

**A Historical-Ecological Approach to Understanding the Effects of Timber Harvest on
Wa'uumst (Devil's Club, *Oplopanax horridus*) in Lax'yip Madii Lii**

by

Adrian Smith

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Abstract

Industrial land-use has had profound impacts on Indigenous peoples' homelands throughout Canada. Over the last century, logging practices in British Columbia have severed peoples' connections to the land-base, creating access challenges and disrupting the availability of important plant resources. Devil's club (*Oplopanax horridus*) is an important medicinal plant to communities in northwestern British Columbia, and there are mounting concerns about the impacts of logging on this ethnobotanically salient species.

Over the last 70 years, swathes of productive forests throughout Gitxsan homelands have been impacted by the logging industry. Wilp (house) Luutkudziiwus has seen ~12% of their territory of Madii Lii altered by industrial-scale clearcut logging, which has left a mosaic of even-aged cutblocks that have potentially altered devil's club habitat. To investigate and detail the potential impacts of logging on devil's club in Madii Lii territory, this research measured devil's club health and vigour across a chrono-sequence of clearcut-logged sites compared with traditionally managed and unlogged sites in the territory. In addition, Species Distribution Models in conjunction with two different climate change scenarios (SSP245 moderate GHGs and SSP585 high GHGs) were used to predict habitat suitability for devil's club in Madii Lii and throughout British Columbia to the end of the 21st century.

Results suggest that, compared to traditionally managed areas (and controls), extensive logging in the territory negatively impacted the health and vigour of devil's club, especially the most desirable individuals (with the largest and thickest stems). In addition, the predictive modelling for both climate scenarios suggest that climate change will increasingly impact high-quality devil's club habitat.

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Chapter 1

1.0 INTRODUCTION

The intergenerational transfer of cultural and spiritual knowledge about traditional medicinal plants is at grave risk due to deforestation and the increasing threat of climate change (Applequist et al., 2020; Buenz, 2005; Sharma et al., 2020). Millions of Indigenous peoples worldwide use traditional herbal medicines as their principal form of healthcare, and as a way of supporting their daily livelihoods. Up to 80% of the world's population depend on medicinal plants for healthcare and income generation (Farnsworth & Soejarto, 1991; Uprety et al., 2012; Zhang et al., 2002).

Since the imposition of colonial states and attendant resource extraction practices, Indigenous communities have witnessed dramatic changes in their landscapes. Globally, Indigenous peoples own and occupy over a third of the earth's remaining intact forested landscape (Fa et al., 2020). In regions where Indigenous peoples continue to maintain and steward their lands, forest biodiversity and productivity are overwhelmingly higher than in areas managed by state governments (Dawson et al., 2021; Garnett et al., 2018). For example, areas of rainforest cultivated and managed by Kayapo people in Brazil's Amazon Basin are more productive and have superior biodiversity value compared with the surrounding forest (Posey, 1984). Similarly, throughout the world, the use of fire stewardship in forested ecosystems by Indigenous peoples has maintained habitat heterogeneity and promoted biodiversity, whereas forested land that has undergone colonial/western-style fire suppression is now experiencing frequent abnormally severe wildfires, negatively impacting biodiversity (Bowman & Haberle, 2010; Hoffman et al., 2021; McWethy et al., 2019). Unfortunately, the practice of unrestricted legal and illegal deforestation continues to increase in order to support the expansion of

agriculture, mining, and oil and gas extraction. For example, in the Brazilian Amazon, annual deforestation dramatically decreased by 80% between 2005 and 2012, but since that low-point, deforestation in the area has increased by 122% per year in 2019 compared with 2012 (Carrero et al., 2020), significantly contributing to greenhouse gas emissions (GHGs) and disrupting global precipitation (Gedney & Valdes, 2000). Regrettably, similar stories of deforestation directly impacting Indigenous peoples are replicated worldwide and continue to threaten communities with alienation from their traditional lands. In many of these cases, Indigenous communities are at the forefront of maintaining impactful stewardship strategies, central to both long- and short-term climate change mitigation (Masson-Delmotte et al., 2021).

The global demand for timber and timber products has increased steadily, with a significant acceleration after World War II (McNeill & Engelke, 2016; Warman, 2014). In Canada, the timber harvesting industry underwent a period of rapid modernization in the 1950s. New mechanized equipment, such as skidders (high-clearance four-wheel drive tractors) and powerful diesel-fueled log-transport trucks, made previously inaccessible forest-stands possible to log. Coupled with the new equipment, the highly efficient method of harvesting known as clearcutting became popular. “Clearcutting” is described as *“the removal of the entire stand in one cutting, with reproduction obtained artificially (by planting or seeding) or by natural seeding from adjacent stands or trees cut in the clearing operation”* (Keenan & Kimmins, 1993, p. 122). In British Columbia (BC), clearcutting became common-place for the logging industry during the 1960s, and has left an indelible mark on the province that remains evident today.

Industrial tree-harvesting in northwestern BC has caused a myriad of detrimental impacts to forested ecosystems, such as slope failure and mass wasting events. For example, in Rennell Sound, Haida Gwaii, research showed that where logging and accompanying forest road

construction had occurred, there was a 34 x increase in landslide frequency and 31 x increase in sediment yield on disturbed areas (Schwab, 1983). Similarly, in 1994, 2.5 million m³ of debris was released during the Mink Creek landslide, near the town of Terrace. The failure occurred at the site of two clearcut harvesting events, one in 1981 and the second in 1985. The failure was likely caused by a combination of successive years of elevated precipitation and the liquefiable nature of the glaciomarine silty-clay sediments. However, the research also showed that almost half of the landslide area had been clearcut and that the retrogression was arrested at the interface with the intact mature forest (Geertsema et al., 2006).

In the Lakelse Lake area of the Skeena Region, the construction of over 300 km of forest access roads between 1964 and 1972 caused a dramatic increase in bedload sediments entering the river system, with associated channel instability, and damage to salmonid habitat (Gottesfeld et al, 2002).] Studies showed that 43 of the 64 stream reaches associated with the Lakelse watershed were highly impacted by logging-related sedimentation and had suffered a reduction in productive capacity (Rabnett, 2006).

For decades, government decision-makers and policymakers in British Columbia have argued that highly regulated forestry practices are sustainable and that they replicate the impacts of natural disturbances, or that silvicultural practices can lead to similar or even accelerate stand development (Kramkowski, 2012). In one example, Barker et al. (2014) argued that disturbances like fire and infestation have similar effects to clearcut logging, using the instance of the McLure Fire of August 2003 in central British Columbia. The study compared seedling establishment and growth performance in five disturbed areas, classified as High Severity Burn, Low Severity Burn, Clearcut, Screefed Clearcut, and Undisturbed Forest. The study found seedling growth in the Screefed Clearcut was comparable to the High Severity Burn treatment. Therefore, logging

can reproduce comparable effects to intensive wildfire regarding seedling establishment, growth and nutrition (Barker, et al. 2014). Increasingly, however, scientists recognize that these studies could be more robust and acknowledge the important role of forest dynamics such as soil nutrient change acidification and compaction and that critical temporal constraints are often ignored (Haeussler & Kneeshaw, 2003). When comparing clearcuts with intensive fires, stand-level disturbances are complex and can differ widely depending on biogeoclimatic zone, variant, elevation and aspect, and can be altered by additional factors such as pine beetle infestation (McIntire, 2001) and canopy-gap size (Coates & Burton, 1997). For the Interior Cedar-Hemlock biogeoclimatic zone, age-class data shows that fire return ranges from 101 years in the dry ICHdw subzone to 129 years in the ICHmw2 variant, to 226 years in the wet ICHwk1 variant (Pollack et al. 1997). However in the Arrow Forest District in southeast BC, disturbance estimated intervals vary dramatically within both the ICHdw subzone and the ICHmw2 variant, with ranges of 65–449 years and 97–458 years, respectively (Wong et al., 2003).

