YELLOW-CEDAR REGENERATION IN WAKE OF ITS DECLINE: AN ANALYSIS OF JUVENILE CALLITROPSIS NOOTKATENSIS (D. DON) VIGOUR AS IT RELATES TO SITE CLASS AND MICRO-SITE ATTRIBUTES IN HAIDA GWAIJI, BRITISH COLUMBIA

In Partial Completion of the University of Toronto Masters of Forest Conservation

Abstract

Yellow-cedar is experiencing decline throughout the northern region of its natural range. The leading hypothesis attributes the decline to root-freeze damage caused by reduced snowpack and exposure to freezing air temperature events in an otherwise warming climate. The objective of this research is to determine if landscape attributes within the range of yellow-cedar decline are associated with poor growth and mortality of young, planted yellow-cedar trees on Haida Gwaii, BC by reducing the impacts of climate change. Landscape attributes such as drainage, aspect, elevation and slope were investigated. This research found that well-drained soil was significantly associated with increased growth indicators and survival rates of young planted yellow-cedar trees, which supports the current decline hypothesis. However, lower elevations and flat aspects were also associated with better growth, which was not consistent with the current hypothesis, although these trends were not supported by statistical significance. More research is required on Haida Gwaii to determine the full range of decline within this region, as well as to identify landscape attributes that are affecting growth and mortality of mature yellow-cedar stands.

Joanna Dobson
December 23, 2018
# Table of Contents

- List of Tables and Figures ................................................................. 2
- Introduction .......................................................................................... 3
- Methods .................................................................................................. 10
  - Site Selection ..................................................................................... 10
  - Data Collection ................................................................................ 11
  - Statistical Analysis .......................................................................... 12
- Results ...................................................................................................... 14
- Discussion ............................................................................................... 16
- Management Implications and Conclusions ............................................ 19
- Acknowledgements ............................................................................... 21
- Literature Cited .................................................................................... 23
- Tables and Figures ............................................................................... 26
- Appendices ............................................................................................ 39
List of Tables and Figures

Table 1 - Seedling Level Analysis of Growth Indicators and Landscape Attributes: p-values ..........26
Table 2 - Transect Level Analysis of Growth Indicators and Landscape Attributes: p-values ..........27
Figure 1 - Transect Level Analysis of Elevation’s Effect on Yellow-Cedar Tree Height ..................28
Figure 2 - Transect Level Analysis of Drainage’s Effect on Yellow-Cedar Tree Height ..................29
Figure 3 - Transect Level Analysis of BCG Variant Effect on Yellow-Cedar Tree Height ..............30
Figure 4 - Seedling Level Analysis of Aspect’s Effect on Yellow-Cedar Tree Height .................31
Figure 5 - Transect Level Analysis of Elevation’s Effect on Yellow-Cedar Tree DBH ...............32
Figure 6 - Transect Level Analysis of Drainage’s Effect on Yellow-Cedar Tree DBH ...............33
Figure 7 - Transect Level Analysis of BCG Variant Effect on Yellow-Cedar Tree DBH ...............34
Figure 8 - Seedling Level Analysis of Microsite Effect on Yellow-Cedar Tree DBH .................35
Figure 9 - Transect Level Analysis of Drainage’s Effect on Yellow-Cedar Tree Mortality ............36
Figure 10 - Seedling Level Analysis of Browse Barrier Type Effect on Yellow-Cedar Tree Height ..37
Figure 11 - Seedling Level Analysis of Browse Barrier Type Effect on Yellow-Cedar Tree DBH .....38
Introduction

Yellow-cedar (*Callitropsis (Xanthocyparis) nootkatensis* (D.Don) Spach) is widely distributed across the archipelago of Haida Gwaii, with integral importance to the culture of the Haida, and of particular ecological significance and economic value. The Haida Nation, who have occupied Haida Gwaii for at least 13,000 years (Takeda & Ropke, 2010) predate the existence of yellow-cedar on the islands, which has been estimated to have populated this region approximately 6,000 years ago (Hebda, 1996). In this time, the Haida have incorporated yellow-cedar into their everyday lives, using bark fibers for rope and baskets, and lumber for paddles, tools and ornamental masks (Hennon & Shaw, 1997). Similar to redcedar (*Thuja plicata*), yellow-cedar create important ecological habitat structures such as black bear dens and epicormic nesting branches (White, 1996).

Economically, yellow-cedar captures premium values, tapping into specialized temple construction markets in Japan and various specialized construction markets across North America (Hennon & Shaw, 1997). Yellow-cedar accounts for approximately 6% of the species composition is harvestable areas of Haida Gwaii (BCTS, 2017), but is valued at higher rates per m³ than any other species on the island (Timber Pricing Branch, 2018), contributing to the revenues of on-island harvesting firms such as Taan (owned entirely by the Haida Nation), Husby Forest Products Ltd., A&A Trading Ltd., O’Brien & Fuerst Logging Ltd., as well as the British Columbia Timber Sales (BCTS, 2017). The revenues collected by these companies contribute to local salaries that funnel throughout the islands’ economies, as well as various municipal and provincial taxes (BCTS, 2017). The persistence of yellow-cedar populations across its range and specifically on Haida Gwaii is especially important because of the values that it provides to the Haida Nation, as well as its ecological and economic values.
Unfortunately, however, mortality of yellow-cedar stands from Southeast Alaska and 150 km south of the border into Northwest British Columbia have been observed since the late 1800s (Daniels et al., 2011; D’Amore & Hennon, 2006; Hennon et al., 2005), giving rise to the term Yellow-Cedar Decline (YCD). As yet, populations of the species remain healthy through a large percentage of its range spanning Southeast Alaska to southern coastal Oregon (see Appendix A for map of yellow-cedar range), hence the species has not been listed as a species of concern internationally (IUCN, 2018) or provincially (BC Ministry of Environment, 2018). Given the ecological, cultural, and economic value of this species, declines are of great concern.

Based on several decades of research, one key hypothesis has been developed to explain YCD. This hypothesis attributes YCD to the relationship that yellow-cedar root systems have with changing conditions of the protective spring snowpack and the resulting vulnerability to injuries associated with thaw-freeze temperature patterns (Daniels et al., 2011; Hennon et al., 2005). As winter approaches, yellow-cedars use temperature indicators to harden their roots, protecting them from damage associated with freezing (D’Amore & Hennon, 2006; Schaberg et al., 2005). Historically, as snow accumulates and persists on the soil, it acts to buffer daily fluctuations of temperatures, which may otherwise prematurely signal yellow-cedar to deharden its roots. This is especially important in seasons where early spring thaws are followed by subsequent freezing events (Daniels et al., 2011). With a generous snowpack buffer, the snow will typically remain intact until the final freeze of the season is well in the past, allowing yellow-cedar to maintain temperature stability until the snow is gone, at which time temperature cues would signal the dehardening process to safely begin (Hennon et al., 2005).

A changing climate, beginning with the end of the Little Ice Age in the mid to late 1800s (Daniels et al., 2011; Hennon et al., 2016) and continuing into an era of anthropogenic warming (Oakes et al., 2014), is creating significant ecological changes in regions where winter mean temperatures hover
slightly below 0°C (Daniels et al., 2011; Hennon et al., 2012). Minor increases in mean winter temperatures have shifted precipitation from predominantly snow to rain fall in some regions (Daniels et al., 2011), resulting in a reduced snowpack. This shift has the potential to cause significant repercussions to ecosystems and species that require winter and spring snow cover. Studies have reflected the trend that warmer air leads to colder soils because of snowpack loss (D’Amore & Hennon, 2006; Drescher & Thomas, 2012; Halim & Thomas, 2018). In the affected regions of YCD, it has been observed that temperatures that previously hovered below freezing are now hovering above freezing, and that snow fall has declined, falling as rain instead (D’Amore & Hennon, 2006; Daniels et al., 2011; Oakes et al., 2014). This process has left winter and spring soils more vulnerable to periodic deeper freezes without the protective snowpack buffer (Drescher & Thomas, 2013; Schaberg et al., 2011). A study conducted in Southeast Alaska analyzed yellow-cedar growth and mortality as a function of several variables, including varied snowpack (D’Amore & Hennon, 2006). They measured diameter at breast height (DBH), heights and live and dead basal areas of yellow-cedar in mixed species forests ranging in elevation, drainage and site series against potential influencing variables such as soil saturation, aluminum and calcium concentrations, snow depth and soil and air temperatures. They found spring soil temperatures to be strongly associated with decline as described by forest zones (where the degree of decline was evaluated and separated spatially into class zones), especially when initial mortality created gaps in the canopy allowing for increased solar radiation exposure, stimulating premature dehardening and subsequent freezing in the early spring (D’Amore & Hennon, 2006).

