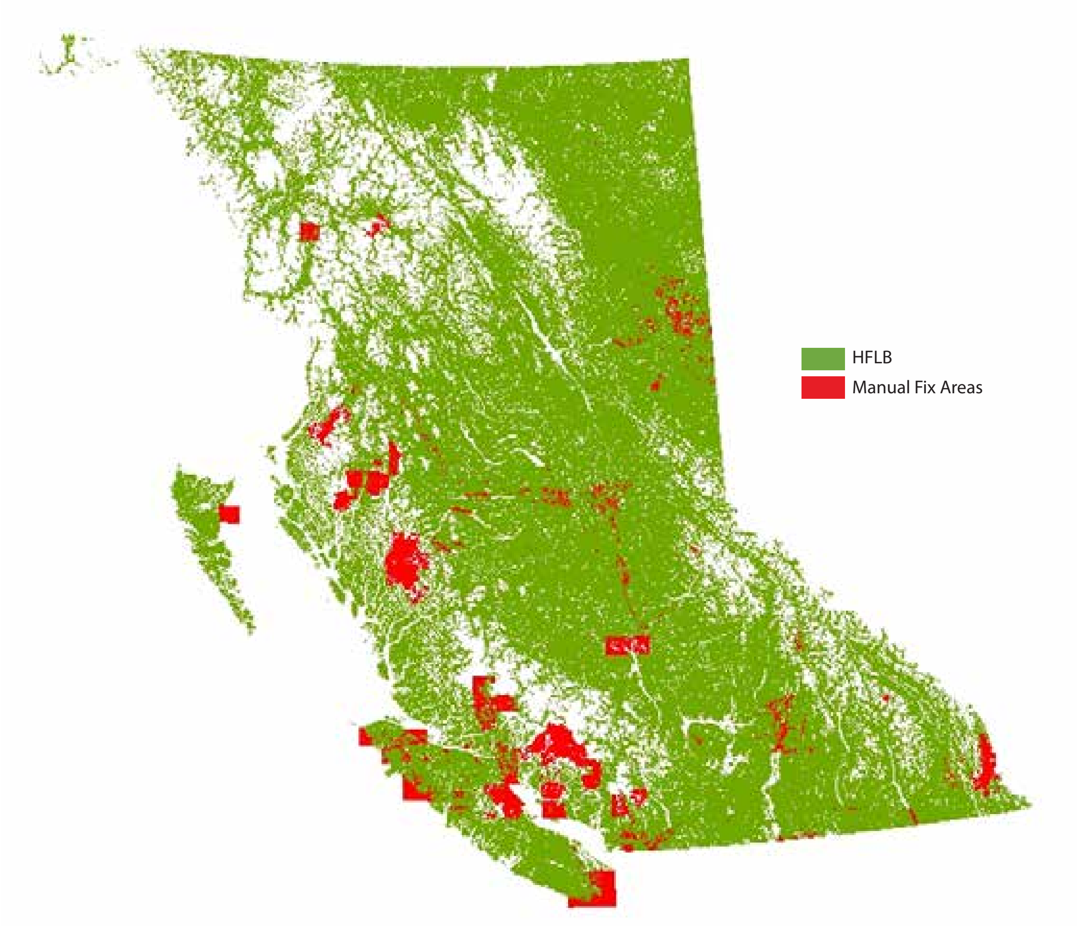


## Map 2: BC Land Cover Classification Level 2

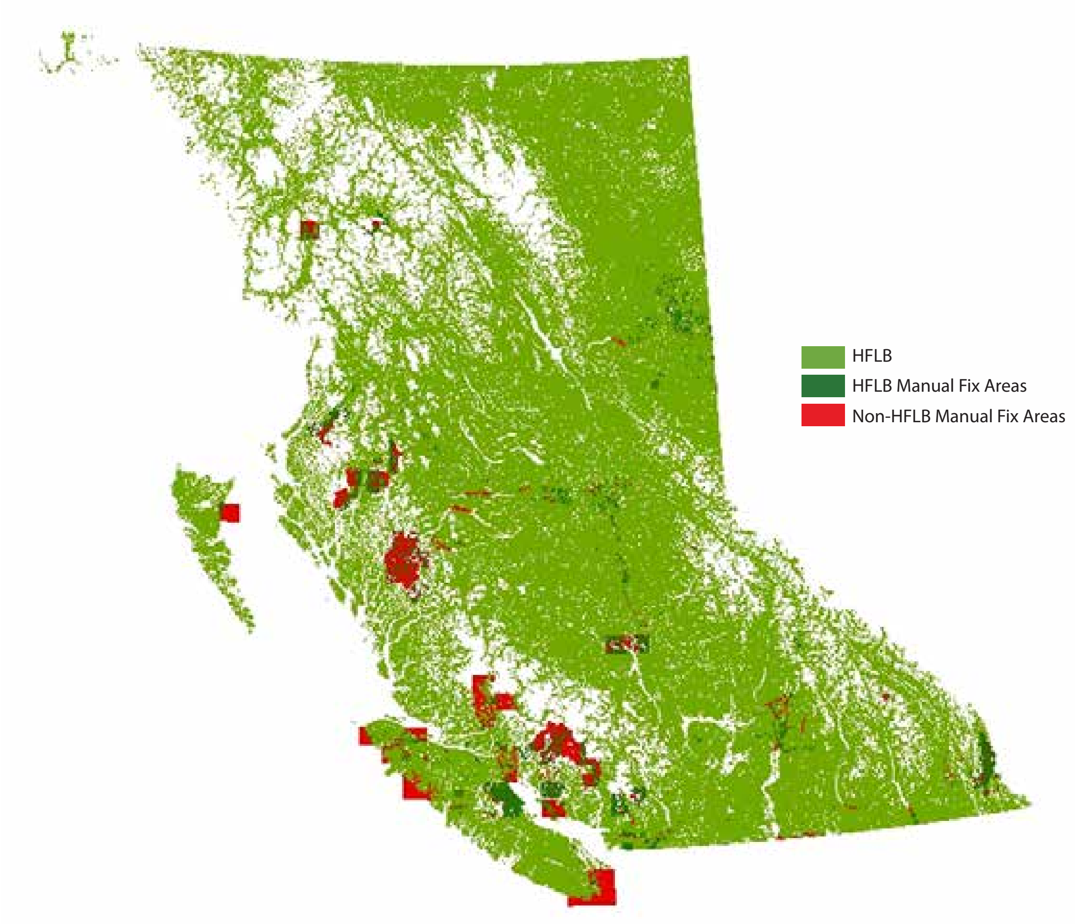


## Map 3: BC Land Cover Classification Level 3

## Map 4: Initial HFLB Classification



## Map 5: Manual HFLB Fix



# Appendix 2: Age-Based Definitions of Early, Mature and Old Seral Stage Forest from the Biodiversity Guidebook

| Biogeoclimatic Unit | Natural Disturbance Type | Mean event interval | Seral Stage | | |
|---|---|---|---|---|---|
| | | | Early | Mature | Old |
| BWBS* | NDT3 | 100yr | <20yr | >80yr | >100yr |
| BWBS** | NDT3 | 125yr | <40yr | >100yr | >140yr |
| CWH | NDT1 | 250yr | <40yr | >80yr | >250yr |
| CWH | NDT2 | 200Yr. | <40yr | >80yr | >250yr |
| CWH | NDT3 | 100yr | <40yr | >80yr | >140yr |
| CDF | NDT2 | 200Yr. | <40yr | >80yr | >250yr |
| ICH | NDT1 | 250yr | <40yr | >100yr | >250yr |
| ICH | NDT2 | 200Yr. | <40yr | >100yr | >250yr |
| ICH | NDT3 | 150yr | <40yr | >100yr | >140yr |
| ICH | NDT4 | 250yr | <40yr | >100yr | >250yr |
| IDF | NDT4 | 250yr | <40yr | >100yr | >250yr |
| ESSF | NDT1 | 350Yr. | <40yr | >120yr | >250yr |
| ESSF | NDT2 | 200Yr. | <40yr | >120yr | >250yr |
| ESSF | NDT3 | 150yr | <40yr | >120yr | >140yr |
| SBS | NDT2 | 200Yr. | <40yr | >100yr | >250yr |
| SBS | NDT3 | 125yr | <40yr | >100yr | >140yr |
| SBPS | NDT3 | 100yr | <40yr | >100yr | >140yr |
| SWB | NDT2 | 200Yr. | <40yr | >120yr | >250yr |
| MH | NDT1 | 350Yr. | <40yr | >120yr | >250yr |
| MS | NDT3 | 150yr | <40yr | >100yr | >140yr |
| PP | NDT4 | 250yr | <40yr | >100yr | >250yr |

* BWBS with deciduous prominent

** BWBS with coniferous prominent

Further breakdowns of specific Biogeoclimatic subzones in each natural disturbance type can be found in the Biodiversity Guidebook (1995).

# Appendix 3: Updated Stand Replacing Disturbance Return Intervals

## Background

The Interim Assessment Protocol for Forest Biodiversity measures the departure of observed forest age distribution (amounts of early, mature and old seral forests) relative to 'expected' estimates based on a natural or historic natural disturbance regime. The 1995 Biodiversity Guidebook provides the original estimates of the natural or historic expected forest age distribution using the disturbance return intervals assigned by Natural Disturbance Type (NDT) and Biogeoclimatic Zone or subzone variant (Table 1, Figure 1). However, since the Biodiversity Guidebook estimates were introduced, ongoing research on disturbance return intervals has been completed in some areas of the province (Eng 2019, Wong et al., 2003). The outcomes of this research have, in some cases, been used to inform or develop subsequent legal or policy targets for early, mature or old seral forest amounts in land use planning processes. The purpose of this document is to update stand-replacing disturbance return intervals in areas of the province where accepted information has replaced the original estimates in the 1995 Biodiversity Guidebook.