Industrial-scale logging in the Skeena Region of BC has generated economic growth for the region, and eventually led to the construction of the Columbia Cellulose pulp mill, which precipitated the expansion of the logging industry in the region (Wedley, 1990). From the 1950s onwards, the wage-labour economy played a progressively significant role for Indigenous communities and sustained local economies (Menzies & Butler, 2008). Many members of the Ts'msyen and Gitksan communities participated in forestry in the early industrial period. Some worked for Columbia Cellulose, which held the first Tree Farm Licence (TFL) and logged Nisga'a and Kitsumkalum territories during the 1960s and 1970s (Menzies & Butler, 2008). Nevertheless, debates continue to emerge about the industry's long-term viability, particularly

given the disparate wealth gaps it has created, and the boom-bust cycling of local economies and environmental impacts that are increasingly felt in an age of climate change.

To regulate industrial-scale logging, Forest Stewardship Plans (FSPs) are required prior to timber harvesting, and are meant to assess logging impacts on a range of values, including biodiversity, fish and riparian areas, soils, visual quality, water quality and recreation (BC Ministry of Forests and Range, 2009). Similarly, heritage impact assessments, legislated under the Heritage Conservation Act (1996), assess logging impacts on cultural and archaeological heritage, particularly Indigenous peoples' cultural heritage. Unfortunately, these pieces of legislation fail to address concerns and issues that arise from logging in areas where there are culturally valued plant species (Lepofsky et al., 2020). In Gitxsan contexts, concerns over the impacts of logging on devil's club (*Oplopanax horridus*) populations are not considered under any legislation or regulation. This is a troublesome gap, given the extreme value and salience of this plant for Gitxsan people, and the recognition that local access to desirable patches is diminishing.

In order to bridge this gap, this research attempts to quantify and qualify the potential impacts of logging on devil's club populations. Specifically, the purpose is to (1) bridge regulatory gaps in the impact assessment process, which divides cultural-ecological values, therefore omitting important components of logging impacts on Gitxsan health, well-being, cultural practices, and livelihoods; and (2) take a historical-ecological approach to assess logging impacts on devil's club over time. Temporal scales, as a component of cumulative effects, are often downplayed in the context of impact studies. As such, I use a chrono-sequence approach centred within the Luutkudziwus (Gitxsan) homeland of Madii Lii.

1.1 Background

1.1.1. *Ethnobotanical Context*

Devil's club, known as *wa'uumst* or *hu'ums* in Gitxsanimx or Gitksenimx, is a perennial, shade-tolerant, understory deciduous shrub that grows throughout northwestern North America, from lowland to subalpine zones, within coastal and mountainous temperate coniferous forests. It is generally found in greater profusion in regions with higher precipitation and on benches, alluvial fans, stream edges and seepages, and flourishes in calcareous soils (Alaback, 1984; Klinkenberg, 2021). Devil's club typically occupies canopy gaps in temperate forests with well-drained, moist, and nitrogen-rich soils (Hemstrom & Logan, 1986; Klinkenberg, 2021). This species occupies various environments and elevations from sea level to 2750 m, and often favours steep, north-facing slopes (Klinkenberg, 2021).

Devil's club produces long spiny stems, which can grow to 3 m tall but can grow up to 5 m in length, often developing along the forest floor in a recumbent position (Lantz, 2001; Lantz & Antos 2002). The stems are protected with thick, yellow spines 5–10 mm long, which can cause infection if left untreated (Drummond, 2018; Klinkenberg, 2021). The plant produces palmately lobed leaves, with between seven to nine lobes per leaf, ranging in size from 10 cm to 35 cm wide with a heart-shaped base (Klinkenberg, 2021). In the late spring the racemes elongate, up to 25 cm in length, and are covered with short-stalked, greenish-white flowers (Figure 1). Later in the summer, the flowers are replaced with bright red berries measuring 5–8 mm in length (Figure 2) (Klinkenberg, 2021).



Figure 1. Devil's club green/white flower, budding in early June. Photo by Haeussler S. (2023)



Figure 2. Devil's club red berries ripening in mid-August. Photo by Smith A. (2021)

As with many understory species with limited resources, vegetative reproduction is the primary source of expansion, and in this case devil's club, it uses clonal layering to reproduce.

Within a patch, new shoots or ramets attempt to occupy gaps to access sunlight, creating a network of crossing stems. Over time the combined weight of the stems forces the bottom-most stems into the soil and expands the patch (Pickett & Kempf, 1980; Roorbach, 1999). Eventually, these ramets produce their own root system and detach from the host plant, becoming a separate entity. In addition to vegetative reproduction, devil's club also possesses the ability to reproduce sexually, though it appears to be infrequent, and it is challenging to quantify how often it is successful (Kachel et al., 2006; Lantz 2001; Lantz & Antos 2002; Roorbach 1999).

Devil's club is used and named by 38 linguistic groups across northwestern North America (Turner, 2014). The healing properties of devil's club have likely been employed by Indigenous peoples over millennia, and remain one of the most commonly used medicinal plant species (Calway et al., 2012; Compton, 1993; Turner, 1982, 2014).

An early account of the medicinal use of devil's club was documented by the chief physician of the Russian-American Company, Eduardo Blaschke in 1842, who observed Tlingit using it to treat sores (Blaschke, 1842 *fide* Lantz et al., 2004). Decades later, anthropologist Harlan Smith, employed by the Canada Department of Mines and the National Museum of Canada, recorded Indigenous communities using devil's club for various medicinal purposes. His documentary films showed how members of Bella Coola (Nuxalk) Nation chewed devil's club bark to treat whooping cough (Smith, 1927b). Dakelh (previously Carrier) drank a tea made from crushed inner-bark as a purgative and as a treatment for dysentery (Smith, 1927a). Smith also recorded how Gitksan Elders made a decoction of boiled bark and twigs as a remedy for consumption (tuberculosis) (Smith, 1927c).

In 1982, renowned ethnobotanist Nancy Turner and her Indigenous colleagues catalogued the multiple ways devil's club is used by Indigenous peoples of the Pacific Northwest (Turner,

1982). Lantz et al., (2004) showed the variety of preparations derived from devil's club as treatments or medicines for more than 34 types of sicknesses or conditions, as well as many spiritual applications. Many of the treatments use a combination of inner bark, root, and root bark to treat arthritis, rheumatism, and diabetes. It is also used as a purgative, laxative, and analgesic for pneumonia, coughs and colds and used for sores, swellings, cuts, bruises and skin infections (Lantz et al., 2004; Turner, 2014). For Gitksan community members, devil's club is used to treat tuberculosis, gynecological issues, and venereal disease (Gottesfeld & Anderson, 1988a; Johnson, 2006a, 2013; Turner, 2014). [there should be semi colon between Johnson, 2006a and 2013 – they are separate references]. The use of devil's club as a treatment for diabetes is commonly cited by Gitksan and neighbouring Ts'msyen Elders (Johnson, 2006). The Northern Health Authority in British Columbia has begun experimenting with trials to support Elders in taking devil's club for diabetes. Over recent years there has been a burgeoning interest in the healing properties of devil's club and salves manufactured from devil's club under the commercially adopted names of "*Alaskan Ginseng*" and "*Pacific Ginseng*" (Lantz et al., 2004; Tilford, 1997; Vuksan et al., 2019).

Multinational pharmaceutical corporations have explored the phytochemicals extracted from devil's club to develop potential treatments for conditions such as cancer and diabetes (Calway et al., 2012; Cheung et al., 2015, 2019; Tai et al., 2014; Wang et al., 2013). Some of the most significant advances have been made in the treatment of colonic carcinoma cell apoptosis (Wang et al., 2019), pancreatic and ovarian cancers, as well as a potential treatment for Type II diabetes (Cheung et al., 2019; Elahmer, 2018; Yang et al., 2018).