Yellow-cedar is more tolerant of poor soil conditions than most other species in its range under ideal climate conditions (Daniels et al., 2011; Hennon et al., 2012; Hennon et al., 2016). Physiological explanations of this resiliency have been reported by Schaberg et al. (2011). Yellow-cedar roots promote higher levels of relative electrolyte leakage (REL) year-round compared to competitor
species (Schaberg et al., 2011). REL refers to a process occurring on fine root membrane tissue, where higher REL outputs allow for the roots to readily engage in physiological activity, contributing to their overall efficiency in nutrient uptake (Schaberg et al., 2011). However, increased REL is also associated with reduced cold hardiness and temperature vulnerability (Schaberg et al., 2011). The Schaberg et al. (2011) experiment, set up near Ketchikan, Alaska, the cold hardiness of four species’ roots in various months in winter and spring was measured by comparing REL values. The results showed that yellow-cedar cold hardiness was reduced well before competing species, with increased REL values as early as March. Additionally, yellow-cedar displayed the highest REL throughout all months of observation, suggesting higher physiological efficiency as well as increased vulnerability to freeze damage (Schaberg et al., 2011). Given their REL vulnerability, yellow-cedar root-interactions with thaw-freeze events (without a snowpack buffer) can create repetitive events of root damage associated with freezing (Schaberg et al., 2005; 2011). Therefore, the mechanism that once gave yellow-cedar a competitive advantage in poorly drained soils may now unfortunately be the cause of its vulnerability to temperature fluctuation compared to other species.

The shallow rooting system of yellow-cedar trees has been observed as a mechanism to avoid fine root anoxia in poorly drained soils (Hennon et al., 2016) and efficiently take advantage of the coupled Ca-NO₃ nutrient cycle where calcium persists in higher concentrations in shallow soils (D’Amore et al., 2009). Where calcium is present, calcium cations and nitrogen anions bind and allow for a more efficient absorption of nitrogen in yellow-cedar (D’Amore et al., 2009). This is another physiological adaptation used by yellow-cedar to increase efficiency in soils with otherwise poor growing conditions, and supported by observations of high relative foliar calcium concentrations found in yellow-cedar by D’Amore and Hennon (2006). However, roots occurring in the top 15 cm of the soil horizon are more susceptible to air temperature dynamics (D’Amore & Hennon, 2006). Therefore, high REL outputs coupled with yellow-cedar’s shallow root system
(Hennon et al., 2016; Schaberg et al., 2011) are thought to be responsible for its disproportionate vulnerability to temperature fluctuations in relation to competing species such as western hemlock (Tsuga heterophylla (Raf.) Sarg.), western redcedar (Thuja plicata), and Sitka spruce (Picea sitchensis (Bong.) Carr.). The root damage associated with intermittent freezing is thought to be the cause of YCD (Daniels et al., 2011; D’amore & Hennon 2006; Schaberg et al., 2005; 2011).

Unfortunately, the landscape attributes that once allowed yellow-cedar to have a competitive advantage may now be contributing to its vulnerability. Poorly drained soil may be contributing to yellow-cedar’s susceptibility to YCD by promoting shallow rooting systems and reducing winter time soil temperatures (Daniels et al., 2011; Hennon et al., 2006). In much of yellow-cedar’s range, it is typically distributed at elevations above 300 m, although in more northerly latitudes, it can persist at sea level (Hennon et al., 2005). However, YCD has been observed to effect these high-latitude, low elevation habitats, which may be a result of locally warmer temperatures compared to higher elevations of the same latitude (Wooten & Klinkenberg, 2011). Where applicable, aspect also may have effects on growth. It is expected that northern aspects will reduce the rate of snow melt due to a decreased concentration of solar radiation, and therefore benefit yellow-cedar survival. This concept has been supported by D’Amore and Hennon (2006), and Wooten and Klinkenberg (2011).

Wooten and Klinkenberg (2011) used remote sensing and Geographic Information Systems technology to identify spatial distributions of healthy and declining yellow-cedar stands overlaid with topographical variables such as elevation, soil saturation, aspect, slope, air temperatures and snowpack presence/absence. They found that elevation, slope and aspect effects were significantly correlated with the distribution of dead yellow-cedar stands. Specifically, elevations between 200-700 m, slopes between 16-24°, and southwest and west facing aspects were reported as significantly correlated with declining or dead yellow-cedar stands (Wooten & Klinkenberg, 2011). It was theorized that these site features increase solar radiation, contributing to reduced snowpack.
Although several lines of evidence support the YCD hypothesis, there may be some logical inconsistencies when attributing YCD to a climate-related, abiotic stressor. Abiotic stressors typically present themselves in gradients, whereas YCD has been spatially reported as patchy (Jones & Gilbert, 2016), although this in part may be attributed to yellow-cedar’s somewhat patchy distribution in mixed species forests. Also, climate related stress in the Northern Hemisphere has often presented itself at the southern range of a species’ distribution (Jones & Gilbert, 2016). If snowpack is required to insulate roots in climates where winter and spring-time air temperatures reach sub-zero levels, then presumably a loss of snow occurring at more southerly latitudes would impact survival prior to the high latitudes that mortality is displayed in. This anomaly could be explained by distinct genetic variations amongst spatially diverse populations, in which southern yellow-cedar have reduced REL or deeper rooting systems to mitigate freeze damage, or perhaps these southerly regions do not receive the freezing presumably required to cause YCD. There is no research currently available on genetic variability as it relates to cold hardiness, although Ritland et al. (2001) have identified high genetic variation when sampling from three distinct locations within the yellow-cedar range, which is potentially a result of different ice age refugia. This variation was relatively high when compared to geographic genetic variation in other conifers in the region (Ritland et al., 2001).

At present, most research supports the hypothesis that YCD is caused by a soil-based stress, indicated by symptoms such as root nodules, wood staining and synchronous crown loss prior to mortality (Daniels, 2011). Various soil-based biotic theories have been presented to explain YCD such as fungal or nematode pathogens, but these stressors have not been consistently observed when evaluating YCD across its range (Daniels, 2011; Hennon et al., 1986; Hennon 1990; Hennon & Shaw, 1994). Additionally, yellow-cedar has been observed to divert internal resources away from steady growth, instead focusing such resources towards maintaining a tolerance to poorly drained,
low nutrient sites and to biotic invasion mitigation, making it additionally unlikely that a biotic stress is at work (Hennon & Shaw, 1997).

As noted above, many aspects of YCD have been studied, including mortality throughout its range (Hennon et al., 2005; Wooten & Klinkenberg, 2011), species comparisons of cold hardiness (Schaberg et al., 2005; 2011), climate related succession (Oakes et al., 2014), and mitigating landscape factors in mature stands (D’Amore & Hennon, 2006; Wooten & Kilinkenberg, 2011). However, there is limited data and analysis available examining the success of yellow-cedar artificial regeneration. Where it has been studied, factors such as deer browse (Hennon et al., 2016) and seeding type (Hennon et al., 2009) have been focal points. Schaberg et al. (2008) conducted a laboratory study on yellow-cedar seedlings that included treatments of continuous simulated snowpack, limited simulated snowpack, and no protective snowpack to determine fine root and foliar survival rates of yellow-cedar under various temperature exposures. They found that seedlings exposed to the treatment with no snowpack exhibited overwhelming indicators of fine root damage and mortality in the spring months (Schaberg et al., 2008). This would suggest that seedlings will be susceptible to similar climactic limitations as adults, and hence that the study of regeneration success might be used to provide more insight into YCD. Of course, at the same time, it makes little sense to attempt to regenerate the species in sites where it is destined to fail. As yet, no field research has been conducted to determine site attribute influences on the vigour and growth of regenerating yellow-cedar. Site conditions affecting growth such as elevation, soil drainage, slope, aspect and ecosite types have been speculated to be indirectly related to YCD, but have not yet received attention in relation to regeneration.