Two areas of the province have completed analysis of stand-replacing natural disturbance return intervals to support land use planning in those areas:

1) **Northeast** – Delong (2011) describes land units and benchmarks for natural disturbance-based forest management guidance in Northeastern British Columbia. This approach divided the land-base into Natural Disturbance Units (NDUs) and Sub-Units. Delong's work has subsequently been applied into several land use planning processes and Land Use Orders in the region.
2) **Coast** – An initial analysis by Price and Daust (2003), and subsequent analyses and interpretations by Price (2008, 2009c) were completed on the frequency of stand-replacing natural disturbances through a large portion of Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) Biogeoclimatic zones. This work was completed for the Coast Information Team to support Ecosystem-Based Management (EBM) for the Central and North Coast (CNC) and South-Central Coast (SCC) Land Use planning processes. The information supports old forest targets in the Great Bear Rainforest (GBR) Land Use Order Regulation.

## Approach

The following sections describe how information from these studies was collated for these areas, updated with recent BEC mapping (BEC Version 11) and consolidated with Biodiversity Guidebook estimates from other regions to create a seamless province-wide spatial dataset with updated natural disturbance return interval information. An important caveat is that estimates provided here are summarized for analysis purposes and may not align with land-based targets in legal orders that are often defined at smaller spatial scales.[1] As a result, this information does not supersede legal targets.

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[1] For example, legal targets for minimum old forest in the GBR Land Use Order are established at the Site Series Group (SSG) level.

***Table 1.*** *Return intervals for stand-replacing natural disturbances based on Biodiversity Guidebook estimates by NDT and BEC zone. "BEC Group" represent a more recent and preliminary categorization of the 210 provincial Biogeoclimatic subzone variants (BEC Version 11) by Regional Ecologists based on similar climate, topography and disturbance regime.*

| Stand-replacing Disturbance Return Interval | Natural Disturbance Type | BEC Group[1] | BEC Subzones and Subzone Variants |
|---|---|---|---|
| N/A | NDT5 | High Elevation | BAFA, CMA, IMA, ESSFdcp, ESSFdkp, ESSFdvp, ESSFmcp, ESSFmkp, ESSFmmp,ESSFmvp, ESSFunp, ESSFvcp, ESSFwcp, ESSFwmp, ESSFwvp, ESSFxcp, ESSFxvp, MH,mmp, MHunp, MHwhp |
| 100[a] | NDT3 | BWBS Dry | BWBS dk, BWBSmk, BWBSmw |
| | | BWBS Wet | BWBSvk, BWBSwk1, wk2, wk3 |
| | | SBPS/SBS-Dry | SBPS |
| 125 | NDT3 | SBPS/SBS-Dry | SBSdh1, dh2, SBSdk, SBSdw1, dw2, dw3 |
| | | SBS Moist | SBSmc1, mc2, mc3, SBSmh, SBSmk1, mk2, SBSmm, SBSun |
| | | SBS Wet | SBSwk3, wk3a |
| 150 | NDT3[b] | MS Dry | MSxk1, xk2, xk3, MSxv |
| | | MS Moist | MSdc1, dc2, dc3, MSdk, MSdm1, dm2, dm3, MSdv, MSdw, MSmw1, mw2 |
| | | ESSF Dry | ESSFdc2, dc3, ESSFdk1, dk2, ESSFdkw, ESSFdv1, dv2, dvw, ESSFxc1, xc2, xc3, xcw |
| | | ICH Dry | ICHdk, ICHdm, ICHdw1, dw3, dw4, ICHmk1, mk2, mk4, mk5, |
| 200 | NDT2 | ESSF Dry | ESSFdcw, ESSFxv1, xv2, xvw |
| | | ESSF Moist | ESSFdc1, ESSFmc, ESSFmh, ESSFmk, ESSFmm1, mm2, mm3, ESSFmmw, ESSFmv1, mv2, mv3, mv4, ESSFmw, mw1, mw2, ESSFmww, ESSFun, ESSFwh2, wh3, ESSFun, ESSFwh2, wh3, ESSFwm1, wm3, wm4 |
| | | ICH Moist | ICHmc1, mc1a, mc2, ICHmk3, ICHmm, ICHmw1, mw2, mw3, mw4, mw5 |
| | | ICH Wet | ICHwc, |
| | | SWB | SWB |
| | | SBS Wet | SBSvk, SBSwk1, wk2 |
| | | Coast Dry | CDFmm, CWHdm, CWHds1, ds2, CWHxm1, xm2 |
| | | Coast Moist | CWHws1 CWHmm1, mm2, CWHms1, ms2, |
| | | Coast Wet | CWHws2 |
| 250 | NDT4 | Open Forest/Grassland | BG, PP, IDFxx2 |
| | | IDF Very Dry | IDFxc, IDFxh1, xh2, IDFxk, IDFxm, IDFxw |
| | | IDF Dry | IDFdc, IDFdk1, dk2, dk3, dk4, dk5, IDFdm1, dm2, IDFdw, IDFxh4 |
| | | ICH/IDF | ICHxw, xwa, IDFmw1, mw2, IDFww,ww1 |
| 250 | NDT1 | Coast Moist | CWHwh1 |
| | | Coast Wet | CWHvh1,vh2, vh3,CWHvm1,vm2,wh2,CWHwm, |
| | | ICH Wet | ICHvc, ICHvk1,vk2, ICHwk1,wk2,wk3,wk4 |
| 350 | | ESSF Moist | ESSFwmw |
| | | ESSF Wet | ESSFvc, ESSFvcw, ESSFwc2,wc3,wc4,wcw, ESSFwh1, ESSFwk1,wk2, ESSFwm2,ESSFwv |
| | | MH | MHmm1,mm2, MHun, MHwh,wh1 |

[1] BEC Groups are a more recent categorization of Biogeoclimatic subzone variants since the Biodiversity Guidebook.

[a] This includes both the 100yr and 125yr return intervals for the BWBS where deciduous and coniferous are prominent.

[b] The Biodiversity Guidebook indicates some of CWH may be in the NDT3 considering the potential for some more frequent stand-replacing disturbance events. The larger disturbance events that led to this discussion (wind on north Vancouver Island and fire events in the southeast) and subsequent possible more frequent, larger-extent wind events were not documented for effective incorporation into these characterizations and information was primarily anecdotal or on the fringe of the units.

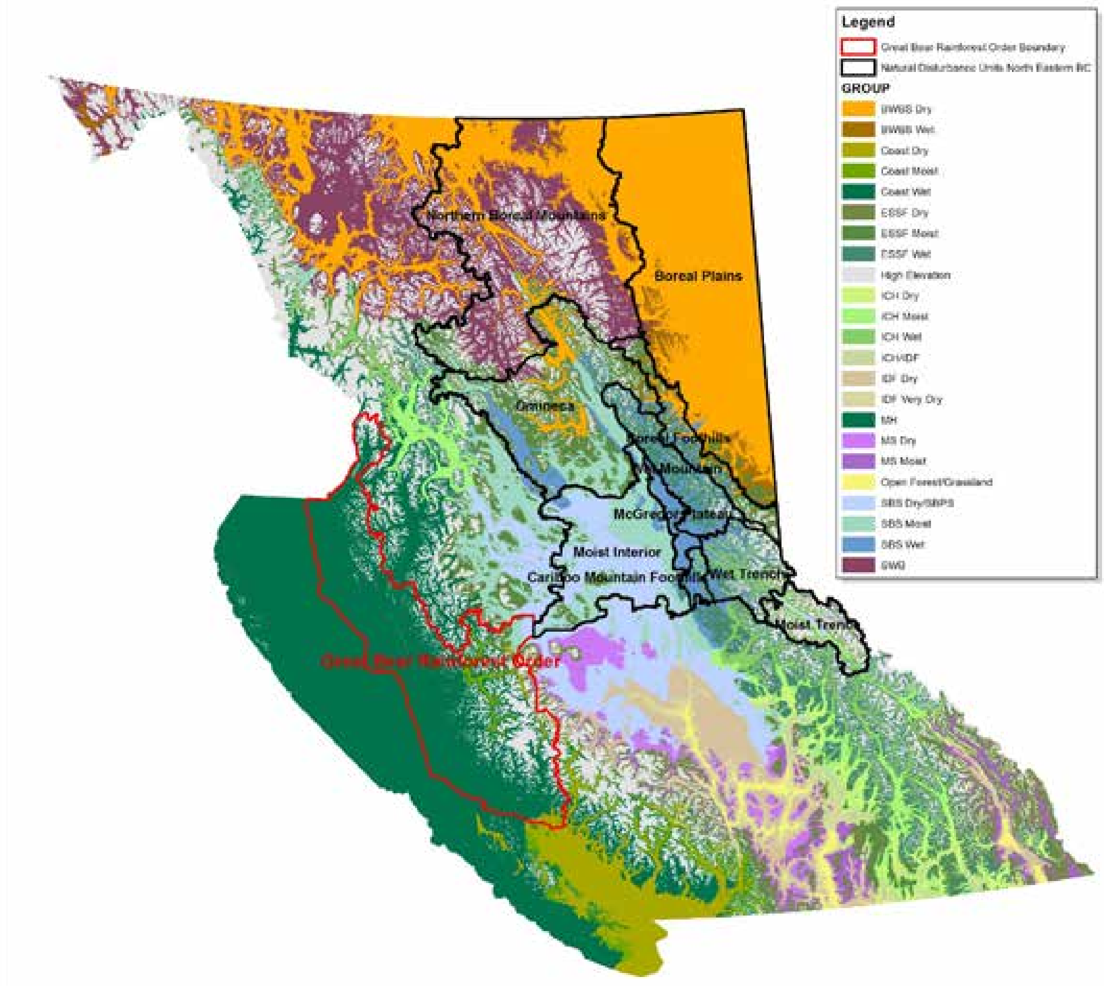

***Figure 1.*** *Biogeoclimatic subzone groups in British Columbia and the location of the coastal Great Bear Rain Forest Land Use Order and Natural Disturbance Units (NDUs) in the Northeast.*