In addition to the medicinal benefits and values of devil's club, the act of harvesting is recognized as a spiritually sanctioned practiced. Conventionally, only those considered to be

specialist medicinal practitioners are authorized to harvest devil's club, and generally prefer to harvest alone and in remote locations (Turner & Berkes 2006; Turner et al., 2004). Protocols for devil's club harvesting are complex and differ for different communities, however the concepts of sustainability and reciprocity are repeated throughout the Ts'msyen and Gitksan canon. For example, Gitga'at (Ts'msyen) protocols note that no more than four stalks should be harvested at a time and the harvester must offer a prayer or leave a gift of tobacco or a coin in the spot from where the plant was taken (Turner & Berkes 2006; Turner et al., 2004). In Haida culture, the numbers four and forty reoccur often and are regarded as having "power". For example, Haida fishermen and hunters would perform a complex ritual for good luck, taking 40 sticks of devil's club; each piece measured from the elbow to the fingertips. These sticks were pushed into the sand to form a circle, and the fisherman/hunter would sit inside. Next, they would use their teeth to gnaw four girdling strips of the inner bark from each of the 40 sticks and slowly chew and swallow them. The ritual would induce nausea and vomiting, eventually leading to a form of hallucination or shamanistic vision, bringing good luck to the trip, with the additional benefit of making the subject attractive to women (Curtis, 1916 *fide* Deagle, 1988).

Previous research indicates that the preferred (size) diameter of devil's club stems for medical or spiritual reasons is larger than 1" diameter (25 mm) (Burton & Burton, 2015). In addition to the significance of stem diameter, the harvest location is a central consideration (Johnson, 2006; Johnson, 2013). It is said that devil's club from higher (montane) elevations has a greater potency than that harvested at a lower elevation, because the brief growing season concentrates the active chemical compounds and the plant benefits from more intense ultra-violet light at higher altitudes (Larson, 1988; Turner et al., 2011).

1.1.2. Logging Context

Throughout British Columbia, forestry has dramatically altered the land cover, and land-use practices since the surge of settler colonial activity, beginning in the mid 19th century. For example, prior to 1827, the forests in the Lower Fraser Basin consisted primarily of coniferous stands on uplands and lowlands in the eastern portion of the basin (North & Teversham, 1984). By 1930, urbanization and agriculture had taken over much of the delta area and lowland near the Fraser River, and approximately 50% of the region's forests were cleared for agriculture. Most of the Sitka spruce (*Picea sitchensis*) and yellow cedar (*Callitropsis nootkatensis*) were removed (McCombs & Chittenden, 1990), while Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) comprised most of the remaining timber. Douglas-fir was common at low elevations, and western redcedar and hemlock was common at higher elevations (British Columbia Department of Lands, 1930). Over time, the less accessible cedar-hemlock forests became logged. By 1990, the amount of coniferous forest in the Fraser Basin had increased due to the reforestation policies implemented during the 1930s. However, the overall forested area (including deciduous forest) was significantly lower than before settler colonialism. Any remaining mature forest was primarily located at higher elevations or areas with challenging access (Boyle et al., 1997; McCombs & Chittenden, 1990). This sequence, of logging floodplains, valley bottoms, benches and lower-elevation shallow slopes, was replicated throughout the province, including in the Skeena Region of northwestern BC. Furthermore, by the 1960s, advancements in tree harvesting technology made accessing highly profitable cedar-hemlock timber from steeper and higher elevation terrain possible. Combined with the new practice of clearcut harvesting increasing threats to devil's club throughout British Columbia has been a concern.

Recently, forestry experts and resource managers have begun to recognize that the impacts of forestry may threaten devil's club habitat. For example, Canfor's Sustainable Forest Management Plan (SFMP) for the Prince George Region, states that ecosystems such as "Devil's club - Ostrich fern" are currently threatened ecosystems and should be protected during future forest harvesting (Kaye, 2012). In addition, the provincial government recognizes there are 8 blue-listed (considered to be of special concern) and 2 red-listed (candidates for extirpated, endangered, or threatened status) devil's club based ecological communities that are either rare or at risk (BC Conservation Data Centre, 2023). For example, red-list status has been designated for *Thuja plicata* / *Oplopanax horridus* / *Matteuccia struthiopteris* found in the ICHvk2/05 Biogeoclimatic Unit, which has been incorporated into the Provincial Forest and Range Practices Act (FRPA). The Act is intended to minimize the effects of forest and range practices on threatened species or habitat and specify a commitment to maintaining their current and historic ranges. Likewise, *Picea engelmannii* x *glauca* / *Oplopanax horridus* / *Hylocomium splendens* ecosystem found in the Biogeoclimatic Unit, SBSmc1/07 is also red-listed, but is yet to receive FRPA protection.

A study undertaken in the Lakelse-Kitimat River Valley over from 1986 to 1987 examined the effects of both natural disturbances and forestry on devil's club and thimbleberry (*Rubus parviflorus*). The study found that both thimbleberry and devil's club grew relatively better when canopy cover decreased due to disturbance. The study found that thimbleberry apportioned more of its resources to flowering within canopy-gaps, whereas devil's club showed an increase in leaf size. The results suggested that, as an early-succession species, thimbleberry was able to out-compete devil's club and better establish in the high-light disturbed habitat,

whereas devil's club was more slow-growing and arrived considerably later in the succession stage (Mason, 1990).

Other research in central British Columbia indicated that twenty years after clearcut logging and post-harvest slash burning, many understory plant species were able to recover. However, several key species, including white-flowered rhododendron (*Rhododendron albiflorum*) and devil's club, had yet to re-establish over the period of study (Chandler et al., 2017). Similarly, research undertaken in the Sitka spruce-western hemlock forests in southern Alaska found that salmonberry (*Rubus spectabilis*), Alaskan blueberry (*Vaccinium ovalifolium*) and red huckleberry (*Vaccinium parvifolium*) recovered within 30 years post-clearcutting. However, devil's club was only present in significant quantities in the mature even-aged forest between 100 and 250 years old (Alaback, 1984).

To date, there are only a handful of studies documenting the extent of timber harvest impacts on ethnobotanically important species for Gitxsan people, including devil's club. Previous research about the effects of clearcut logging on devil's club in British Columbia indicates a complex interplay of factors that affect the persistence and regrowth of devil's club after timber harvesting. During their research on Vancouver Island, Lantz & Antos, (2002) found that devil's club can persist through clonal expansion following clearcutting. However, there was significantly increased ramet mortality, and as could be expected, growth was slow in logged areas compared to unlogged areas. In a more recent study also located in northern Vancouver Island, Beese and colleagues (2022), observed that in four different silvicultural systems (clearcutting, patch cutting, dispersed retention, and shelterwood) adjacent to old-growth forest, the only shrub to exhibit continued adverse effects from logging was devil's club. For their pilot study in the Nass Valley near Terrace, Burton and Burton (2015) noted that the thickest stemmed

devil's club (over 25 mm diameter), which are preferred for traditional medicinal use, were uncommon and difficult to find in replanted forest-stands that were less than eleven years old. Further research in the Date Creek Experimental Forest in northwestern British Columbia indicated that devil's club had been negatively impacted by clearcut logging, during both initial logging events and during forest recovery (Lilles et al., 2018).

These findings leave outstanding questions about the impacts of logging on devil's club—particularly *how* populations are impacted and over what temporal range. Furthermore, most studies assessing the impact of logging on devil's club is relatively short-term (2–20 years). Lastly, BC is relatively culturally and biologically diverse, impacts studied on Vancouver Island, for example, do not necessarily scale up to studies in Gitxsan territories.