Here, I address this shortcoming by examining the relationships between landscape attributes and the survival, growth and vigour of juvenile, artificially-regenerated yellow-cedar on Haida Gwaii. It is expected that higher survival rates, higher growth rates (as measured by height and DBH), and
strongest vigour will be associated with higher elevations, well-drained soils, and north aspects. In addition, variation in seedling characteristics among ecosite types (known locally in BC as site variants and site series), are of exploratory interest to this study, as there is no current expectation as to which types will foster healthier yellow-cedar trees. Due to the unique conditions on Haida Gwaii, several other features of the regeneration were of interest. An overabundance of invasive Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) prevent any meaningful regeneration of yellow-cedar to occur without browse barriers, which vary in brand, design, and timing of removal, and all have the potential to interfere with seedling growth. Seedling origin (nurseries) also vary and may affect survival and growth of planted trees.

**Methods**

*Site Selection*

Prior to field data collection, sites were identified through the review of licensee planning documents. Reports were used to identify sites that had been harvested between 2000-2010 (which should have achieved the “free to grow” silvicultural designation, meaning that the regrowth had reached acceptable levels of regeneration and that the licensee was not required to contribute further silvicultural activities to the site) and sites where yellow-cedar was included in the regenerating species composition. All sites meeting these criteria were short-listed to evaluate accessibility and representation of various site class compositions, licensees, tree planting contractors, seed lot suppliers, and browse barrier types. The number of sites visited was maximized given the six weeks available for the research. For a map of sites visited, see Appendix B.

In relation to the British Columbia Biogeoclimatic Ecosystem Classification System, several levels of classification were considered in order to better understand yellow-cedar growth indicators. Haida
Gwaii contains five biogeoclimatic (BGC) zones across its islands. The most common zone, Coastal Western Hemlock (CWH) occurs in almost all regions of the island where harvesting and silvicultural activities take place. The CWH BGC zone occurs on leeward, low to subalpine elevations (0-600 m), which explains the limited elevation variance found across the distribution of the data set. There are two BGC subzones that fall within the CWH zones of Haida Gwaii, being Wet Hypermaritime (wh) and Very Wet Hypermaritime (vh). Again, the wh subzone was much more prevalent in harvested areas; especially areas that were of accessibility, given limited resources (refer to Appendix I for a map of the subzone distributions across Haida Gwaii). The vh subzones tended to occur on the west coast of Graham Island, where helicopter access was often the only feasible transportation. Due to these limitations, wh subzones dominated the sample, making it impossible to evaluate subzone effects on yellow-cedar regeneration in this research set. Therefore, site variants and site series were the only BGC designations considered in this data set (see below).

**Data Collection**

At each site, belt transects were run with a 2 m width (unless otherwise stated), beginning at the point closest access away from the road, and in a direction that maximized transect length based on the shape of the planting unit. Transect start and end coordinates were recorded. Any yellow-cedar tree, or evidence of a yellow-cedar tree that was once present (i.e., browse barrier presence) that fell within the transect was recorded for both micro-site characteristics as well as growth and vigour measurements (see below). Also, each individual that fell within the transect boundary received a paired location, 15 m from the original in a random direction. These paired locations were assessed in the same way that the transect sites were, and if there was a yellow-cedar stem present (or evidence that there once was a stem) within 1 m of the micro-site, it too was noted and measured. The site (=block), transects, individuals stems and paired locations were assessed as per the field data sheets (Appendix C) to capture: (1) aspect, (2) elevation, (3) microsite classification, (4) slope, and
(5) drainage. Each tree was measured for growth and vigour, as per the indicators: (1) mortality (2) free to grow status, (3) height, (4) diameter at breast height (DBH), (5) new leader length, (6) vigour, (7) form, and (8) natural regeneration. Other data collected included browse barrier type and presence.

**Site and tree characteristics**

Aspect was captured using a compass and elevation was determined using a Garmin GPS. Slope was determined using a clinometer. Microsites were descriptively classified into 15 categories (Appendix D), and drainage was assessed as a rank (1-3) by eye and feel to assess the upper soil horizon. Mortality was determined by either the presence of a browse barrier with no stem, or a stem with no green foliage. Free to grow designation was determined using the BC Silviculture Survey Guide for yellow-cedar (Appendix E). Height was measured to the nearest cm for stems ≤ 2 m, and with a clinometer at a distance of 15 m from the stem for trees > 2 m. DBH was measured at approximately 1.2 m directly above the point of germination. Length of the top leader shoot, or the closest accessible leader shoot to the top of the tree, was measured to the nearest millimeter. Vigour and form were classified as described in Appendix D. Natural regeneration was measured by counting the number of natural recruits within a 1 m radius of the planted stem. Additional information from site plans and silvicultural activity reports included: (1) BGC site variation (2) site series, (3) licensee, (4) seed lot, and (5) planting contractor identification.

**Statistical Analysis**

The data set was investigated through both seed- and transect-level analyses. Seed-level analysis offered a large sample size \( n = 534 \) seedling pairs across the sites), but in some cases resulted in pseudo-replication in that site characteristics were constant, or nearly constant, within a site. Hence, any significance must be interpreted with caution. Transect-level analysis avoided this problem, but
sample sizes were relativity small \((n = 19\) sites). Where applicable, both seed- and transect-level analyses were completed to better understand trends and identify relationships of interest. However, there were instances in which an independent variable was reasonably analyzed at only the transect- or the seedling-level. For example, microsites types exhibited great variation within every site and hence means, medians or modes did not reasonably represent sites; as a result, analysis was at the seedling level. Site series, site variant and seedlot were always constant within a site and hence were analyzed exclusively at the transect level.

When height and DBH were the dependent variables within a test, their residuals compared to age were used to partial out age, which would naturally affect these growth indicators. In most cases, transformed data were used (primarily logged\((x+1)\)) in order to satisfy normality and homogeneity for the purpose of parametric statistics. General linear models were used to determine correlations between continuous dependent variables (logged height and DBH) and both class (aspect, microsite, drainage, site variation, site series, seedlot and barrier type) and continuous (elevation and slope) independent variables at the seedling level. At the transect level, linear models were used by correlating the mean values of dependent variables with the median (class-ranked), mode (class-discrete), or mean (continuous) values of independent variables. Aspect was simplified into three classes: flat, NE (when transects had a mode of NW, N, NE or E) and SE (when transects had a mode of SE, S, SW or W). When evaluating class dependent variables such as mortality, chi-squared tests were used. Non-parametric generalized linear models with negative binomial distributions, Kruskal Wallis, and Chi-squared tests were used to analyze count data when assumptions of normality and homogeneity were violated (for example, natural regeneration counts).
Results

When seedling height was analyzed at the seedling level against landscape attributes using multiple regressions with seedling age as a covariate, aspect (p<0.0001), elevation (p<0.0001) and drainage (p=0.004) were significant (see Table 1 for a full list of seedling p-values, complimented by figures demonstrating means and ranges in Appendix F). At the transect level, elevation (p=0.010; Fig. 1), drainage (p=0.041; Fig. 2), and site variants (p=0.0003, Fig. 3) also were significant (see Table 2 for a full list of transect level p-values, complimented by figures demonstrating means and ranges in Appendix G). Lower elevations and sites with zero aspect displayed greatest relatives heights.

Although sites with zero aspect returned best height results, sites with NE aspects had greater relative heights than SE aspects (Fig. 4). Well drained sites showed significantly greater relative heights than poorly drained sites and BGC site variant 1 (lower elevations with warmer, drier climates) showed significantly greater relative heights than site variant 2.

When relative DBH was analyzed at the seedling level it responded similarly to height in that aspect (p<0.0001), elevation (p<0.0001) and microsite (p=0.019) returned significant correlations. At the transect level, elevation (p=0.0323; Fig. 5), drainage (p=0.0428; Fig. 6), and site variants (p=0.0012; Fig. 7), had significant relationships. Similar to the results associated with height, lower elevations and sites with zero aspect displayed highest relative DBHs. Again, well drained sites showed significantly larger relative DBH than poorly drained sites. Site variant 1 showed significantly larger relative DBH than site variant 2. Microsites comprised of mounds or grass (p=0.019; Fig. 8) were also associated with larger relative DBH at the seedling level.