## Northeast Biogeoclimatic Zones

Delong (2011) grouped Biogeoclimatic subzones and subzone variants into Natural Disturbance Units (NDUs) and sub-units (NDS) for most of northeastern BC based on differences in disturbance processes, stand development and temporal and spatial pattern (Table 2, Figure 1). These units are intended to better reflect these important elements that were not sufficiently dealt with in NDT mapping in the 1995 Biodiversity Guidebook. Further description of NDU delineation can be found in Delong (2007) Estimated stand replacing natural disturbance return intervals illustrated in Table 2 below are directly from Delong (2011) with only minor modifications to update changes in Biogeoclimatic subzone variant mapping.

***Table 2.*** *Disturbance return intervals by Biogeoclimatic, Natural Disturbance Units and sub-units in Northeastern British Columbia.*

| Natural Disturbance Unit | Natural Disturbance (Sub)Unit | Biogeoclimatic units[1] | Return interval |
|---|---|---|---|
| Boreal Foothills | Boreal Foothills-Mountain | ESSFmv2, (ESSFwk2, ESSFwc3) | 150 |
| | Boreal Foothills- Valley | BWBSwk1 (BWBSmw[a]) | 120 |
| Boreal Plains | Boreal Plains - Alluvial | BWBSmk[b] | 200 |
| | Boreal Plains - Upland | BWBSmw, BWBSmk[b] (BWBSwk1, BWBSwk2, SWBmk) | 100 |
| Cariboo Mountain Foothills | | SBSwk1 (ESSFwk1) | 400 |
| MacGregor Plateau | | SBSwk1 (ESSFwk2, SBSwk2) | 220 |
| Moist Interior | Moist Interior-Mountain | ESSFmv1, ESSFmv3, (ESSFwk1) | 200 |
| | Moist Interior - Plateau | SBSdk, SBSdw2, SBSdw3, SBSmc2, SBSmc3, SBSmk1, SBSmw, SBSwk3a, (SBPSdc, SBPSmc, SBSdw1, SBSmh, SBSwk1) | 100 |
| Moist Trench | Moist Trench- Mountain | ESSFmm (ESSFwc2) | 300 |
| | Moist Trench - Valley | ICHmm, SBSdh, (ICHwk1, SBSvk) | 150 |
| Northern Boreal Mountains | | BWBSdk1, BWBSwk2, SBSmk1, (ESSFmc, ESSFmv4, BWBSmk, BWBSwk2, BWBSwk3) | 180 |
| Omineca | Omenica- Mountain | ESSFmc2, ESSFmv3, ESSFmv4, (ESSFww, SWBmk) | 300 |
| | Omenica-Valley | BWBSdk1, BWBSwk2, SBSmk1, SBSmk2, SBSwk2, SBSwk3, (ICHmc1, SBSdk, SBSmc2, SWBmk) | 120 |
| Wet Mountain | Wet Mountain | SBSvk, ESSFwk2, ESSFwc3, (SBSwk1, SBSwk2, ESSFmv2) | 900 |
| Wet Trench | Wet Trench- Mountain | ESSFwk1, ESSFwk2, ESSFwc3, (ESSFmm) | 800 |
| | Wet Trench - Valley | ICHwk3, ICHvk2, SBSvk, (ICHwk2, SBSwk1) | 600 |

[1] Units in brackets cover a minor (i.e. <5%) portion of the Natural Disturbance Unit.

[a] BWBSmw is the new BEC version, replaces BWBSmw1 (B. Rogers pers comm, Sept. 2019).

[b] BWBSmk is the new BEC version, replaces BWBSmw2 (B. Rogers pers comm, Sept. 2019).

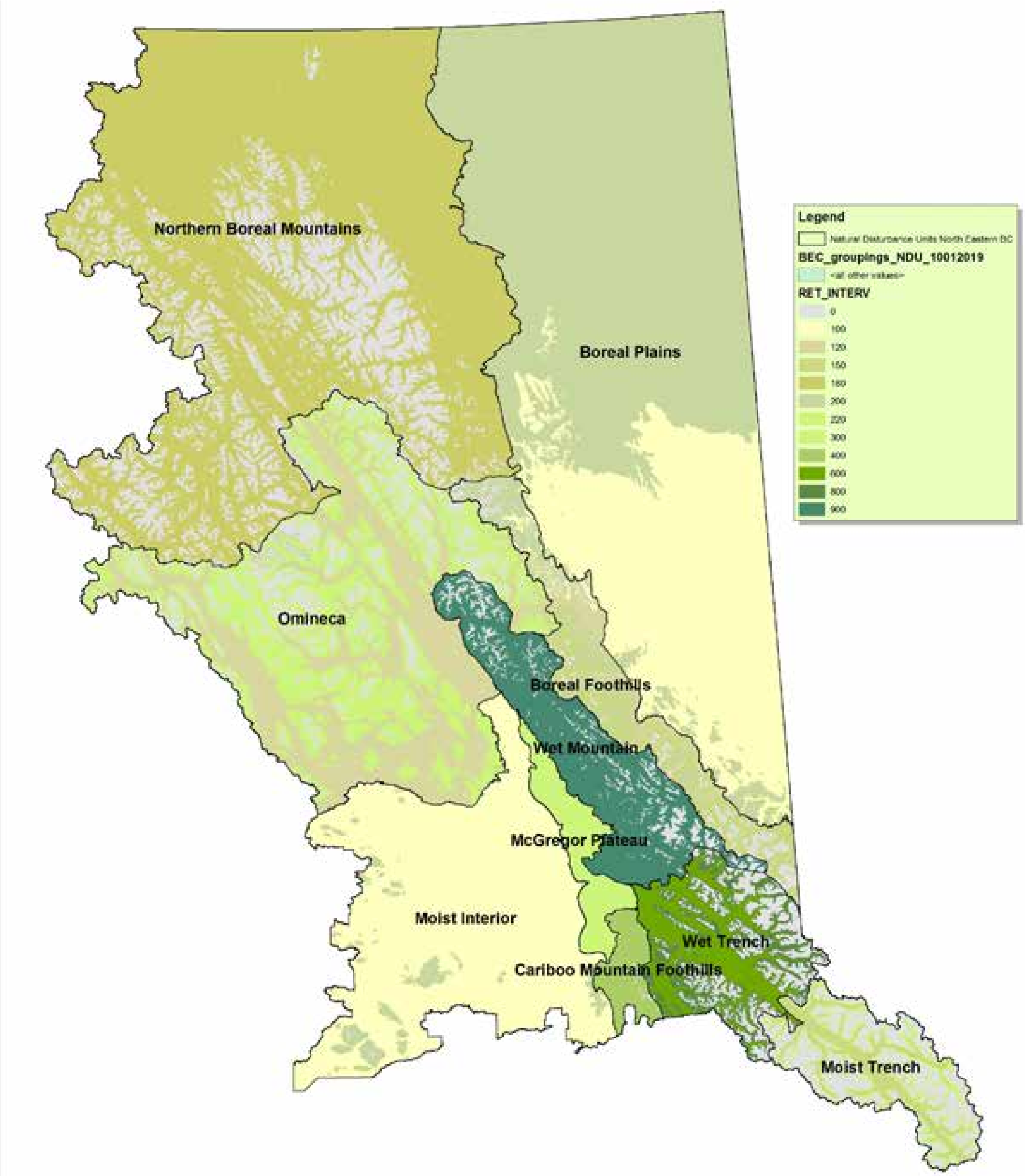

***Figure 2.*** *Natural Disturbance Units (NDUs) and associated stand-replacing disturbance return intervals for northeastern British Columbia from Delong (2011).*

## Coastal Biogeoclimatic Zones

Stand replacing disturbance return intervals provided in the Biodiversity Guidebook have been shown to largely overestimate the frequency of stand-replacing disturbances in Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) Biogeoclimatic zones, particularly in the very wet hypermaritime (vh) and very wet maritime (vm) subzones (Eng 2019, Daniels and Gray 2006, Price and Daust 2003, Wong et al. 2003); these being dominated by smaller-scale, gap-phase dynamics. The most extensive work on disturbance return intervals for coastal ecosystems was completed by Price and Daust (2003) for the Coast Information Team (CIT) analysis area and in subsequent analyses and interpretations including Price (2008, 2009a, 2009b, 2009c). The work was incorporated into the Central and North Coast (CNC) and South Central Coast (SCC) Land Use Planning Areas and subsequently informed legal targets for ecosystem representation planning in the Great Bear Rainforest (GBR) Land Use Order. However, legal targets for old forest (>250 years) in the GBR Land Use Order are applied at the Site Series Group (SSG) level.