1.2 Research Objectives

This study aims to understand the effects of timber harvest on devil's club in Lax'yip Madii Lii, one of two territories of Wilp (house) Luutkudziiwus (Gitxsan), between Smithers and Hazelton, along the Suskwa River drainage in northwestern British Columbia. Concerns over logging in the region are not new. Objections to illegal logging and land theft in Gitxsan territories led to the precedent setting *Delgamuukw and Gisday'wa v. the Crown* (S.C.C.44) in the Supreme Court of Canada. For millennia, Gitxsan house groups, including Wilp Luutkudziiwus, have successfully managed their valued resources by increasing productivity of desired habitats for animals and plants, for food and medicinal purposes (Armstrong, 2017). However, clearcutting accelerated in the 1960s and continues to have compounding effects and impacts on the Madii Lii landscape. The near extirpation of the high-value western redcedar from Madii Lii, and the ongoing fragmentation of the Interior Cedar-Hemlock (ICH) biogeoclimatic zone (a preferred habitat for devil's club), has drastically reduced the principal environment where devil's club can flourish.

Today, the landscape is a patchwork of former cutblocks with immature and young pine forest dominating stands logged in 1970s and 1980s, through to grassy scrub communities, with sparsely scattered shrubs and herb assemblages from those sites logged in the late 1990s and 2000s. The logging industry may have reduced availability and possibly disrupted access (even with the construction of logging roads) to preferred devil's club harvesting sites, therefore impeding the transfer of significant cultural knowledge and practices concerning this valuable medicinal plant.

To assess logging impacts on devil's club in Madii Lii, I analyze devil's club distributions in relation to timber harvesting events and consider the health and vigour of patches throughout in the territory. Overall, the goal is to consider the role of logging history in shaping the structure of devil's club habitat, compared with sites that have been maintained by Luutkudziiwus, and without industrial logging.

With their determination to assert Aboriginal rights and title, promote a cultural resurgence, and engage with younger community members, in the last decade Luutkudziiwus leaders and house members constructed a culture camp, also called Madii Lii. The camp fosters pride in Gitksan history and promotes values, language, and cultural knowledge, and provides opportunities for members to re-engage in traditional practices and livelihoods such as fishing, hunting, and medicinal and food plant harvesting—including the harvest and preparation of devil's club. Without access to high-quality (e.g., thick-diameter stems, isolated stands) this fundamental knowledge is consistently challenged. Therefore, plant morphology data collected during the research process could be used as an inventory of the locations of the longest and thickest stemmed devil's club specimens in Madii Lii. In addition, these data make it possible to calculate the time interval required after logging before devil's club reaches the desired size for

medicinal and cultural use to be harvested; therefore, a harvesting schedule and land-use plan that consider important plants like devil's club could be generated to ensure future availability.

This research was designed to help inform Wilp Luutkudziiwus land-use planning objectives by identifying important aspects of devil's club habitat, distribution, and access. For example, data collected on stem length and diameter — both important characteristics for harvest — were assessed, mapped, and disseminated to house members. I also use species distribution models to assess where populations currently thrive, should thrive, and if/how those aspects of habitat determination will change under various climate change scenarios.

Table 1. Thesis research objectives and the research questions that need to be answered to achieve those objectives.

Research Objective	Research Question
1) Compile a series of recommendations for future forest management practices and landscape-level planning objectives concerning the health and location of culturally preferred devil's club specimens	a) What is the impact on devil's club caused by logging on the culturally salient medicinal plant for wilp Luutkudziiwus? b) Where are the locations of the most accessible devil's club plants of a preferred size suitable for cultural purposes?
2) Understand the local variation in the presence/absence of devil's club within Madii Lii	c) What environmental factors, such as slope, aspect, and elevation, play a role in the size of devil's club? d) What is the nature of the current access and availability of devil's club in the territory?
3) Understand the effects of logging on the abundance and morphology of devil's club in Madii Lii.	e) Compared to unlogged areas, is there a relationship between devil's club stem abundance, length and diameter in forest

	harvest cutblocks and the time since logging (TSL)?
4) Examine the effect of shade on the abundance and morphology of devil's club in Madii Lii.	f) Is there a relationship between leaf area and shade provided by the forest canopy? g) Is there a relationship between shade and devil's club leaf area, on devil's club stem abundance, length and diameter in forest harvest cutblocks from different TSL compared to the unlogged areas?
5) Use species distribution models to understand the projected impact of future climate change on devil's club's presence within Madii Lii and throughout British Columbia.	h) What is the current species distribution for devil's club in Madii Lii? i) What is the expected species distribution for devil's club based on climate change prediction models in Madii Lii and throughout British Columbia?

1.3 Species Distribution Models Literature Review

Species distribution models, also known as environmental (or ecological) niche models (ENMs), or predictive habitat models (PHMs), are used in biology, conservation ecology and quantitative ecology to project expected variations in the geographic ranges of species as the effects of global warming become increasingly apparent (Iverson & Prasad, 2001; Lawler et al., 2009; Thuiller, 2004; Thuiller et al., 2005). (Peterson et al., 2011; Peterson & Soberón, 2012). For example, SDMs have been useful for predicting potential extirpations and/or extinctions of species over broad time scales (Condro et al., 2021; Franklin, 2010; Gregory et al., 2012). By combining environmental, climate, and geospatial data describing the current range and habitat associations of a species, an ecological envelope is defined, and the probability of it persisting

within a distinct multidimensional environmental envelope can be determined (Bunce et al., 2013; Guisan & Zimmermann, 2000; Wong et al., 2007).

Conservation biologists and resource managers often use SDMs to determine the range of a species of particular interest, for example plant species that are used for food, technology, or medicinal purposes. In Egypt, a study used the SDM algorithm MaxEnt (Phillips et al., 2006) to generate species-richness maps for 114 medicinal plants growing in protected areas (Kaky & Gilbert, 2016). The SDM data showed that species richness was significantly higher in protected areas than outside, and conservation management—at least for those species—was effective (Kaky & Gilbert, 2016). In the Indian state of Jharkhand, researchers used SDMs to understand the impact of over-harvesting and changes in land-use and land cover on the deciduous tree species *Buchanania cochinchinensis* (Mishra et al., 2021). Indigenous peoples of the region use virtually every part of this plant for various medicinal purposes, including treatment of fever, ulcers, diarrhea, dysentery, asthma and snakebite (Siddiqui et al., 2014). The research determined where the region's most suitable habitat is today and identified potentially suitable sites on which to focus conservation planning in the future (Mishra et al., 2021). The pharmacologically and commercially valuable plant species American ginseng (*Panax quinquefolius*) has been grown commercially in China since the 1980s. However, cropping has become increasingly difficult in recent years due to continuous over-harvesting, soil degradation, and reduced genetic diversity (Cruse-Sanders and Hamrick, 2004). Therefore, researchers have generated SDMs using 37 ecological variables based on precipitation–temperature ratios to establish a suitable model to determine the location of potential new producing areas of American ginseng using the maximum entropy model. (Zhang et al., 2018).

A handful of studies have utilized SDMs to understand the impact of deforestation on culturally important and medicinal plant species (Benner et al., 2019; Nimasow et al., 2016; Wan et al., 2016). A study based in British Columbia's Great Bear Rainforest used SDMs to help predict the distribution of “monumental” western redcedar (Benner et al., 2019). The research showed that this culturally important tree was disproportionately affected by industrial logging and negatively impacted the traditional livelihoods of Indigenous communities in the region (Benner et al., 2019). Monumental redcedar are typically over 250 years old, and are exceptionally large, high-quality trees suitable for cultural purposes such as carving dug-out canoes and totem poles, and for building long houses (e.g., Garibaldi & Turner, 2004).

Recently the most common application for SDMs is for predicting future distributions of taxa which are confronted with the increasingly dire consequences of climate change. Researchers have used SDMs to determine the expected range of medical and culturally important plants growing within the Pacific Northwest (Bogawski et al., 2019; Hirabayashi et al., 2022; Mucioki et al., 2022; Prev  y et al., 2020; Prev  y et al. 2020b). For example, Prev  y et al., (2020a; 2020b) examined the potential impacts of climate change on three culturally relevant plant species (used for food and medicine) for Indigenous peoples across the Pacific Northwest, including beaked hazelnut (*Corylus cornuta*), Oregon grape (*Mahonia aquifolium*), and salal (*Gaultheria shallon*). In another study, researchers examined how change in weather patterns, precipitation, and temperature will affect the phenology of huckleberry (*Vaccinium membranaceum*) and how this will impact the range of this vital food source (Prev  y et al. 2020b).