Vigour was simplified into a three-class system (Appendix H). Vigour was found to be associated with age (p<0.0001), where older trees tend to have better vigour. Because of this, vigour was divided into two age classes to control for the age affect: age class one included transects with trees
aged 9-12 years and age class two included transects with trees aged 13-16 years. At the seedling level, vigour levels in age class one was significantly associated with aspect (p=0.0058), elevation (p=0.0024) and slope (p=0.0499). In age class two, vigour at the seedling level correlated significantly with drainage (p=0.0019). However, at the transect level, vigour was not significantly correlated with any landscape attribute. Trends suggest that younger seedlings were most vigorous on zero and NE aspects, lower elevations and flat ground. Older seedlings showed greatest vigour on well drained sites.

Mortality did not have a relationship with seedling age, so age effects were not controlled for when analyzing this indicator. Logistic regressions were used to analyze these data. At the seedling level, mortality was significantly correlated with aspect (p=0.0014), drainage (p<0.0001), and microsite (p<0.0001). At the transect level, mortality was significantly correlated with drainage (p<0.0001; Fig. 9). Mortality was higher in sites with SE aspects and poor drainage, including bogs and toes.

When evaluating natural regeneration counts, non-parametric tests such as the Kruskal-Wallis or Chi-squared test were used. In some cases, generalized linear models with negative binomial distributions were used. At the seedling level, natural regeneration presence significantly correlated with aspect (p<0.0001) and elevation (p=0.0003). Aspect was nearly significant at the transect level (p=0.055). Trends associated with natural regenerations mimicked those of the other growth indicators.

Seedlot was analyzed at the transect level due to its within-site consistency, and returned no significance across any of the seedling variables. Browse barrier type occasionally varied within a site, making it possible to analyze at the seedling level (analyses at the site level were not possible because of small sample sizes). Barrier type had a significant effect on relative height (p=0.0005; Fig. 10) and DBH (p=0.0238; Fig. 11) at the seedling level; however, this was entirely due to the Tubex brand of barrier at one site (Demon 411), which had significantly shorter and thinner trees.
This site also showed relatively high elevations, which could have been the explanation for the low growth.

**Discussion**

The results of this research were consistent throughout the dataset in regard to landscape attributes and their effects on growth, vigour and mortality of artificially regenerated yellow-cedar in clear-cut harvesting blocks on Haida Gwaii. Well drained soils, lower elevations, zero aspect and BGC site variant 1 were all associated with best growth, vigour and survival rates. However, these effects were not always consistent with results from previous research, although a few of my findings compliment the current hypothesis concerning yellow-cedar decline (YCD).

As expected, yellow-cedar height, DBH and survival rates were associated with well-drained sites. This is consistent with yellow-cedar growth expectations with and without YCD as a consideration (Daniels et al., 2011; Hennon et al., 2012; Hennon et al., 2016). Although yellow-cedar has a higher tolerance for poorly drained soil than competitor species under ideal climate conditions, the species would still attain better performance on drier soils should competition be excluded. Of course, in wake of YCD, well-drained soil are thought to be a necessity rather than an asset for survival and growth. As has been discussed in previous literature, poor drainage reduces winter time soil temperatures (Hennon et al., 2012) and encourages shallower rooting behaviours (Hennon et al., 2012), exposing yellow-cedar roots to potential freeze injuries. Microsites that exhibited characteristics that would support drainage such as mounds and well-drained grass also tended to foster more successful yellow-cedar regeneration, whereas poorly drained microsites such as bogs and toes tended to host yellow-cedars with poor growth indicators.

Site series did not exhibit significance at the transect level in relation to any growth indicator. This is unexpected due to the site series’ reliance on site type descriptors such as soil moisture and nutrient
composition (Banner et al., 1993). Site series are also used to describe a site’s potential for stable plant communities at given successional stages (Banner et al., 1993). In part, a small sample size ($n = 19$) combined with a large set of site series alternatives (11) posed significant challenges from a statistical power perspective. However, a consistent trend was that site series 10 and 4 returned relatively positive growth indicators, whereas site series 5, 2 and 1 returned relatively negative growth indicators. More research is required to determine whether these trends are real.

Low elevations, which were significantly correlated with better growth and survival rates in my research are an unexpected finding when considering the current YCD hypothesis. I expected higher elevations to promote better growth and survival, as higher elevations are typically associated with lower temperatures and more significant snowpack accumulation and retention. However, the distribution of elevation in this study occurs between 31 m and 490 m, which relative to other studies that range beyond 700 m of elevation (Wooten & Klinkenberg, 2011), may not capture the variation of elevation classes required to witness YCD mitigation. Still, these findings do not appear to be consistent with the YCD hypothesis.

BGC subzones are classified into variants in the B.C. system; in my case, variants wh1 and wh2. Variant wh1 refers to submontane elevations (0-350 m above sea level) and accounts for 49% of Haida Gwaii’s land area. Variant wh2 refers to montane elevations (350-600 m above sea level) and accounts for 7% of Haida Gwaii’s land base. The wh2 variant is wetter and cooler (2536 mm mean annual precipitation, 6.2°C mean annual temperature) than wh1 (1948 mm mean annual precipitation, 7.4°C mean annual temperature) and has more persistent winter-time snowpack (Banner et al., 2014).

At the transect level of analysis, sites with the wh1 variant returned significantly stronger yellow-cedar heights and DBH. Although not significant, all other indicators, including vigour, mortality and natural regeneration all returned trends of wh1 hosting better conditions for yellow-cedar regeneration and growth. The low elevations and reduced snowpack of this variant compared to the
wh2 variant suggest that these findings are not consistent with the current YCD theory, which suggests that elevations above 700 m, with persistent snowpack should foster better growth (Wooten & Klinkenberg, 2011). In addition to the wh2 variant being the expectantly more hospitable BGC variant to yellow-cedar given the YCD hypothesis, wh2 has historically supported yellow-cedar growth at higher rates than wh1 (Banner et al., 2014). Banner et al. (2014) list yellow-cedar as one of four dominant species in the wh2 variant (alongside western redcedar, Sitka spruce and mountain hemlock), whereas in the wh1 variant it is listed as a minor species. This could be the result of competition, suggesting that without silvicultural activities, yellow-cedar might not compete well against dominating species in wh1, despite the variant exhibiting more favourable growing conditions. This is supported by the physiological characteristics listed in the literature regarding yellow-cedar’s advantages against other species in the poorer growing conditions that are exhibited in variant wh2 (Daniels et al., 2011; Hennon et al., 2012; Hennon et al., 2016). This introduces a hypothesis regarding the role that silvicultural activities play in establishing species composition prior to the free growing stage of a new forest’s life cycle. Perhaps the wh1 variant supports better growing conditions for yellow-cedar given that competition is removed from the equation. However, this does not explain the deviation of the results from expected favourable growing conditions that the YCD theory suggests yellow-cedar currently require.

Another potential deviation from the YCD hypothesis can be seen in yellow-cedar’s response to aspect. I found that the absence of aspect (no slope) had positive effects on growth, although not significant at the transect level. Lower elevations, well-drained soil and more exposure to sun (associated with south or flat aspects) stimulate growth and vigour for many species, assuming that extenuating circumstances are absent (such as YCD) (Daniels et al., 2011; Hennon et al., 2012; Hennon et al., 2016). If YCD is caused by a biotic stressor that has not yet been identified rather than snowpack and climate dynamics, it might be expected that these site conditions would stimulate
growth. However, south-east aspects exhibited the poorest yellow-cedar growth, which is consistent with the YCD hypothesis, but conflicts with this alternative hypothesis. Perhaps these young recruits have not yet experienced significant late-spring freeze events without snowpack within their short lifespans (9-16 years) and due to this lack of exposure, are not yet exhibiting symptoms that one would expect amongst specific landscape attributes. This may be unique to Haida Gwaii, as these coastal climates may remain too mild year-round to ever cross the freeze-damage threshold.

Alternatively, it is possible that juvenile yellow-cedar have alternative sensitivities to external inputs than their mature counterparts given a certain stress, explaining why the mitigating YCD factors identified for adults are not consistent with young recruits. If this is the case, the forestry community faces serious complications regarding yellow-cedar regeneration within the range in which decline has been identified, as transplanting recruits from one landscape to another part way through the lifecycle would not be unfeasible.