The estimates of stand replacing natural disturbance return intervals and expected forest >250 years used in the Forest Biodiversity Protocol use this accepted information to update the return intervals for CWH and MH ecosystems from those originally published in the Biodiversity Guidebook (Table 3, Figures 2 and 3 ). The estimates are primarily derived from the results of Price and Daust's (2003) original analysis. However, more recent information and knowledge of relationships between climate and disturbance frequency were also considered. Thus, additional modifications and revisions to the original Price and Daust (2003) estimates and estimates for subzone variants not included in the original Price and Daust (2003) analysis are based on documentation from Price (2008), Price (2009a, b, and c), Banner et al (2009b), and subsequent input from regional ecologists.[2] The primary changes from Price and Daust (2003) outlined in Table 3, are summarized below and include:

- The CWHmm1 was grouped with the CWHmm2 variant and moved from the Hypermaritime Biogeoclimatic Unit cluster to the Dry Maritime and Wet Sub Maritime cluster. Both CWHmm variants are assigned a return interval of approximately 1,100 years (80% forest >250 yrs old). The change was recommended by regional ecologists to better reflect climatic factors that influence disturbance frequency.
- The MHmm1 was grouped with the MHmm2 and moved to the Hypermaritime cluster with the MHmm2. Both MHmm variants are assigned a return interval of 3,000 years (92% forest >250 years). This change recognizes that, although the MHmm is not a hypermaritime ecosystem, grouping in this cluster better reflects climatic factors (cold temperatures and high snowfall) that influence disturbance frequency.
- The CWHwm was added to the Very Wet Maritime cluster with a return interval of 2,000 years (89% forest >250years). This area was excluded from the original Price and Daust (2003) analysis due to issues in distinguishing between natural disturbance and older harvest. The estimated return interval and percent of forest >250 years is provided in Banner et al. (2009b) based on grouping the CWHwm with subzones with similar climatic conditions.
- The CWHws1 was grouped with the CWHws2 and added to the Dry Maritime and Wet Sub Maritime Cluster with the CWHws2 with a return interval of 1,100 years (80% forest >250 yrs old). This area was excluded from the original Price and Daust (2003) analysis due to issues in distinguishing between natural disturbance and older harvest. The estimated return intervals and percent of forest >250 years is provided in Banner et al. (2009) based on grouping with subzones with similar climatic conditions. Important to note that the CWHws1 is in the 'Coast Moist Bec

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[2] Input was provided through additional correspondence with Sari Saunders, Andy MacKinnon, Allen Banner, Heather Klassen, and Will MacKenzie in 2020.

Group and the CWH ws2 in the "Coast Wet" BEC Group in table 1 above. However, there is not enough evidence to assign different return intervals currently.

- Return intervals in the CWHdm2 and xm2 subzone variants were reduced to 700 years from 1,100 and 2,000 years respectively (a reduction to 70% of the forest expected >250 years compared to 80% and 89% >250 years). This change was recommended by ecologists to better reflect climatic factors that influence disturbance frequency.
- The Montane Spruce dry cold (MSdc2) variant was originally include in the Hypermaritime cluster in Price and Daust (2003) but was later recommended to be excluded in Price (2009).
- Stand replacing disturbance return intervals for several CWH subzone variants including the CWHxm1, ms1, ds1, and mm2 that occur on the south coast mainland and Vancouver Island, mainly outside of the original CIT analysis area, were estimated by grouping within the same subzone given similar climatic conditions, and assigned the same return interval and expected amounts of old forest as the other variants in that subzone.

***Table 3.*** *Stand-Replacing natural disturbance return intervals for Biogeoclimatic units in coastal British Columbia. Table adapted from Price and Daust (2003) with modifications based on summary of reviews applied here.* [a] *The Blue hi-lighted columns illustrate the mean return interval and mean expected % of old forest >250 years used as historic estimates in the Cumulative Effects Framework Forest Biodiversity Protocol. Yellow hi-light indicates BEC units for which current recommendations from ecologists regarding return intervals/percent old forest vary from those same parameters provided within earlier documentation (provided here in columns 2009, CNC, and SCC). CEF = Cumulative Effects Framework; CNC = Central and North Coast; SCC = South Central Coast.*

| Biogeoclimatic Unit Cluster[1] | Est. Return Interval (Yrs) & % Forest >250 Yrs (2003)[2] | Biogeoclimatic Unit[1] | Est. Return Interval (CEF)[3] | Est. % Forest >250 Yrs | | | |
|---|---|---|---|---|---|---|---|
| | | | | CEF | 2009[4] | CNC[5] | SCC[5] |
| **Hypermaritime** | 4,000-20,000<br>(94-99) | CWHvh1, vh2, vh3 | 10,000 | 95-99 | 97 | 84-97 | 41-97 |
| | | CWHwh1[7], wh2[8] | 3,000 | 90-95 | | | |
| | | MHwh, MHwh1[6] | 3,000 | 90-95 | 92 | 84-97 | 97 |
| | | MHmm (1 and 2) | 3,000 | 90-95 | 92 (80) | 70-93 | 41-93 |
| **Very Wet Maritime** | 1,400-3,000<br>(84-93) | CWHvm1, vm2 | 2,000 | 85-90 | 89 | 70-93 | 41-93 |
| | | CWHwm | 2,000 | 85-90 | 89 | 84-97 | |
| **Dry maritime and wet sub-maritime** | 700-5,000<br>(70-95) | CWHdm | 700 | 70 | 80 | | 41-87 |
| | | CWHxm (1 and 2) | 700 | 70 | 89 | | 41-87 |
| | | CWHws (17 and 2) | 1,100 | 80 | 80 | 60-97 | 41-86 |
| | | CWHmm (1 and 2) | 1,100 | 80 | 92 | | 41-87 |
| | | ESSFmw | 1,500 | 85 | 89 | | 41-86 |
| **Dry sub-maritime** | 400-1,500<br>(53-85) | CWHms (1 and 2) | 700 | 70 | 66 | 58-87 | 41-87 |
| | | CWHds (1 and 2) | 500 | 60 | 60 | 60-97 | 41-86 |
| | | IDFww | 500 | 60 | 60 | | 41-86 |

[a] Biogeoclimatic units on Haida Gwaii (CWHvh3, wh1, wh2) were included in the original Price and Daust (2003) analysis (with the exception of Gwaii Haanas Park) but were not dealt within subsequent analysis (i.e. Price 2008, 2009a,b,c, Banner et al 2009a,b) as these focussed on the North and Central Coast planning areas.

[1] Biogeoclimatic clusters and Biogeoclimatic units from Table 9 (Price and Daust, 2003).

[2] Return intervals by Biogeoclimatic unit cluster from Table 13 (Price and Daust, 2003).

[3] Return intervals by Biogeoclimatic unit (BGC subzone variant) are estimated to the nearest 100 years from a back-calculation using the negative exponential model based on percent of area >250 years (100% RONV).

[4] 2009 inputs are from Banner et al. (2009b).

[5] % forest > 250 years for CNC and SCC are from Banner et al. (2009a) and reflect the range of expected forest in Schedule 4a and 4b of the Land Use Plans.

[6] Under current classification the MHwh is the Haida Gwaii subzone (not differentiated to variant) while the MHwh1 refers to the mainland variant.

[7] Both the CWH wh1 and CWH ws1 subzone variants have slightly warmer and drier climates than the wh2 and ws2 subzone variants respectively. For example, the CWHws2 is in the Coast Wet BEC Group while the CWH ws1 is in the Coast Moist BEC Group (Table 1). However, there is not enough data to differentiate return intervals between these subzone variants.

[8] The CWHwh1 and wh2 on Haida Gwaii were originally analysed in Price and Daust (2003) and included in the Hypermaritime cluster. These subzone variants were not reviewed in subsequent analyses for the GBR Order.