Finally, with the simplification of SDMs and the perception that SDMs are now generating more accurate species distribution predictions, they have become increasingly

popular. Such modelling, provides conservation biologists with a valuable tool for planning the management of endangered species (Olden et al., 2010). However, some scholars have indicated that there are fundamental concerns about data availability and quality (Dormann, 2007; Santini et al., 2021). This suggests there could be a danger in over-relying on SDM when making critical decisions and shaping policy (Sinclair et al., 2010). All SDM research should be done critically and with all limitations honestly and succinctly laid out.

Chapter 2

2.0 RESEARCH METHODS

2.1 Introduction

To understand the effects of industrialized logging on devil's club over five decades, I used geospatial and statistical data analysis, and predictive habitat modelling methods based on field-data collected in Madii Lii in 2021 (Figure 5). I compared devil's club growing in timber harvested areas from decadal periods, beginning in the mid-1970s onwards until the last large-scale logging events in 2012. Timber harvest sites with devil's club were then compared with devil's club patches growing in relatively undisturbed sites (controls) and sites that were utilized by Gitxsan people, but had not been logged (e.g., cultural use sites, archaeological sites, etc.).

In order to achieve these objectives, I employed a four-phase approach. First, I characterized potential devil's club habitat to ascertain potential sampling locations. Second, I conducted fieldwork in the territory, searching potential sampling locations. Where devil's club was present, I collected habitat data and individual plant morphology measurements. Third, habitat and morphology data were analyzed to determine any correlations or patterns using the R Studio data analysis platform. Finally, devil's club species distribution models were constructed to map potential distribution under current habitat conditions and future climate scenarios.

2.2 Study Area

Madii Lii lies approximately 300 km inland from the British Columbian coastal port-city of Prince Rupert, within the Babine sub-basin watershed of the Skeena River, northeast of the town of Hazelton (Figure 3).



Figure 3. Madii Lii and the Northwest coast of British Columbia.

The Suskwa River watershed defines most of the borders around Madii Lii territory, which extends as far as the Suskwa-Bulkley Rivers confluence to the west, and the Babine drainage to the northeast. The highest elevation landform in the territory is found *Hahla Gyoot* (Thoen Mountain) at 2285 m in the Babine Range. The lowest point of elevation in the territory is where Fifteen-Mile Creek joins the Suskwa River at 360 m, with the mean basin elevation being 1160 m (Rabnett, 2018). The climate in Madii Lii is largely transitional, being warmer and wetter than the interior climate to the east but cooler and drier than the coastal climate to the west (Meidinger & Pojar, 1991). The territory is characterized mostly by the Interior Cedar-Hemlock

(ICH) biogeoclimatic zone (variants moist-cold-1 and moist-cold-2), representing the transitional influence of maritime and continental climates at lower elevations. Engelmann Spruce-Subalpine Fir Biogeoclimatic zone (ESSF) is strictly interior (continental) and reflects the mountainous terrain and shorter growing seasons found at higher elevations. The upper limits of the territory are characterized by treeless alpine tundra of the Boreal Altai Fescue Alpine (BAFA) Zone, which has more boreal (northern interior) affinities than coastal/southern interior mountains (Banner et al. 1993).

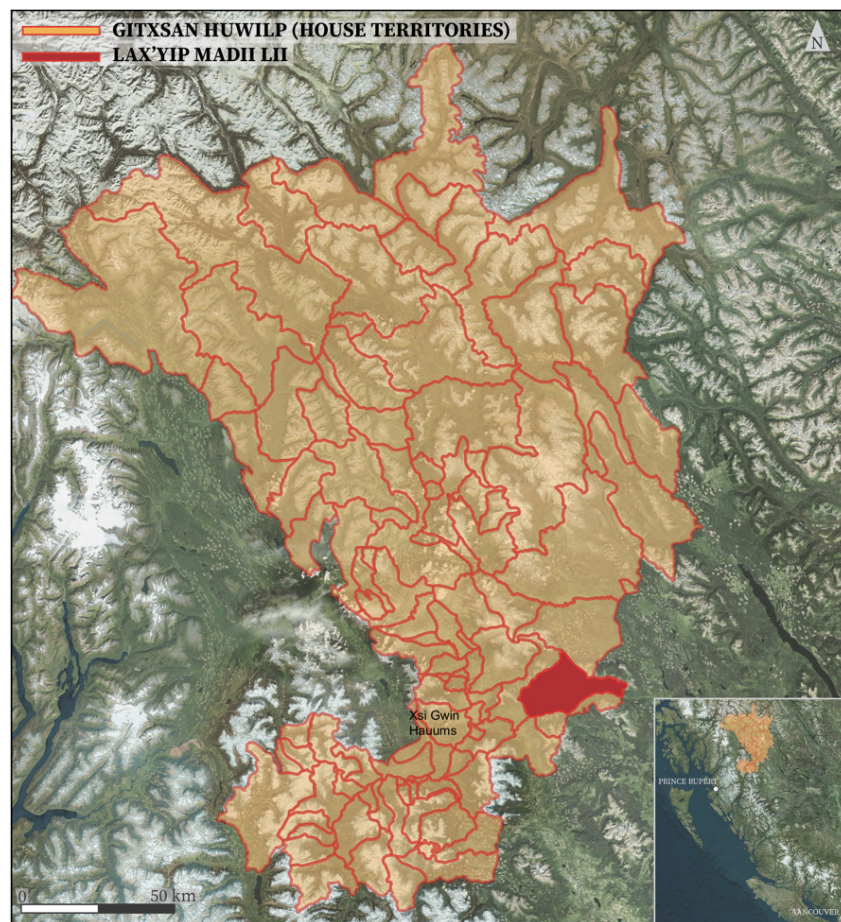


Figure 4. Luutkudziiwus' Xsi Gwin Hauums and Madii Lii territories.

Study sites were sampled within two ICH variants present in the territory: the Nass Moist Cold (mc1) variant and the Hazelton Moist Cold (mc2) variant. The dominant tree species in the ICH

zone are western hemlock (*Tsuga heterophylla*), spruce (*Picea*), lodgepole pine (*Pinus contorta* var. *latifolia*), and subalpine fir (*Abies lasiocarpa*). The ICHmc1 variant lies slightly higher than the ICHmc2, between 750 m and 1100 m. In the ICHmc1, seral species such as trembling aspen (*Populus tremuloide*) and paper birch (*Betula papyrifera*) are often found on southern aspects. Step moss (*Hylocomium splendens*), red-stemmed feathermoss (*Pleurozium schreben*), and knight's plume (*Ptilium crista-castrensis*) cover the forest floor, and the herb and shrub-layers comprise of black huckleberry, oval-leaved blueberry (*Vaccinium ovalifolium*), and false azalea (*Menziesia ferruginea*) (Banner et al. , 1993; Burton et al., 2000). The ICHmc2 subzone appears at 350 m lower elevation and consistently ascends to 750 m. At the lower elevations human activities occur more frequently. It differs mainly from the mc1 subzone due to the presence of small, scattered stands of western redcedar and also contains a much greater abundance of broad-leaved deciduous trees such as aspen, paper birch and black cottonwood. Similar to the mc1 variant, the most abundant ground cover is step moss, with herbs and shrub layers consisting of huckleberry and blueberry (Banner et al., 1993). The ICHmc1 variant blends into the Engelmann Spruce-Subalpine Fir (ESSF) zone at higher elevations (900 m-1300 m above sea level), depending on localized variations in topography, aspect, and microclimates. Subalpine fir and western hemlock co-dominate in this zone with lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*) interspersed throughout. The ground cover comprises of a mixture of red-stemmed feathermoss and leafy liverworts (*Barbilophozia* spp.). The shrub layer consists of black huckleberry and false azalea, with a variety of ferns, and five-leave bramble (*Rubus pedatus*) is a prominent species in the herb layer (Banner et al., 1993, Burton et al., 2000). The Boreal Altai Fescue Alpine (BAFA) zone is found at higher elevations above the timberline and supports small amounts of ground vegetation. Madii Lii's climate and

weather patterns are typically produced in the northeastern Pacific Ocean from the “Aleutian Low” This extratropical-low typically produces severe winter storms, often containing exceptionally high-moisture content, which precipitates as either rain or snow depending on local temperatures. The Suskwa Valley weather station (Environment Canada-107G879) is located adjacent to the Suskwa-Harold Price confluence at an elevation of 534 m. The 35-year record shows mean annual precipitation is 757 mm, of which 551 mm is rainfall and 206 mm as snow (Environment Canada 2010). Temperature measurements indicate the average minimum winter-low as -9.3°C, average winter-low of -6.4°C and the maximum summer-high of 20.8°C with the average summer-high of 14.5°C over the last 35 years (Environment Canada-107G879).