It is difficult to speculate on these inconsistencies further without more firmly confirming the cause of YCD. Until further research is completed on mature stands to reach a higher level of confidence regarding the YCD stressor, identifying how regeneration dynamics are impacted by the stressor is difficult. Of course, it is helpful to examine regeneration in the way that has been done in this research as an indirect test of the current hypothesis. However, without clear confidence in the YCD hypothesis, speculation into juvenile:mature requirements may be premature.

**Management Implications and Conclusions**

Further research is required to determine what is causing YCD, how YCD interacts with young recruits, and whether the decline on Haida Gwaii is consistent with the YCD on the mainland in both impact and causation. There is currently limited aerial data available on yellow-cedar dieback on Haida Gwaii, and so the range and intensity of YCD in this region is still unknown. Using remote
sensing to identify the geographic location of declines could be used to undertake research similar to that of Wooten and Klinkenberg (2011), allowing for landscape attributes to be layered and matched with areas of YCD. Given that planting data is available, the additional layer of yellow-cedar age could be added to this data set to comprehensively analyze YCD, the landscape attributes associated with it, the age of the affected stands, and classification of old-growth versus artificial new growth, teasing out the intricacies of this decline phenomena.

Once YCD is better understood within the Haida Gwaii region, ecological niche modelling can be used to identify the most ideal landscapes for yellow-cedar silviculture. Ecological niche modelling is a tool used to predict hospitable landscapes given required habitat features and changing climates and landscapes (Kearney et al., 2010). This would require both a thorough and confident knowledge of the attributes associated with mitigating YCD, a comprehensive database of presence and location of said attributes across the harvestable regions of Haida Gwaii, and several climate simulators to predict future snowpack occurrences. These models have the capacity to identify niche habitats that yellow-cedar would display strongest growth and limited dieback in, based on the YCD theory. This would be a large project, requiring the attention of GIS staff at the government and/or industry level.

Yellow-cedar stands identified as experiencing mortality on Haida Gwaii using remote sensing technology should be prioritized for harvest to salvage the value of standing dead wood and to reduce the chance of forest fires, which may become increasingly more common as the climate continues to change (Flannigan et al., 2000).

Overall, this research has contributed to a working body of understanding YCD and has confirmed that well-drained soils are important for the success of yellow-cedar growth. Current silvicultural activities such as planting on mounds (to avoid poorly drained soils) and reducing competition through planting and brushing may be enough to mitigate YCD on Haida Gwaii. However, once
Further research has been completed, new silvicultural strategies involving the assisted migration of yellow-cedar to niche habitat growing locations could be the best chance at maintaining the yellow-cedar populations on Haida Gwaii.

Acknowledgements

I would like to extend my gratitude to the entire Haida Gwaii District office of the Ministry of Forests, Lands and Natural Resource Operations, starting with my direct supervisor, Leonard Munt. Your support preceding, during and after my time in the Village of Queen Charlotte was integral to my ability to successfully collect the primary data for this project. Your generosity in housing, resources, and crab dinner helped to ease my transition and normalize the experience of island life. Other FLNRO staff that helped me both in the office in the field included Erica Reid, Anicette Labonte, Berry Wijdeven, Sheena Duncan, Becky Cadsand, Ayla Pearson, Teresa Russ, Daryl Sherban, Larry Duke, Jasmine Soles, Jeff Young, Aline Lachapelle, Percy Crosby, Mark Salzl, Sean Muise and Alissa MacMullin. Each of these people offered distinct and unique expertise in either formation or execution of this capstone that I am continually grateful for.

It is extremely important to acknowledge the Haida Nation, including the Council of the Haida Nation, all Haida citizens and the Haida land base. It is within your lands that I humbly lived and researched, with a culturally significant species being central to my investigations. During my first week on Haida Gwaii, a Haida Elder mentioned the influx of foreign researchers, but an exodus of the research results. I do not want to contribute to this phenomenon. This research is dedicated to the Haida people, to enact upon as they see fit. I extend my deep gratitude for hosting me on your incredible lands.

I would also like to extend my most sincere gratitude to Professor Jay R. Malcolm, who’s assistance in project design and analysis was absolutely vital to the success of this research. In addition to your
expertise, your bird calls and laughs were always appreciated. Thank you to Sally Krigstin for facilitating the connection between my advisors and I, and for support throughout the duration of the MFC Program. I would also like to thank Professor Sean Thomas for his expertise in tree physiology and winter-time soil dynamics.

Finally, thank you to my family, colleagues and friends for keeping my head up when the going got tough. Your support, love, laughs and casseroles have been more important to me than I am able to convey.
Literature Cited


Tables and Figures

TABLE 1- SEEDLING LEVEL ANALYSIS OF GROWTH INDICATORS AND LANDSCAPE ATTRIBUTES OF YELLOW-CEDAR ARTIFICIAL-REGENERATION ON HAIDA GWAI I, BRITISH COLUMBIA, 2018. P-VALUES INDICATED DEMONSTRATE STRENGTH OF RELATIONSHIP BETWEEN VARIABLES, WITH HIGHLIGHTED CELLS REACHING OR SURPASSING THE STATISTICAL SIGNIFICANCE THRESHOLD OF P=0.05. PLEASE REFER TO APPENDIX F FOR CELL SPECIFIC FIGURES, AS IDENTIFIED BY COLUMN AND ROW LABELS (NUMBER:LETTER).

<table>
<thead>
<tr>
<th></th>
<th>a) Aspect</th>
<th>b) Elevation</th>
<th>c) Drainage</th>
<th>d) Slope</th>
<th>e) Microsite</th>
<th>f) Site Variant</th>
<th>g) Site Series</th>
<th>h) Seedlot</th>
<th>i) Barrier Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Height</td>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td>p=0.004</td>
<td>p=0.294</td>
<td>p=0.074</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>P=0.0005</td>
</tr>
<tr>
<td>2) DBH</td>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td>p=0.056</td>
<td>p=0.2261</td>
<td>p=0.019</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>P=0.0238</td>
</tr>
<tr>
<td>3) Vigour (Age Class 1)</td>
<td>p=0.0058</td>
<td>p=0.0024</td>
<td>p=0.788</td>
<td>p=0.0499</td>
<td>p=0.634</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4) Vigour (Age Class 2)</td>
<td>p=0.338</td>
<td>p=0.119</td>
<td>p=0.0019</td>
<td>p=0.401</td>
<td>p=0.347</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>5) Mortality</td>
<td>p=0.0014</td>
<td>p=0.0567</td>
<td>p&lt;0.0001</td>
<td>p=0.2994</td>
<td>p&lt;0.0001</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>6) Natural Regeneration</td>
<td>p&lt;0.0001</td>
<td>p=0.0003</td>
<td>p=0.051</td>
<td>n/a</td>
<td>p=0.565</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
TABLE 2- TRANSECT LEVEL ANALYSIS OF GROWTH INDICATORS AND LANDSCAPE ATTRIBUTES OF YELLOW-CEDAR ARTIFICIAL-REGENERATION ON HAIDA GWAI, BRITISH COLUMBIA, 2018. P-VALUES INDICATED DEMONSTRATE STRENGTH OF RELATIONSHIP BETWEEN VARIABLES, WITH HIGHLIGHTED CELLS REACHING OR SURPASSING THE STATISTICAL SIGNIFICANCE THRESHOLD OF P=0.05. PLEASE REFER TO APPENDIX G FOR CELL SPECIFIC FIGURES, AS IDENTIFIED BY COLUMNN AND ROW LABELS (NUMBER:LETTER).