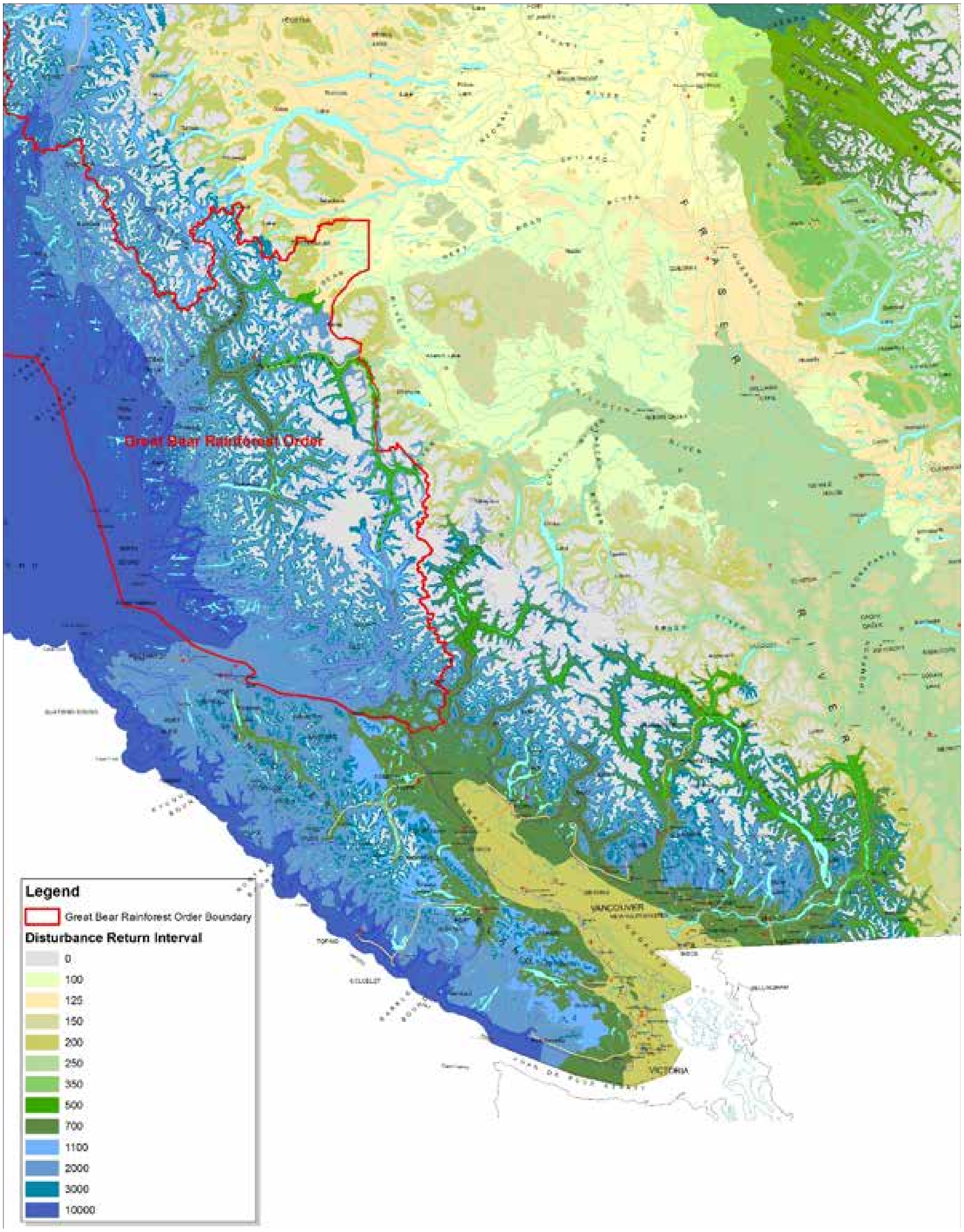

***Figure 3.*** *Estimated natural disturbance return intervals at the Biogeoclimatic subzone variant level for the southern portion of the Great Bear Rainforest Land Use Order area and adjacent areas of the south coast of BC and Vancouver Island.*

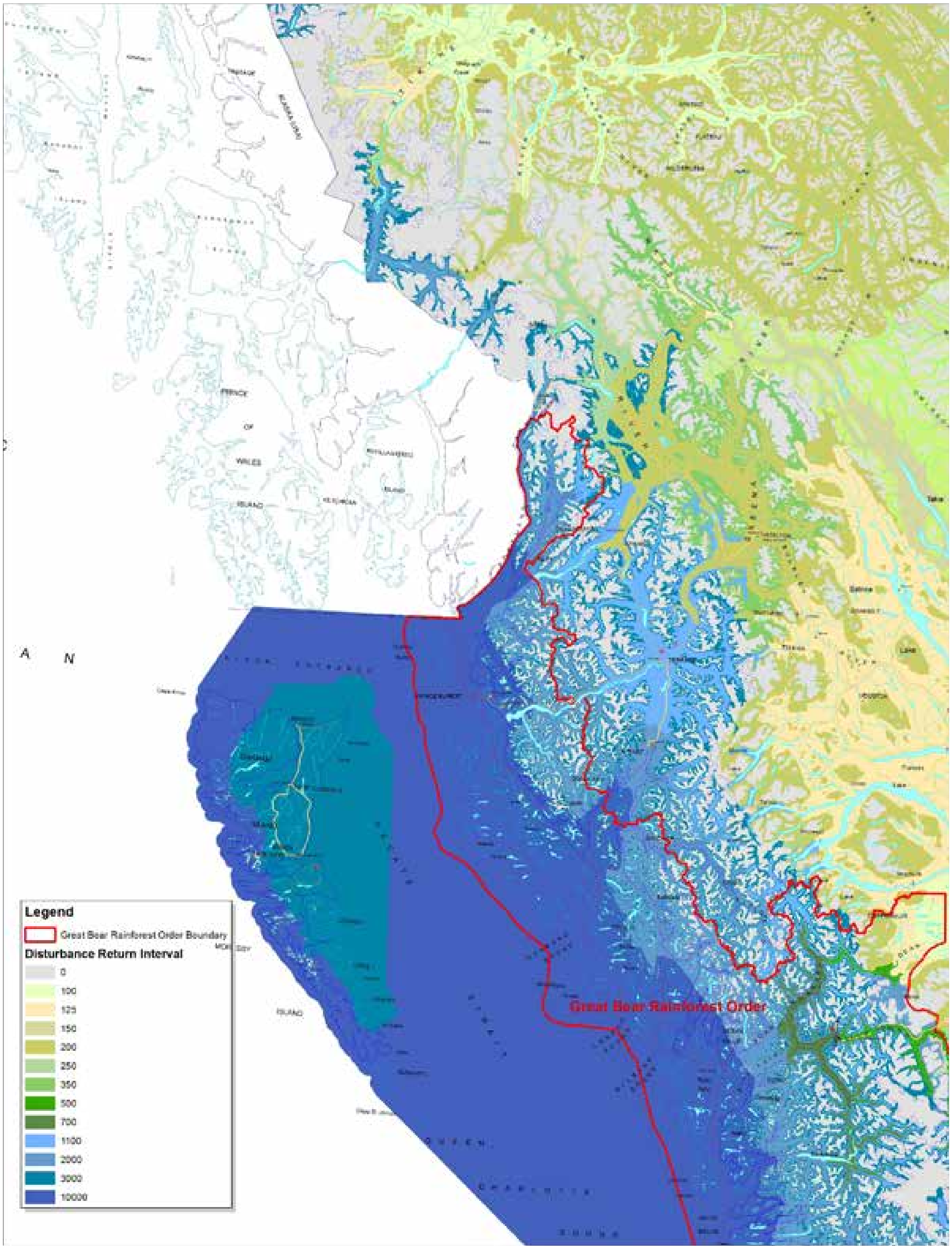

***Figure 4.*** *Estimated natural disturbance return intervals at the Biogeoclimatic subzone variant level for the northern portion of the Great Bear Rainforest Land Use Order area and adjacent areas of the north coast and Haida Gwaii.*

# Appendix 4: Historic Estimates of Variability in Expected Forest Age

A synthesis of existing studies was completed to provide an estimate of the historic variability around the expected amount of forest in different forest age/seral stages (Figure A4-1). The synthesis includes results from modelled studies that simulate disturbance dynamics, studies that estimate return intervals and forest age class distributions from forest inventory maps to estimate fire frequency.

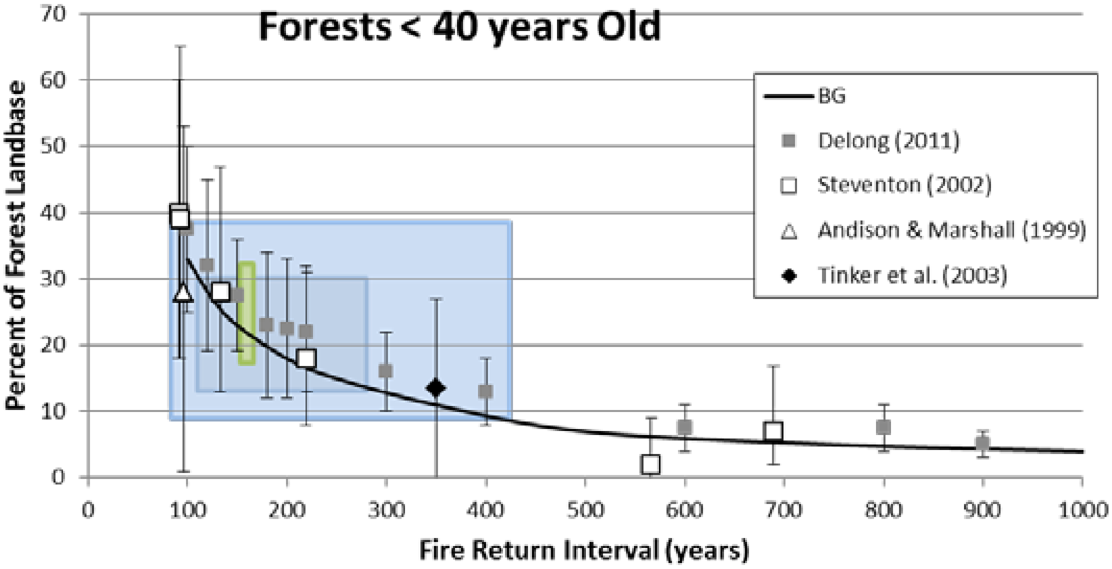

***Figure A4-1.*** *Estimated variability for expected amounts of early seral forest (<40 years old) from different published studies in B.C., the Pacific Northwest and eastern boreal forests of Canada. Dark line illustrates the average expected amount of forest <40 years by applying the negative exponential equation. Points illustrate the median value (Steventon, 2002) and implied mean (Delong, Tinker et al., 2003). Whiskers show reported 90% (Steventon, 2002), or 95% (Delong, Andison and Marshall) confidence intervals at specific return intervals. Shaded boxes show 95% CI of expected forest <40 yrs old where the FRI is expressed as a range (e.g. 150-160 years) from Didion et al 2007 (green box), and from Cyr et al. 2008 the conservative range of 111- (inset blue box) and expanded 82-(larger blue box) 95% CI.*

In general, the variability around expected amounts of forests increases as fire return interval decreases (Figure A4-1). The review suggests that where the FRI >250 years, the 95% Confidence Interval (CI) around the amount of forest <40 years is approximately 10-20% of the forested land-base. As the Stand-replacing FRI drops below 250 years, the 95% CI can range from 30-40% of the forested land-base. The two studies (Andison and Marshall, 1997 and Steventon, 2002), that incorporate a FRI<100 years show the 95% CI around the expected amount of forest <40 years old could be as high as 40-60% of the forested land-base. The variability around the amount of old and late-successional forests showed a similar pattern with greater variability in expected amounts of mature and old forest where stand-replacing FRI was lower.