2.3 Site Selection

Madii Lii territory covers a 352 km² area, encompassing mountainous terrain and deeply incised valleys. There are over seven decades of logging history in Madii Lii territory, which has resulted in a patchwork mosaic of regenerating cutblocks at different stages of succession and forest recovery. To subdivide the territory into manageable sampling sites representative of the various stages and temporal scales, and to increase the likelihood of locating devil’s club patches, I compiled remote sensing data, habitat data, previous ecological studies in the region, and timber harvest data. A table was created to characterize accessible devil’s club habitat based on features such as slope, elevation, aspect, and logging history (Table 2). The table was compiled using data from United States Geological Survey (USGS) and mapping data acquired from the Province of British Columbia Ministry of Forest, Land, Natural Resources Operations and control sampling sites.

Table 2. Ecological criteria, parameters and analysis method to determine the location of control sampling sites.

Variable	Parameters	Analysis Method	Data source	References
Not Clearcut Logged	Sites that have not experienced clear cut logged	Visual assessment of satellite image	LandSat_8 (2018-07-27) WRS PATH 52 ROW 21	USGS satellite image Landsat 8
Forest type	Coniferous forest	Visual assessment of satellite image	LandSat_8 (2018-07-27) WRS PATH 52 ROW 21	USGS satellite image Landsat 8
Forest type	Coniferous forest	vector analysis	British Columbia Vegetation Resource Inventory	(British Columbia. FLNROD 2018a)
Age of stand	Lead species over 100 years old	vector analysis	British Columbia Consolidated Harvest Areas	British Columbia. FLNROD 2018b)
Dominant ICH tree species	Lead species is typically found in ICH mc1/mc2	vector analysis	British Columbia Forest Tenure License	(British Columbia. FLNROD 2017)
ICHmc1 elevation	750 - 1100m	raster analysis	Digital Elevation Model (DEM) T093M-25m resolution	(Canada 2019)
ICHmc2 elevation	350m-750m	raster analysis	Digital Elevation Model (DEM) T093M-25m resolution	(Canada 2019)
Slope	slope between 11 ⁰ and 35 ⁰ (avg 21 ⁰)	raster analysis	Digital Elevation Model (DEM) T093M-25m resolution	(Canada 2019)
North aspect	355 ⁰ - 0 ⁰	raster analysis	Digital Elevation Model (DEM) T093M-25m resolution	(Canada 2019)
Northeast aspect	0 ⁰ – 45 ⁰	raster analysis	Digital Elevation Model (DEM) T093M-25m resolution	(Canada 2019)
Water bodies	Within 50 m of moving or static water bod	vector analysis	British Columbia Rivers streams, lakes wetlands atlas	British Columbia. FLNROD 2018d) (Roorbach 1999)
located within 1000 m of Arterial FSR	Forest Service Roads (FSR)	vector analysis	British Columbia Forest roads atlas	(British Columbia. FLNROD 2018c)
located within 500 m of active/deactivated resource roads	Open or abandoned forest roads	vector analysis	British Columbia Forest roads atlas	(British Columbia. FLNROD 2018c)
located within 500m of trail system	Gitxsan Trails System	vector analysis	Gitxsan Cultural Heritage Trail System	(Rabnett 2018)
Edge effect mitigation	120 m wide buffer zone around internal perimeter of potential control site	vector analysis	120m <i>no-sample</i> edge zone within potential devil's club control sites	(Harper et al., 2005)

To further characterize and predict the location of typical devil's club habitat, supporting information was obtained from a variety of sources, including Biogeoclimatic Ecosystem Classification zones (BEC) program (BC Ministry of Forests and Range 2021). In addition, the vegetation tables from Banner et al. (1993) describe where and on which site-series devil's club is likely to occur in each biogeoclimatic variant and in what relative abundance. I also assessed research such as MacKinnon et al. (1992), Lantz and Antos (2002), Burton and Burton (2015), and Mackenzie and Meidinger (2018) to further refine my search areas for representative devil's club habitat. These locations meeting the criteria outlined in Table 2 were then overlaid with the Kispiox Predictive Habitat Mapping (PHM) used for grizzly bear habitat modelling, which provided a high-resolution, site-series description of the habitat and ecology of the region (Hanchard, 2021). These GIS data were then processed to identify potential devil's club habitat and sampling sites within the ICH mc1 and ICH mc2 BEC zone using a weighted overlay (ArcMap, 2021). Because access to field sites containing devil's club was essential for the research, but also for Luutkudziiwus community members for their continued access to high quality harvesting opportunities, the distance from Gitxsan trail system (500 m buffer) and forest roads (1000 m buffer) was used as a matrix parameter to determine potential field-sampling locations.

In order to assess the effects of logging on devil's club habitat, timber harvest data from Harvested Areas of BC (FLNROD 2018b) was used to build a geodatabase of timber harvest events in the territory, what we refer to as *Time Since Logging* (TSL). To compare areas that have been logged with areas that have not (i.e., controls) we referenced the Vegetation Resources Inventory (VRI) Province of British Columbia (FLNROD 2018a). We selected each sample site based on logging events over four ten-year period intervals: 1970–1979, 1980–1989, 1990–1999,

and 2000–2012. Throughout the subsequent chapters, I refer to these as “groups”, that is, Group 1 (1970–1979), Group 2 (1980–1989), Group 3 (1990–1999), and Group 4 (2000–2012), (Figure 5).