<table>
<thead>
<tr>
<th>Cell</th>
<th>a) Aspect</th>
<th>b) Elevation</th>
<th>c) Drainage</th>
<th>d) Slope</th>
<th>e) Microsite</th>
<th>f) Site Variant</th>
<th>g) Site Series</th>
<th>h) Seedlot</th>
<th>i) Barrier Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Height</td>
<td>p=0.061</td>
<td>p=0.010</td>
<td>p=0.041</td>
<td>p=0.075</td>
<td>n/a</td>
<td>p=0.0003</td>
<td>p=0.1572</td>
<td>p=0.515</td>
<td>n/a</td>
</tr>
<tr>
<td>2) DBH</td>
<td>p=0.123</td>
<td>p=0.0323</td>
<td>p=0.0428</td>
<td>p=0.133</td>
<td>n/a</td>
<td>p=0.0012</td>
<td>p=0.355</td>
<td>p=0.553</td>
<td>n/a</td>
</tr>
<tr>
<td>3) Vigour (Age Class 1)</td>
<td>p=0.347</td>
<td>p=0.387</td>
<td>p=0.170</td>
<td>p=0.449</td>
<td>n/a</td>
<td>p=0.0865</td>
<td>p=0.7476</td>
<td>p=0.66</td>
<td>n/a</td>
</tr>
<tr>
<td>4) Vigour (Age Class 2)</td>
<td>p=0.0477</td>
<td>p=0.6733</td>
<td>p&lt;0.0001</td>
<td>p=0.5321</td>
<td>n/a</td>
<td>p=0.1424</td>
<td>p=0.3750</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>5) Mortality</td>
<td>p=0.055</td>
<td>p=0.245</td>
<td>p=0.268</td>
<td>p=0.239</td>
<td>n/a</td>
<td>p=0.067</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
FIGURE 1- COUNTER FIT PLOT DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO MEAN ELEVATION (M) AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAIIL, BC IN 2018. DIAGONAL LINES REPRESENT MEAN HEIGHT (M), DEMONSTRATING INCREASED HEIGHT AS ASSOCIATED WITH INCREASED AGE AND REDUCED ELEVATION.
FIGURE 2- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO DRAINAGE AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAI', BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
FIGURE 3- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO BC BIOGEOCLIMACTIC VARIANTS AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAI, BC IN 2018. VARIANT 1 REPRESENTS SITES AT ELEVATIONS BETWEEN 0-350 M ABOVE SEA LEVEL, AND WITH WARMER AND DRIER CLIMATES. VARIANT 2 REPRESENTS SITES AT ELEVATIONS BETWEEN 350-600 M ABOVE SEA LEVEL, AND WITH COLDER AND WETTER CLIMATES.
FIGURE 4 - ANALYSIS OF COVARIANCE DEMONSTRATING MEAN LOGGED (X+1) YELLOW-CELER SEEDLING HEIGHT (M) AS RELATED TO ASPECT AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAIJI, BC IN 2018. ASPECT CLASSES WERE SIMPLIFIED SO THAT ALL NORTHERLY CLASSES WERE INCLUDED IN NE (NORTH-EAST), AND ALL SOUTHERLY ASPECTS WERE INCLUDED IN SE (SOUTH-EAST).
FIGURE 5 - COUNTER FIT PLOT DEMONSTRATING MEAN LOGGED (X+1) YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) (DBH) AS RELATED TO MEAN ELEVATION (M) AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAIIL, BC IN 2018. DIAGONAL LINES REPRESENT MEAN LOGGED DBH (CM), DEMONSTRATING INCREASED DBH AS ASSOCIATED WITH INCREASED AGE AND REDUCED ELEVATION.
FIGURE 6- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO DRAINAGE AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAI, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
FIGURE 7- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO BC BIOGEOCLIMACTIC VARIANTS AND AGE AT THE TRANSECT LEVEL ON HAIDA GWAI, BC IN 2018. VARIANT 1 REPRESENTS SITES AT ELEVATIONS BETWEEN 0-350 M ABOVE SEA LEVEL, AND WITH WARMER AND DRIER CLIMATES. VARIANT 2 REPRESENTS SITES AT ELEVATIONS BETWEEN 350-600 M ABOVE SEA LEVEL, AND WITH COLDER AND WETTER CLIMATES.
FIGURE 8- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO MICROSITES AND AGE AT THE SEEDLING LEVEL ON HAIDA GWAI, BC IN 2018. FOR A DESCRIPTION OF MICROSITES, PLEASE REFER TO APPENDIX D.
Figure 9: Distribution of survival rates of yellow-cedar seedlings as related to drainage class on Haida Gwaii, BC in 2018. Drainage class 1 represents best drained sites, whereas drainage class 3 represents worst drained sites.
FIGURE 10 - ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO DEER BROWSE BARRIER TYPE.
FIGURE 11- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-cedar SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO DEER BROWSE BARRIER TYPE.
Appendices

A. Full range of yellow-cedar

Adapted from U.S. Geological Survey, 1999
B. Yellow-cedar Regeneration Site Map, Haida Gwaii, British Columbia
C. Field Data Sheet

### Site Information (Office- SU level):

<table>
<thead>
<tr>
<th>Date:</th>
<th>SU:</th>
<th>Contractor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Licence No.:</td>
<td>PU:</td>
<td>Seedlot:</td>
</tr>
<tr>
<td>Permit No.:</td>
<td>Site Series:</td>
<td>Fertilizer:</td>
</tr>
<tr>
<td>Block No.:</td>
<td>Silviculture Label:</td>
<td>Distance From Coastline:</td>
</tr>
</tbody>
</table>

### Transect Information

<table>
<thead>
<tr>
<th>1. Coordinate N:</th>
<th>2. Coordinate N:</th>
<th>3. Coordinate N:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Coordinate W:</td>
<td>2. Coordinate W:</td>
<td>3. Coordinate W:</td>
</tr>
<tr>
<td>1.-2. (a) Distance (m):</td>
<td>2.-3. (b) Distance (m):</td>
<td>(c) Total Distance (m) (a+b):</td>
</tr>
<tr>
<td>(d) Total Area (c*2):</td>
<td>(e) Total YC Stems:</td>
<td>YC Density (d/e):</td>
</tr>
</tbody>
</table>

### Stem and Pair Analysis

#### Stem 1:

<table>
<thead>
<tr>
<th>Coordinates N:</th>
<th>Alive:</th>
<th>Pathogens/Fungi:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates W:</td>
<td>FG:</td>
<td>Barrier Presence:</td>
</tr>
<tr>
<td>Elevation:</td>
<td>Height (m):</td>
<td>Barrier Type:</td>
</tr>
<tr>
<td>Aspect:</td>
<td>DBH (cm):</td>
<td>Girdling:</td>
</tr>
<tr>
<td>Canopy Cover (%):</td>
<td>Leader Length (mm):</td>
<td>Barrier Removal Timing Info (office):</td>
</tr>
<tr>
<td>Microsite:</td>
<td>Leader Direction:</td>
<td></td>
</tr>
<tr>
<td>Slope:</td>
<td>Vigour:</td>
<td></td>
</tr>
<tr>
<td>Drainage:</td>
<td>Form:</td>
<td></td>
</tr>
</tbody>
</table>

#### Pair 1:

<table>
<thead>
<tr>
<th>Coordinates N:</th>
<th>Alive:</th>
<th>Pathogens/Fungi:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates W:</td>
<td>FG:</td>
<td>Barrier Presence:</td>
</tr>
<tr>
<td>Elevation:</td>
<td>Height (m):</td>
<td>Barrier Type:</td>
</tr>
<tr>
<td>Aspect:</td>
<td>DBH (cm):</td>
<td>Girdling:</td>
</tr>
<tr>
<td>Canopy Cover (%):</td>
<td>Leader Length (mm):</td>
<td>Barrier Removal Timing Info (office):</td>
</tr>
<tr>
<td>Microsite:</td>
<td>Leader Direction:</td>
<td></td>
</tr>
<tr>
<td>Slope:</td>
<td>Vigour:</td>
<td></td>
</tr>
<tr>
<td>Drainage:</td>
<td>Form:</td>
<td></td>
</tr>
</tbody>
</table>

#### Stem 2:

<table>
<thead>
<tr>
<th>Coordinates N:</th>
<th>Alive:</th>
<th>Pathogens/Fungi:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates W:</td>
<td>FG:</td>
<td>Barrier Presence:</td>
</tr>
<tr>
<td>Elevation:</td>
<td>Height (m):</td>
<td>Barrier Type:</td>
</tr>
<tr>
<td>Aspect:</td>
<td>DBH (cm):</td>
<td>Girdling:</td>
</tr>
<tr>
<td>Canopy Cover (%):</td>
<td>Leader Length (mm):</td>
<td>Barrier Removal Timing Info (office):</td>
</tr>
<tr>
<td>Microsite:</td>
<td>Leader Direction:</td>
<td></td>
</tr>
<tr>
<td>Slope:</td>
<td>Vigour:</td>
<td></td>
</tr>
<tr>
<td>Drainage:</td>
<td>Form:</td>
<td></td>
</tr>
</tbody>
</table>