<table>
<tr><th>Study</th><th>Approach</th><th colspan="4">Historic Range Estimates</th></tr>
<tr><td rowspan="5">**Delong, 2010**<br>**Northeastern British Columbia, Canada**</td><td rowspan="5">Used estimated stand-replacing disturbance return cycle for each Natural Disturbance Unit(NDU)<br>Used stochastic landscape model in SELES, run 1000 years to reach equilibrium, then another 1000 years.<br>Highest and lowest value in each class used as range.</td><td rowspan="2">Stand Replacement Disturbance</td><td colspan="3">Time Since Disturbance (% of Forested Area)*</td></tr>
<tr><td>**>250yr**</td><td>**>100yr**</td><td>**<40yr**</td></tr>
<tr><td>150</td><td>15-25%</td><td>43-62%</td><td>19-36%</td></tr>
<tr><td>300</td><td>39-50%</td><td>66-77%</td><td>10-22%</td></tr>
<tr><td>900</td><td>74-80%</td><td>88-93%</td><td>3-7%</td></tr>
<tr><td rowspan="6">**Cyr et al. 2009**<br>**Boreal Forest, Quebec, Canada**</td><td rowspan="6">Calculated expected ages using negative exponential model, but varied estimates using MFI based on lake sediment data<br>Conservative range 111-267 years.<br>95% CI of MFI Interval = 82-419 years.</td><td rowspan="2">Forest Age</td><td colspan="3">Range (% of Landscape)**</td></tr>
<tr><td colspan="2">**Conservative**</td><td>**Extended (5-95% C.I.)**</td></tr>
<tr><td>0-40yr</td><td colspan="2">14-30%</td><td>9-38%</td></tr>
<tr><td>41-80yr</td><td colspan="2">13-22%</td><td>9-24%</td></tr>
<tr><td>81-100yr</td><td colspan="2">6-8%</td><td>4-8%</td></tr>
<tr><td>101+yr</td><td colspan="2">41-68%</td><td>30-80%</td></tr>
<tr><td rowspan="5">**Didion et al. (2007)**<br>**Fall et al. (2004)**<br>**Boreal Forest, Mauricie Region, south central Quebec, Canada**</td><td rowspan="5">Used landscape simulator SELES to model HRV.<br>Pre-development estimates of Mean Fire Return Interval (MFI) = 150-160 years.<br>Historic Range defined by minimum and maximum modelled age classes.</td><td colspan="2">Forest Age</td><td colspan="2">Range*** (% of Forest Area)</td></tr>
<tr><td colspan="2">Early seral ( 0-40yr)</td><td colspan="2">18-26%</td></tr>
<tr><td colspan="2">Immature ( 41-100yr)</td><td colspan="2">22-64%</td></tr>
<tr><td colspan="2">Mature (101-200yr)</td><td colspan="2">8-47%</td></tr>
<tr><td colspan="2">Old (>200yr)</td><td colspan="2">7-30%</td></tr>
<tr><td rowspan="4">**Wimberley et al. (2000)**<br>**Oregon Coast Range Oregon, USA**</td><td rowspan="4">Modelled stand age using landscape age-class dynamics simulator.<br>100 model runs simulating 3000 years.<br>Varied fire frequency size, spread and severity.<br>Natural Fire Rotation (NFR) estimated at 152-294years (base)based on charcoal analysis of lake sediments from past 3000 years.</td><td rowspan="2">Forest Age</td><td colspan="3">% of Landscape****</td></tr>
<tr><td colspan="2">**Mean**</td><td>**Range**</td></tr>
<tr><td>Old-growth</td><td colspan="2">45.5%</td><td>30.6-61.3%</td></tr>
<tr><td>Late successional</td><td colspan="2">69.8 %</td><td>48.8-82.5%</td></tr>
</table>

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* From Table 2. (Delong, 2011).

** Estimated from Figure 4 (Cyr et al., 2009).

*** Estimated from grey shaded areas Figure 7 (Didion et al., 2007).

****Used numbers provided in Table 2 for 0-500 years before present, provincial-scale (>2 million ha) (Wimberley et al., 2000).

# Appendix 5: Historic Estimates for Forest Patch Sizes

Historic estimates of patch sizes that occurred following natural disturbance processes were provided from a review of recent literature. Two studies from northern British Columbia (Delong, 1998; Steventon, 2002), that reconstructed patch size distribution from forest inventory maps, provide some evidence of differences in patch size distribution associated with climatic and topographic variability. In general, both studies found the size of early seral patches created by wildfires increased in forest ecosystems with shorter fire return intervals. Delong (1998) found that forest ecosystems with moderate levels of precipitation (Moist compared to Dry and Wet units) had the greatest mean, maximum and standard deviation (SD) of patch sizes. (Delong, 1998) also found topographic differences within similar climatic regimes played a role in early seral patch size. Plateau sub-boreal topoclimatic units had larger mean, maximum and SD of patch sizes compared to montane units (Table A5-1). Delong (1998) suggested larger patch sizes on plateau units was likely due to proximity to structurally and climatically similar forests in adjacent units, such that wildfires would carry across units, whereas in montane units wildfires burn upwards into higher elevation units. Delong (1998) reported his findings were consistent with results from White (1985) for subalpine forest in Banff National park for the period for the period of 1910-1930 with 2.3, 14.8 and 82.4% of area in patches of 40-100, 101-1000 and 1001-10,000 ha in size. Steventon (2002) also found similar effects of climate on patch size distribution across a range of forest ecosystems in the Morice and Lakes TSA area (Table A5-1 and A5-2).

***Table A5-1.*** *Estimated percentage of total disturbed area by patch size compared to recommended range in the Biodiversity Guidebook for NDT3 ecosystems. Table format adapted from Delong (1998).*

| Study | Assessment Unit | Patch Size (ha) | | | | |
|---|---|---|---|---|---|---|
| | | <40 | 40-250 | 251-1000 | >1000 | >250 (max ha)*** |
| | | Percentage of total disturbed area | | | | |
| | *Recommended for NDT3* | *10-20* | *10-20* | *60-80* | | |
| **Delong (1998)*** | Dry Warm Plateau (SBSdw3) | 9 | 13.4 | 20.9 | 56.7 | 77.6 (7693) |
| | Moist Cold Plateau (SBSmc3) | 4.5 | 7.4 | 15.9 | 72.2 | 88.1 (19,030) |
| | Moist Cool Plateau (SBSmk1) | 5.5 | 7 | 9.4 | 78.0 | 87.4 (41,787) |
| | Moist Cool Montane (SBSmk1) | 4.7 | 9.3 | 12.6 | 73.4 | 86.0 (10,458) |
| | Wet Cool Plateau (SBSwk1) | 10.4 | 18.3 | 33.8 | 37.5 | 71.3 (2515) |
| | Dry Cool Boreal (BWBSdk1) | 9.3 | 27.5 | 22.4 | 40.8 | 63.2 (2691) |
| **Steventon (2002)**** | SBPSmc | 13.8 | 21 | 30.5 | 34.7 | 65.2 |
| | SBSdk | 30 | 20.5 | 22.5 | 27 | 49.5 |
| | SBSmc | 22.8 | 20.1 | 24.2 | 22.9 | 47.1 |

* Patch size distributions for NDT3 are from reported from Table 8 in Delong (1998).

** Patch size distribution estimates for each BGC subzone from Steventon (2002) were derived by applying the parameters for each BGC subzone using the formula for the Beta distributions provided in Table 4. This approach was used to make direct comparisons with Biodiversity Guidebook recommendations and estimates from Delong (1998).

*** (max ha) shows the maximum patch size reported for each topoclimatic unit from Delong (199) only.

For NDT2 and NDT1 ecosystems, results from both Delong (1998) and Steventon (2002) suggest that the mean and maximum size of disturbed patches is smaller in forested ecosystems with greater precipitation. Delong (1998) noted the proportion of area in patches <1,000 ha generally increases in these wetter ecosystems, however a large portion of total disturbed area still occurs in patches >250ha in size (Table A5-2).