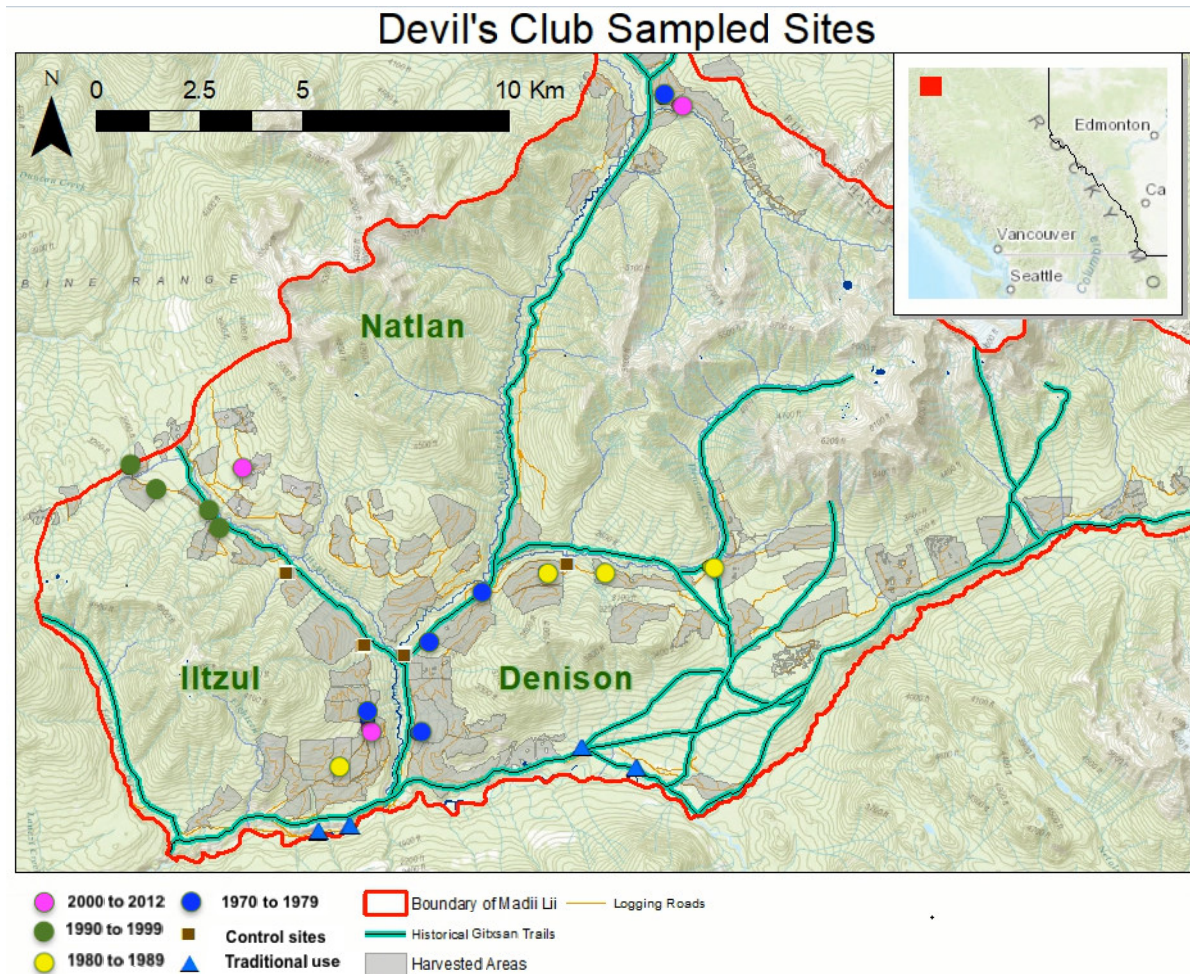


Figure 5. Devil's club sampling sites (24) on Luutkudziiwus traditional territory Madii Lii.

All preferred habitat data and timber harvest history data were then overlayed to recommend potential sampling sites and control sites. It was apparent that many of the potential control sites were adjacent to timber harvested areas, so a buffer zone of 120 m was established around all potential control sites to reduce the influence of any edge effects (e.g., higher light or wind due to nearby canopy removal, drainage impacts, etc.).

Fifty potential sample sites were identified using ArcMap 10.8.1 as either control sites or logged sites, including 8 control sites, and 42 logged sites from 1970–1979 (n=12), 1980–1989 (n= 12), 1990–1999 (n=12), and 2000–2012 (n=6). In addition, I selected four (n=4) samples sites that were neither logged, nor technically “controls” but had undergone land-use changes by Wilp members over the last 200+ years. These “traditional use” sites are located near to the Suskwa River, along the ancient Gitxsan trail system, now known as The Babine Trail, as well as near archaeological village sites and sites with important place names, such as *Nox*, *Nox Lobbit* (“Faces of Our Ancestors”).

2.4 Data Collection

Field data were collected in June 2021. A visual assessment of the pre-selected sites (50 sites) was undertaken to confirm the accessibility to the site and the presence/absence of devil’s club. In total, 24 suitable sites (26 sites were unreachable due to access issues) were sampled (Figure 5), including: 4 control sites, 4 traditional-use sites, and 16 timber harvest sites from 1970–1979 (n=5), 1980–1989 (n= 4), 1990–1999 (n=4), and 2000–2012 (n=3). The logged stands sampled ranged between approximately 20 ha and 60 ha with a mean area of about 40 ha, with forest stands identified as control sites and traditional use sites being considerably smaller. At each site, I recorded the location (at the mid-point of the site perimeter, at the 30 m mark perpendicular to the forest road) and elevation, and surveyed the area for devil’s club (presence/absence). Tree cover at each site was described by percent cover of tree species in the overstory and was estimated visually. A general description of the site was noted (evidence of burning, proximity to water, understory shrubs), but was not used in analyses. At each site, four circular plots were sampled at 20 m intervals on an 80 m transect (Appendix 1). Each plot had a 5.64 m radius,

equating to a total sampling area of 100 m² plot (0.01 ha). Where devil's club was absent, a maximum of two plots were sampled. At each plot I recorded (1) a range of ecological variables, (2) devil's club presence/absence and cover, and (3) in each plot a series of morphometric measurements were taken as a proxy for devil's club health and vigour.

2.4.1. Ecological Variables

At each plot, I characterized ecological and geophysical characteristics, including 1) forest type, (e.g., coniferous, deciduous or open), (2) dominant tree species in descending order of frequency, (3) slope, (4) aspect, (5) canopy closure, and (6) understory plant assemblages. The slope was obtained using the Measure® software application on an Apple iPhone. Each plot's location, elevation; and aspect were recorded by using the applicable functions available on a Garmin handheld GPS. Canopy openness was measured using the %Cover™ (version 2.1) canopy application on an Apple iPhone. The phone/camera was placed at the centre of the plot at shoulder height, and 4 photos were taken from different directions and a mean value of percent canopy cover was determined. The software immediately processed the image for light and shade and then expressed the amount as a percentage, and it was then recorded onto the datasheet. To describe the relative ground cover for understory species of shrubs, herbs, mosses and lichens, I used the Cover Abundance Scale (Blanquet 1964) method. The Cover Abundance Scale uses a 1–5 ranking system, where : 5 = >75 percent cover; 4 = 50-75 percent cover; 3 = 25-50 percent cover; 2 = 5-25 percent cover; 1 = numerous, but less than 5 percent cover, or scattered, with cover up to 5 percent. Any unidentified specimens were photographed for later identification, and any presence of water, either flowing or standing water were recorded.

2.4.2. Presence-Absence Data

At each plot, devil's club presence-absence and stem abundance was recorded. Only devil's club stems greater than 30 cm in length (including recumbent stems) were recorded, because the stem diameter measurement was taken 30 cm above the stem base. Therefore, any specimen plant < 30 cm height would not be able to have its diameter recorded. However, to ensure that all presence-absence data was recorded, any stems < 30 cm were noted separately and recorded and included in presence-absence modelling

2.4.3. Devil's Club Measurements

In each plot, a series of morphometric measurements were taken as a proxy for devil's club health and vigour (Dawe et al., 2017). New growth was measured from the leaf scars defining the end of the previous year's growth to the tip of the terminal bud using a flexible centimetre measuring tape. The stem diameter was measured at 30 cm above the base of the stem with digital-calipers. A representative sample of four leaves was removed from each plot, then labelled and measured for leaf area. The four representative leaf samples were obtained by taking a single large leaf from a plant in each quadrant of the plot (wherever possible), and if there was not an available plant in each quadrant, the next-nearest plant was selected. All the leaf samples which had been collected and labelled earlier in the day were processed at the fieldwork accommodation camp in the evening. The samples are positioned flat on a whiteboard, and leaf area was then calculated using the iPhone application LeafByte™ (version 1.3.0) (Getman-Pickering et al., 2020). Four dots surround the leaf in a square; these constitute the scale for area calculations; a 30 cm square frame was used for most of the larger leaves and 20 cm for the smaller samples. The four dots gave a frame of reference for determining absolute areas in the image and for image-size correction if the image was taken at an angle. A photograph was taken,

and the image was processed to provide leaf area in cm², and the results were recorded in a spreadsheet for later analysis.