#### Pair 2:

<table>
<thead>
<tr>
<th>Coordinates N:</th>
<th>Alive:</th>
<th>Pathogens/Fungi:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates W:</td>
<td>FG:</td>
<td>Barrier Presence:</td>
</tr>
<tr>
<td>Elevation:</td>
<td>Height (m):</td>
<td>Barrier Type:</td>
</tr>
<tr>
<td>Aspect:</td>
<td>DBH (cm):</td>
<td>Girdling:</td>
</tr>
<tr>
<td>Canopy Cover (%):</td>
<td>Leader Length (mm):</td>
<td>Barrier Removal Timing Info (office):</td>
</tr>
<tr>
<td>Microsite:</td>
<td>Leader Direction:</td>
<td></td>
</tr>
<tr>
<td>Slope:</td>
<td>Vigour:</td>
<td></td>
</tr>
<tr>
<td>Drainage:</td>
<td>Form:</td>
<td></td>
</tr>
</tbody>
</table>
D. Microsite, Vigour and Form Class Guidelines

<table>
<thead>
<tr>
<th>Microsite Variants</th>
<th>Vigour Variants</th>
<th>Form Variants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- slash/stump mound</td>
<td>1- strong</td>
<td>1- crook</td>
</tr>
<tr>
<td>2- soil mound</td>
<td>2- moderate</td>
<td>2- fork</td>
</tr>
<tr>
<td>3- well-drained flat grass</td>
<td>3- poor</td>
<td>3- sweep</td>
</tr>
<tr>
<td>4- grass bog</td>
<td>4- chlorosis (A (mild), B (moderate), C (severe))</td>
<td>4- scar/wound</td>
</tr>
<tr>
<td>5- sphagnum bog</td>
<td>5- necrosis (A (mild), B (moderate), C (severe))</td>
<td>5- undefined leader</td>
</tr>
<tr>
<td>6- dense slash</td>
<td>6- flagging (% cover indicated)</td>
<td>6- deer browse</td>
</tr>
<tr>
<td>7- crest/ hummock</td>
<td></td>
<td>7- deer browse barrier constriction</td>
</tr>
<tr>
<td>8- depression</td>
<td></td>
<td>8- dieback</td>
</tr>
<tr>
<td>9- grassy slope</td>
<td></td>
<td>9- fallen over (refers to the majority of the stem- typically associated with deer browse barrier failure)</td>
</tr>
<tr>
<td>10- adjacent to full slash pile</td>
<td></td>
<td>0- nothing, good form</td>
</tr>
<tr>
<td>11- toe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12- mossy slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13- bare slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14- bedrock/gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15- well-drained flat moss</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
E. Yellow-cedar free-to-Grow British Columbia Silviculture Guidelines (BC Forest Service, n.d.)

17. Potentially free growing trees

Tree 1 = Potential

Tree 2 = Potential

Tree 3 = Potential

C/B Ratio

Tree 4 = Free Growing

Tree 5 = Not Free Growing

Tree 6 = Not Free Growing

C/B Ratio

3.99m
18b. COASTAL Vegetation Competition Decision Key for a Free Growing Crop Tree

Must:
1) be Well Spaced
2) be Preferred or Acceptable Species – per SP, FDP or FSP
3) meet Damage Criteria
4) meet Minimum Height – if in SP, FDP or FSP

Is the site in BEC zone CDF, CWH or IDFww?

Is the Herb and/or Shrub vegetation taller than the crop tree in more than 1 quadrant?

Yes No

Does the crop tree meet the Conifer/Brush Ratio for any Broadleaf (including Mb and Act) vegetation?

Yes No

Not FG

Does the crop tree meet the Conifer/Brush Ratio for any Mb and Act vegetation?

Yes No

Not FG

Is there any Herb and/or Shrub vegetation taller than the crop tree in more than 1 quadrant?

Yes No

Does more than 1 quadrant contain any Broadleaf Dr, Ep, and/or Vb vegetation that is taller than the allowable Conifer/Brush Ratio?

Yes No

Potentially FG

1) Determine all Potentially Free Growing crop trees & calculate Median Height;
2) Count the Dr, Ep & Vb in 3.99 m. radius plot that are taller than the Median Height of the Potentially Free Growing crop trees.

Does the crop tree meet the Conifer/Brush Ratio for any Broadleaf, Herb and/or Shrub vegetation (including Mb and Act)?

Yes No

Is the number of Dr, Ep & Vb > the allowable from the table?

Yes No

Potentially FG

Crop tree species Biogeoclimatic Site Series Allowable countable Site Series

<table>
<thead>
<tr>
<th>Species</th>
<th>Subzone</th>
<th>Site Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fd, Hw, Cw, Ba, Ye, Sa, Pic</td>
<td>CWH dm, ds, m, xm</td>
<td>01</td>
</tr>
<tr>
<td>CWH dm, ds, m, xm</td>
<td>03</td>
<td>2 Dr, Ep, or 4 Vb</td>
</tr>
<tr>
<td>CWH xm1</td>
<td>03</td>
<td>1 Dr, Ep, or 2 Vb</td>
</tr>
<tr>
<td>CDF mm, IDF ww</td>
<td>01</td>
<td>2 Dr, Ep, or 4 Vb</td>
</tr>
<tr>
<td>All other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* When a survey unit contains more than one subzone or site series, use the lower countable broadleaf limit.

2014-02-14
21. Free growing acceptability guidelines for layer 3 and 4 advanced regeneration

<table>
<thead>
<tr>
<th>Species*</th>
<th>Ba, Bl</th>
<th>Cw**</th>
<th>Hm, Yc</th>
<th>Hw</th>
<th>Sx, Se, Sw</th>
<th>Fdi, Lw</th>
<th>Pa, Pli, Py</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEC Zones</td>
<td>All***</td>
<td>CWH, CDF, MH, ICH</td>
<td>CWH, CDF, MH, ICH (Pr. Rup.)</td>
<td>ICH (Other regions)</td>
<td>All*** (except BWBS)</td>
<td>All***</td>
<td>All***</td>
</tr>
<tr>
<td>Height at release</td>
<td>No height limit</td>
<td>&lt;0.5m</td>
<td>No height limit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scars and damage</td>
<td>All species: No open (unhealed) injuries; no closed (healed) injuries with a horizontal width at the widest point(s), which is greater than 25% of the circumference of the tree at that point; no closed injuries that exceed 10% of the total length of the stem; no stem infection caused by a stem rust or dwarf mistletoe; no other externally visible pathological indicators including broken top, frost crack, conk, extreme basal sweep or unacceptable forks a and crooks (see 23b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Continuous live crown | All species: An acceptable tree has greater than 30% continuous live crown. Continuous live crown is the length of continuous green foliage on a tree expressed as a percentage of its total height. Continuous live crown refers to foliage on adjacent live green branches that forms the main part of the crown of a tree and extends over at least half of the circumference of the tree. |

| Vigour | All species: Evidence of release (i.e., generally good post-harvest height increment) – Increased leader growth is not a requirement for trees in layer three and four in partial cut situations with low basal area removal where the trees remain heavily shaded by layer one and two trees. |

* For those species not listed here, the normal free growing acceptability criteria apply. At regeneration delay, consider whether naturals will meet these criteria by free growing. If western white pine (Pw) is to be considered, consult the Pine Stem Rust Management Guidebook.

** Beware of sun scald. If advance regeneration western redcedar is to be used, check for incidence of heart rot.

*** “All” refers to zones where these species are acceptable.
23d. Damage types

Crooks (old stumps)
A crook is unacceptable if it is displaced more than 30 cm and originates above 30 cm.

Defoliation, general
Defoliation is unacceptable if more than 80% of the needles are removed due to insects or disease.

Defoliation, for determinate growth species, (e.g. true firs, Douglas fir, spruces, pines)

1. Determine the % live crown.
2. Determine how many of the most recent 4 nodes have >50% of their foliage, express it as a %.
3. Step 1% x Step 2%:
   - for Dothistroma, in ICH, CWH and SBS >50% = acceptable
   - all other causes and biogeoclimatic zones >20% = acceptable

Forks

Wounds
Damage to the cambium or deeper is unacceptable where it is:
• more than one-third the circumference, or
• more than 20% of the height of tree.