***Table A5-2.*** *Estimated percentage of total disturbed area by patch size compared to recommended range in the Biodiversity Guidebook for NDT1 and NDT2 ecosystems. Adapted from Delong (1998)*

| Study | Assessment Unit | Patch Size (ha) | | | | |
|---|---|---|---|---|---|---|
| | | <40 | 40-80 | 80-250 | >250 | >80 |
| | | Percentage of total disturbed area | | | | |
| | *Recommended for NDT1 and 2* | *30-40* | *30-40* | *20-40* | | |
| **Delong (1998)*** | Wet Cool Montane (SBSwk1) | 12.6 | 8.5 | 16.8 | 62.1 | 78.9 |
| | Very Wet Cool Montane (SBSvk) | 14.4 | 10.1 | 13.4 | 62.1 | 75.5 |
| | Moist Very Cold Sub-alpine (ESSFmv1) | 4.1 | 2.5 | 7.8 | 85.6 | 93.4 |
| **Steventon (2002)**** | ESSFmc | 18.3 | 7.9 | 20 | 53.8 | 73.8 |
| | ESSFmk | 14.5 | 7.6 | 20.9 | 57 | 77.9 |
| | ESSFwv | 14.5 | 8.7 | 26.1 | 49.5 | 76.3 |

* Patch size distributions for NDT3 are from reported from Table 8 in Delong (1998).

** Patch size distribution estimates for each BGC subzone from Steventon (2002) were derived by applying the parameters for each BGC subzone using the formula for the Beta distributions provided in Table 4. This approach was used to make direct comparisons with Biodiversity Guidebook recommendations and estimates from Delong (1998).

Results from these studies suggest that the Biodiversity Guidebook recommendations likely over-represent the area in smaller sized patches (Table A5-1 and A5-2). For NDT3 ecosystems, Delong (1998) suggested that the Biodiversity Guidebook recommended patch distributions were reasonable for patches <40, 40-250 in size, but that patches 251-100 and >1000 were under-represented, or absent in the case of large patches >1000 to up to 10,000 ha or more in size. Steventon (2002) showed similar results for SBS and SBPS subzones in the Morice-Lakes area where the greatest area was associated with larger patches (>250 ha). In wetter NDT2 and NDT1 ecosystems that typically experience frequent (gap phase) disturbances, the area affected annually by fire is much less and patches are generally smaller. However, most disturbed area was associated with larger >80 and >250 ha patches.

Although historic patch size distribution estimates summarized here are limited to northern B.C., studies on fire regimes in the western USA (Littel et al., 2009), and southern B.C. (Whitman et al., 2015) show strong correlations between fire regimes and climate gradients. Both fire return interval and fire size increase in the ‘environmental middle ground’ of precipitation and climate, where climatic conditions support contiguous forest fuels, conditions conducive to burning, and ignitions sources (i.e. lightning) such as the montane and subalpine forests of the interior of B.C. (Whitman et al., 2015). Annual area burned and large fire sizes tend to be limited at the extremes of precipitation and temperature, where climatic condition are less conducive to burning, such as wet coastal ecosystems, or very dry (e.g. bunchgrass/dry forest) or cold (e.g. alpine) conditions that do not support contiguous forest fuels (Whitman et al., 2015; Parisien and Moritz, 2009). Thus, the historic estimates of patch sizes from these northern B.C. studies, that provide estimates across a broad climatic gradient within the BGC zones studied, can be used as a guide to estimate expected patch size distributions through much of B.C. Although caution needs to be applied in extrapolating these results elsewhere, particularly due to effects of topographical differences on fire behaviour in within similar climatic regimes (Delong, 1998), the results can provide a reasonable first approximation for other subzones in the province, at least as a preliminary estimate until further information is available. Based on the historic estimates from Table A5-1 and A5-2 above, preliminary benchmarks for patch size distributions by NDT are provided in Table A5-3.

For all forest ecosystems, the historic estimates suggest a much greater proportion of forest area likely occurred in larger early seral patches compared to the original Biodiversity Guidebook estimates. As suggested by Delong (1998) topographic differences may mean that portions of early seral forest in very large patches (>10,000 for NDT3 or >1,000 ha for others) can vary.

***Table A5-3.*** *Estimated proportions early seral forest by patch size class*

| | **Patch Size (ha)** | | | | |
|---|---|---|---|---|---|
| | **<40** | **40-250** | **251-1,000** | **>1,000** | **>10,000** |
| | Proportion of total old or mature forest area | | | | |
| *BG Recommended for NDT3* | *10-20* | *10-20* | *60-80* | | |
| Estimated for NDT3 | 10-20 | 10-20 | 20-40 | 20-60 | (10-30)* |

| | **Patch Size (ha)** | | | | |
|---|---|---|---|---|---|
| | **<40** | **40-80** | **81-250** | **251-1,000** | **>1,000** |
| | Proportion of total old or mature forest area | | | | |
| *BG Recommended for NDT1, 2 and 4* | *30-40* | *30-40* | *20-40* | | |
| Estimated for NDT1, 2 and 4 | 10-20 | 10-20 | 20-40 | 30-50 | (5-15)* |

* Estimated values in parentheses () for the largest patch size classes estimate the proportion of total area >1,000 ha for NDT3 and >250 ha for others that should be in the largest class. For example in NDT3 20-60% of total area is estimated in patches >1,000 with anywhere between up to 50% (10-30) of that area >1000 ha in patches >10,000 ha.

### *Historic Estimates for Mature and Old Forest Patches*

Less information exists to estimate historic patch size distributions for old and mature forests. In general, existing studies show the area in large old and mature patches decreases as the fire return interval increases. In reconstructed forest age maps from the 1960's, Delong (2007) reported a larger proportion of old forest area in smaller patches (<100ha) in Boreal Plains ecosystems that receive more frequent fires (100-200 yr. fire cycle) compared to Wet Mountain NDU with an estimated fire cycle of 900 years (Table 3-8). Despite the increase in old forest area in smaller patches where fire return intervals are shorter, Delong (2007) noted most old forest still occur in larger patches (>100ha) with a significant amount (>30%) of area) in patches >1000 ha. Andison (2003) found similar results with most of the area of old forest in patches >200ha in Alberta montane and foothill forests where fire cycles ranged from 61 to 180 years. In montane and subalpine forests of Kootenay National Park with an estimated 250-year fire return interval, Mori and Lertzman (2011) showed a high proportion of mature, old and late old forest occurred in large patches (>1000 ha), although the proportion of total area by patch size class was not reported.

Modelling studies generally confirm the pattern of increase old forest in small patches sizes where disturbance return intervals are lower (Table A5-4). Daust (2008) suggest larger old forest patches are less related to the size of younger patches (recent disturbance) as they are to the rate of disturbance, as larger old forest patches reflect the process of surviving disturbance. Repeated natural disturbances slowly 'chip away' at remaining mature and old forest patches over time with a greater likelihood of smaller patches occurring as the rate of disturbance on the land-base increases (Daust, 2008; Andison and Marshall, 1997). Most studies report the proportion of old forest (>140 yrs) in each patch size class, so the area of mature + old forest (generally >100 yrs) is likely to be greater than reported here.

***Table A5-4.*** *Historic estimates for the proportion of total old and mature forest in different patch size categories based on forest age maps and modelled studies.*

| Study | NDT | Assessment Unit | Patch Size (ha) | | | |
|---|---|---|---|---|---|---|
| | | | <50 | 51-100 | 101-1000 | >1000 |
| | | | Proportion of Area | | | |
| **Andison and Marshall (1999)*** – modelled landscape | NDT3 | Mature (>100yrs) | 15 | 35 | 50 | - |
| | | Old (>140yrs) | 15 | 30 | 50 | - |
| **Delong (2007)** – Northeast BC- 1960 reference landscape | | Boreal Foothills (old >140 yrs) | 17 | 8 | 28 | 46 |
| | | Boreal Plains BWBS (old >140 yrs) | 26 | 7 | 33 | 37 |
| **Daust (2008)***– modelled landscape | | SBSmc old (125yr FRI) | 15 | 10 | 30 | 45 |
| | | SBSmc old (65yr FRI) | 50 | 20 | 25 | 5 |
| **Andison (2003)***– Alberta Montane and Foothills<br>1950 reference landscape<br>(Est. 61-180yr. FRI) | N/A | Montane | 12 | 5 | 62 | 22 |
| | | Subalpine – Jasper NP | 12 | 3 | 23 | 62 |
| | | Subalpine - East | 14 | 5 | 51 | 30 |
| | | Upper Foothills | 12 | 7 | 26 | 55 |
| | | Lower foothills | 11 | 8 | 31 | 50 |
| **Delong (2007)***– Northeast BC – 1960 reference landscape | NDT2 | Wet Mountain –Old (>140yrs) (SBSvk, ESSF) 900 Yr FRI | 8 | 5 | 37 | 50 |

* Cumulative frequency distributions were derived from results reported for each study to standardize the proportion of area in each patch size class.

Since patch size distribution is related to disturbance return interval, extrapolating young, mature and old forest patch size distributions from studies in northern B.C. through to other areas in the province based on the relationship with fire return interval is reasonable. Table A5-5 provides initial estimates of historic benchmarks for mature and old forest patch size distributions. These results can provide a reasonable first approximation for other subzones in the province, at least as a preliminary estimate until further information is available.

***Table A5-5.*** *Estimated proportions for mature and old forest by patch size class*

| Estimated for NDT3* | Patch Size (ha) | | | | |
|---|---|---|---|---|---|
| | <40 | 41-250 | 251-1,000 | >1,000 | >5,000 |
| | Proportion of total old or mature forest area | | | | |
| | 10-30 | 10-30 | 20-40 | 20-40 | <5 |

| Estimated for NDT1, 2 and 4* | Patch Size (ha) | | | | |
|---|---|---|---|---|---|
| | <40 | 41-250 | 251-1,000 | >1,000 | >5,000 |
| | Proportion of total old or mature forest area | | | | |
| | 5-15 | 5-15 | 20-40 | 30-70<br>(30-50) | 5-15 |

* Cumulative frequency distributions were derived from results reported for each study to standardize the proportion of area in each patch size class.

# Appendix 6: Habitat Subdivision Rating

To calculate the Habitat Subdivision Rating a standardized measure of divergence (*D*) is used. This measure is based on Kullback-Leibler (K-L) divergence as a measure of how one probability distribution is different from a second probability distribution, In this application, the distributions to be compared represent the percent of total area of mature and old forest that is in different patch size classes (patch size distribution); one from a measured or 'observed' patch size distribution of mature and old forest of interest to a hypothetical or 'expected' distribution that would have occurred under historic disturbances. In the following example, a hypothetical 'observed' distribution measured as the proportion of total mature and old forest in each patch size class from a forested landscape is compared to the average expected distribution for an NDT3 forest ecosystem (Figure A6-1).

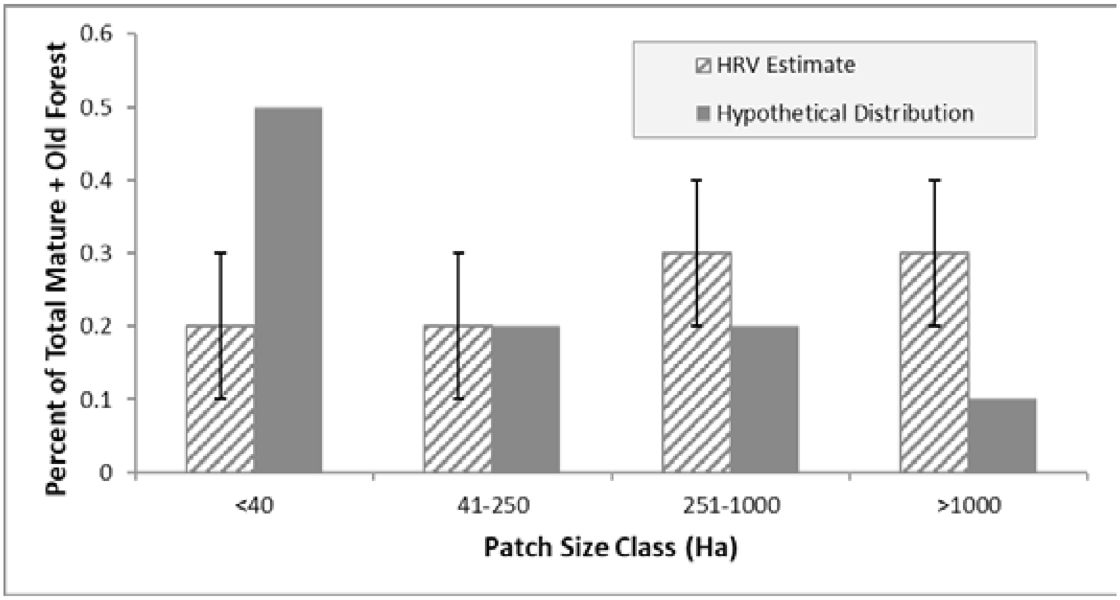

***Figure A6-1.*** *A hypothetical 'observed' patch size distribution compared to the average (bars) and variability (error bars) used to represent the historic range and variability (HRV) estimate for mature and old forest patches in NDT3 ecosystems*

The proportion of area of is shown in the following table:

| | Patch Size Class | | | | |
|---|---|---|---|---|---|
| | **0-40 ha** | **41-250 ha** | **250-1,000 ha** | **>1,000 ha** | **>10,000 ha** |
| | Percent (%) of Forested Land-base | | | | |
| Observed Distribution (Hypothetical) | 0.5 | 0.2 | 0.2 | 0.1 | |
| Expected Distribution (HRV Estimate) | 0.2 | 0.2 | 0.3 | 0.3 | (10-30)* |

The measure of Divergence of observed from expected D(Obs//Exp) is calculated as follows:

$D = 0.5\text{Ln}(0.5/0.2) + 0.2\text{Ln}(0.2/0.2) + 0.2\text{Ln}(0.2/0.3) + 0.1\text{Ln}(0.1/0.3)$

In this example,
$D = 0.267$

A Divergence (*D*) value of '0' would mean that the two distributions are identical. This example shows that the 'observed' distribution diverges beyond the expected range of variability in two of the four patch size classes. A value above 0.3 generally results in divergence in 3 or more patch size classes, whereas below 0.1, the observed distribution falls within the expected range in all patch size classes.

### *Application*

In real-world applications, some patch size classes may have no measurable area in one or more patch size class. To avoid natural logarithm of a zero value, which would result in a NULL Value, the equation adds a small percentage (0.001) to each patch size class.

Measuring patch sizes in a GIS environment must be necessarily restricted by an arbitrary cutoff, such as a study area boundary, where in real-life the forest may extend beyond that boundary. In the assessment protocol, Landscape Unit (LU) boundaries were used as this arbitrary cut-off. This arbitrary cut-off may split particularly large mature and old forest patches (250-1000, >1000 ha). This outcome can often result in no area measured in these larger patch size classes. Therefore, in the assessment protocol proportional area the two largest patch size classes for both the observed and expected are combined (all patches >250 ha).

# Appendix 7: Historic Estimates of Interior Forest Habitats

The existing recommendations for interior old forest in the Biodiversity Guidebook and other legal objectives involve trade-offs to balance timber production and biodiversity conservation, and so likely underestimate the historic range and variability in edge density and interior forest. Estimates of interior forest area under historic, unmanaged conditions were examined through a review of existing published studies that report common metrics associated with quantifying edge influence, including interior forest and edge density (Figure A7-1). The results from several studies showed a strong linear relationship between interior forest area and edge density (Figure A7-1 top), suggesting both metrics could be used interchangeably. The results also showed a strong linear relationship of interior forest area to percent early seral area with a linear decline in interior forest up to where 50% of an area is disturbed whereby no interior forest would remain. The results of these studies are also consistent with results of modelled landscapes (Franklin and Forman, 1987; Spies et al., 1994). However, the strong linear relationship at low levels of disturbed area (<20-30%) appears to diverge at moderate levels (>30% disturbed) of early seral, suggesting the spatial pattern of disturbance can affect the amount of interior forest area (Figure A7-1 bottom). These results suggest that expected early seral amounts under HRV can be used to guide estimates for interior forest area, but greater variability may be expected in disturbance-prone landscapes that historically experienced greater amounts of early seral forest.

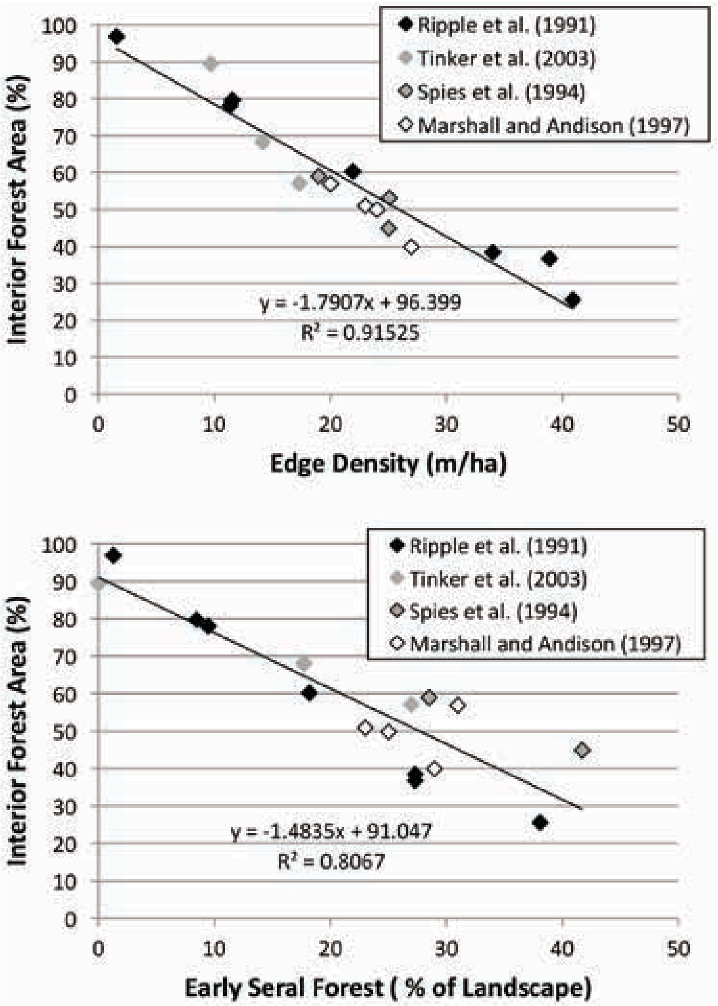

***Figure A7-1.*** *Relationship between interior forest area and edge density (top) and percent early seral forest (bottom) summarized from existing published studies.*

BRITISH COLUMBIA

CEF Cumulative Effects Framework

FREP Forest & Range Evaluation Program