Gall and Canker
Distance measurement from point of infection by canker or gall to main stem (measured along the branch).
F. All Figures Pertaining to Seedling Level Analysis as Demonstrated in Tables 1

EXHIBIT I-1A: ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR HEIGHT (M) AS RELATED TO ASPECT AND AGE ON HAIDA GWAI, BC IN 2018.
EXHIBIT II- 1B- COUNTER FIT PLOT DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR HEIGHT (M) AS RELATED TO ELEVATION (M) AND AGE ON HAIDA GWAII, BC IN 2018.
EXHIBIT III-1:C- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR HEIGHT (M) AS RELATED TO DRAINAGE AND AGE ON Haida Gwaii, BC in 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
EXHIBIT IV- 1:D- COUNTER FIT PLOT DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR HEIGHT (M) AS RELATED TO SLOPE (DEGREES) AND AGE ON HAIDA GWAI, BC IN 2018.
EXHIBIT V- 1:E: ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO MICROsites AND AGE ON HAIDA GWAI\, BC IN 2018. FOR A DESCRIPTION OF MICROsites, PLEASE REFER TO APPENDIX D.
EXHIBIT VI-1:I- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO DEER BROWSE BARRIER TYPE.
EXHIBIT VII- 2:A- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO ASPECT AND AGE ON HAIDA GWAIIL, BC IN 2018.
EXHIBIT VIII- 2:B- COUNTER FIT PLOT DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO ELEVATION (M) AND AGE ON HAIDA GWAI,, BC IN 2018.
EXHIBIT IX- 2:C- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO DRAINAGE AND AGE ON HAIDA GWAI, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
EXHIBIT X- 2:D- COUNTER FIT PLOT DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO SLOPE (DEGREES) AND AGE ON HAIDA GWAI; BC IN 2018.
EXHIBIT XI-2:E- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO MICROSITES AND AGE ON HAIDA GWAI, BC IN 2018. FOR A DESCRIPTION OF MICROSITES, PLEASE REFER TO APPENDIX D.
EXHIBIT XII- 2:I- ANALYSIS OF COVARIANCE DEMONSTRATING LOGGED (X+1) YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO DEER BROWSE BARRIER TYPE.

PLEASE NOTE THAT TABLE 1 CELLS: 3:A-E AND 4:A-E DO NOT HAVE CORRESPONDING FIGURES DUE TO THE NATURE OF THE STATISTICAL ANALYSES THAT WERE COMPLETED ON THESE DATA (CHI-SQUARED TESTING).
EXHIBIT XIV- 5:B- PREDICTED PROBABILITIES (WITH 95% CONFIDENCE) OF MORTALITY OF YELLOW-CEDAR SEEDLINGS GIVEN ELEVATION (M) ON HAIDA GWAII, BC IN 2018.
EXHIBIT XV- 5:C- PREDICTED PROBABILITIES OF MORTALITY OF YELLOW-CEDAR SEEDLINGS GIVEN DRAINAGE CLASS ON HAIDA GWAI, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
EXHIBIT XVI-5:D- PREDICTED PROBABILITIES OF MORTALITY (WITH 95% CONFIDENCE) OF YELLOW-CEDAR SEEDLINGS GIVEN SLOPE (DEGREES) ON HAIDA GWAIILI, BC IN 2018

PLEASE NOTE THAT TABLE 1 CELLS 5:E AND 6:A-E DO NOT HAVE CORRESPONDING FIGURES DUE TO THE NATURE OF THE STATISTICAL ANALYSES THAT WERE COMPLETED ON THESE DATA (CHI-SQUARED TESTING).
G. All Figures Pertaining to Transect Level Analysis as Demonstrated in Tables 2

EXHIBIT XVII- 1:A- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR HEIGHT (M) AS RELATED TO ASPECT AND AGE ON HAIDA GWAIJI, BC IN 2018.
EXHIBIT XVIII- 1:8- COUNTER FIT PLOT DEMONSTRATING MEAN YELLOW-CEDAR HEIGHT (M) AS RELATED TO MEAN ELEVATION (M) AND AGE ON HAIDA GWAI'I, BC IN 2018.
EXHIBIT XIX-1:C- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR HEIGHT (M) AS RELATED TO DRAINAGE AND AGE ON HAIDA GWAI, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
EXHIBIT XX- 1:D- COUNTER FIT PLOT DEMONSTRATING MEAN LOGGED (X+1) YELLOW-CEDAR HEIGHT (M) AS RELATED TO MEAN SLOPE (DEGREES) AND AGE ON HAIDA GWAI, BC IN 2018.
EXHIBIT XXI- 1:F- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO BC BIOGEOCLIMACTIC VARIANTS AND AGE ON HAIDA GWAI, BC IN 2018. VARIANT 1 REPRESENTS SITES AT ELEVATIONS BETWEEN 0-350 M ABOVE SEA LEVEL, AND WITH WARMER AND DRIER CLIMATES. VARIANT 2 REPRESENTS SITES AT ELEVATIONS BETWEEN 350-600 M ABOVE SEA LEVEL, AND WITH COLDER AND WETTER CLIMATES.
EXHIBIT XXII-1:G- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING HEIGHT (M) AS RELATED TO BC BIOGEOCLIMACTIC SITE SERIES AND AGE ON HAIDA GWAIIL, BC IN 2018.
EXHIBIT XXIII- 2:A- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO ASPECT CLASS AND AGE ON HAIDA GWAI, BC IN 2018.
EXHIBIT XXIV-2-B: COUNTER FIT PLOT DEMONSTRATING MEAN LOGGED (X+1) YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO MEAN ELEVATION (M) AND AGE ON HAIDA GWAI I, BC IN 2018.
EXHIBIT XXV- 2:C- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO DRAINAGE AND AGE ON HAIDA GWAII, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
EXHIBIT XXVI- 2:D- COUNTER FIT PLOT DEMONSTRATING MEAN YELLOW-CEDAR DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO MEAN SLOPE (DEGREES) AND AGE ON HAIDA GWAI, BC IN 2018.
EXHIBIT XXVII- 2:F- ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO BC BIOGEOCLIMACTIC VARIANTS AND AGE ON HAIDA GWAII, BC IN 2018. VARIANT 1 REPRESENTS SITES AT ELEVATIONS BETWEEN 0-350 M ABOVE SEA LEVEL, AND WITH WARMER AND DRIER CLIMATES. VARIANT 2 REPRESENTS SITES AT ELEVATIONS BETWEEN 350-600 M ABOVE SEA LEVEL, AND WITH COLDER AND WETTER CLIMATES.
EXHIBIT XXVIII-2: G - ANALYSIS OF COVARIANCE DEMONSTRATING MEAN YELLOW-CEDAR SEEDLING DIAMETER AT BREAST HEIGHT (CM) AS RELATED TO BC BIOGEOCLIMACTIC SITE SERIES AND AGE ON HAIDA GWAI, BC IN 2018.

EXHIBIT XXIX- 5:A- PROBABILITY OF SURVIVAL OF YELLOW-CEDAR SEEDLINGS GIVEN ASPECT CLASS ON HAIDA GWAI, BC IN 2018.
EXHIBIT XXXI: PROBABILITY OF SURVIVAL OF YELLOW-CEDAR SEEDLINGS GIVEN DRAINAGE CLASS ON HAIDA GWAI, BC IN 2018. DRAINAGE CLASS 1 REPRESENTS BEST DRAINED SITES, WHEREAS DRAINAGE CLASS 3 REPRESENTS WORST DRAINED SITES.
H. Vigour Analysis Simplification Code

If Vigour= “1” or if vigour= “6(1)” than Vigour Class= “strong”;

If Vigour= “2” or if Vigour= “6(5)” or if Vigour= “4A” or if Vigour= “4B” or if Vigour= “5A” or if Vigour= “5B” than Vigour Class= “moderate”;

If Vigour= “3” or if Vigour= “4C” or if Vigour= “5C” than Vigour Class= “poor”;

(Reference Appendix for description of Vigour Variants)
I. British Columbia Biogeoclimatic Zone Map of Haida Gwaii, with research site area indicated in green

Adapted from Banner et al., 2014