2.5 Data Analysis

Site-level data (slope, elevation, tree cover, plant assemblages) were analyzed and assessed along with plot data (devil's club stem length, stem diameter, stem abundance, leaf area, and shade), and site use history (e.g., control, traditional use, or timber harvest site). The statistical analysis software environment R Studio Version 4.1.1 (*R Core Team*, 2021) was used for all data analysis. A Shapiro-Wilks (1965) test was employed to examine the distribution normality of stem abundance, stem length and stem diameter.

Due to the non-normal distribution of the data, a non-parametric significance test (Kruskal-Wallis, 1952) was used to evaluate the effect of time since logging (TSL) or stand-age/time since disturbance (TSD) on plot-level data. Then a posthoc Dunn (1964) test was used to test for any significant relationships between individual pairs (e.g., control sites with Group 1). I then used the Bonferroni-Holm method (Holms, 1979) p-value adjustment to adjust for multiple comparisons. To illustrate the effect of site history on stem abundance, stem length, and stem diameter, a series of boxplots were generated. Next, a Spearman Rank Correlation Test package (Savicky, 2022) was used to identify any relationship between pairs of these three variables.

It was expected that site-elevation would have a confounding effect on the data with regards to devil's club presence/absence, stem abundance, stem length, and stem diameter when comparing sites which experienced different histories –Time Since Logging (TSL) and stand age/Time Since Disturbance (TSD). Therefore, testing was performed on the TSL (industrial-scale logging) and stand age/TSD for control and traditional use sites while controlling for the

influence of elevation on the morphometric variables. First, the normality of distribution was tested using the Shapiro-Wilks test. To examine the relationships between TSL and elevation on stem abundance, stem length, and stem diameter, a Kendall-Theil Sen Siegel non-parametric analysis of covariance (Siegel, 1982) was employed in conjunction with the R Studio Median Based Linear Models (mblm) package (Komsta, 2013). The mblm analysis provides linear models based on Theil-Sen single median, and Siegel repeated medians. This formula provides a robust 29 or 50 percent breakdown point, respectively. For each point, the slopes between it and the others are calculated (resulting $n-1$ slopes) and the median is taken. This results in (n) medians and median from this median then calculates the slope estimator. Consequently, the only additional values provided are slope and the intercept, and it does not provide a Multiple R-squared value. Therefore, to attain an R^2 value a pseudo-R-squared value was generated with the R-Studio script “*efronRSquared*” (Mangiafico & Mangiafico, 2017)

Finally, given devil’s club proclivity for shaded environments, I tested stem abundance, stem length, stem diameter, and size of individual leaves as relates to tree cover by using Spearman correlation. Due to the non-normal distribution of the data, any regression analysis required non-parametric tests. Kendall-Theil Sen Siegel non-parametric analysis of covariance was performed for each variable. Finally, the frequency of devil’s club occurrences was analyzed with respect to the presence of the differing tree species associated with each plot and was illustrated with a bar chart.

2.6 Species Distribution Modelling

The final component of this research was to determine current devil’s club habitat availability in Madii Lii and for its potential distribution across the province of British Columbia, and to assess

how habitats may be altered due to impacts from climate change. To do this, I used the presence-absence data from the fieldwork to create a species distribution model for Madii Lii and data from the online repository Global Biodiversity Information Facility (GBIF) (www.gbif.org, 2022) to create a species distribution models for devil's club throughout British Columbia. In addition, all modelling bioclimatic data was retrieved from the WorldClim® (worldclim.org) global data-repository (Fick & Hijmans, 2017). To generate the SDMs, a workflow employing computational operations was performed in the R version 4.1.1 environment (R Core Team 2021) in a stepwise procedure that incorporated several statistical analysis packages. In preparation for the modelling, a map representing Madii Lii and devil's club presence-absence data-points recorded during the data collection was generated in ArcMap 10.8.1 (ESRI, 2020) (Figure 6.). The SDM modelling package “*dismo*” version 1.3.5 (Hijmans & Elith, 2021) was used as the foundation for model development on the R Studio platform. The “*dismo*” (version 1.3.5) package applied several species distribution model profiles, BIOCLIM (Nix, 1986) and Domain (Hijmans, 1996) models, and also provided a link from the R environment to the

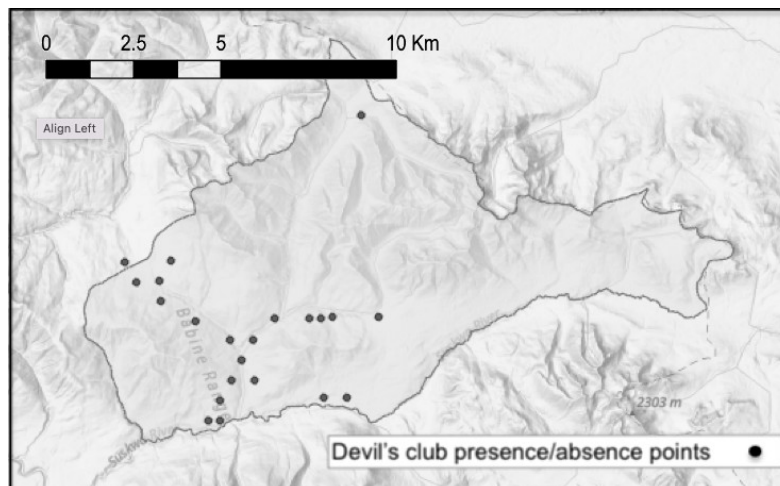


Figure 6. Devil's club species occurrence within Madii Lii recorded during fieldwork data collection in June 2021.

maximum entropy 'MaxEnt' (version 3.4.3) model (Phillips et al 2006) General Linear Regression/Gaussian (GLM) model (McCullagh & Nelder, 1989), and the Support Vector Machine (SVM), (Vapnik, 1998) models. Hence, all five SDM model profiles were used during the model generation process. The stepwise process was as follows: (1) BIOCLIM analysis used the 17 bioclimatic variables derived from WorldClim 2 (www.worldclim.org) model for the current period (1970-2000) to derive the entire dataset to generate the initial base SDM, and was visualized with seventeen individual graphic outputs displaying each variable (www.worldclim.org; Fick & Hijmans, 2017) (Appendix 2). (2) Having generated the multiple BIOCLIM outputs, the data were then used to extract raster values and generate data points assigned to the bioclimatic variables as predictors. (3) The model algorithm then used the BIOCLIM layers to generate testing and training points from the presence-absence data collected during fieldwork, and these points were then used to evaluate the model-quality by producing a Relative Operating Characteristics (ROC) plot.

The Relative Operating Characteristics (ROC) plot indicates the quality of the model, initially for the BIOCLIM, then for subsequent model profiles. The model output was assessed using the Area Under Curve (AUC) for the receiver operator curve (ROC). The AUC is a measure of rank correlation. The higher AUC indicates that sites with high predicted suitability values are areas of known presence. A satisfactory AUC value would range from 0.6 to 0.7 for the model. When AUC is approximately 0.5, the model has no discrimination capacity to distinguish between positive class and negative class. The higher the AUC, the better the model performs at differentiating between the positive and negative classes. (4) A response plot was produced to show the relationship between the probability of the occurrence of devil's club with

each environmental variable. The plots then indicated which variable had the most influence on devil's club distribution. (5) The Domain, GLM, MaxEnt and SVM models were tested, and their AUC output values were compared with each other to ascertain which was the best performing model (Appendix 4). (6) The "average score model" was produced by combining the output from BIOCLIM, Domain, GLM, and SVM. In addition, a weighted mean of three models (BIOCLIM, GLM and SVM) was also generated but was not used (Appendix 5).

2.6.1. Madii Lii Predicted Habitat Model

In order to estimate the future availability of devil's club in Madii Lii for Luutkudziiwus community members, I generated species distribution models for two different climate scenarios. This analysis used the Shared Socioeconomic Pathways (SSPs) scenarios (Riahi et al., 2017; IPCC AR6 2021) to illustrate how global warming and the subsequent disruption to localized weather patterns may affect devil's club viability within the territory and the species range provincially. The analysis used the Future climate projection from Canadian Earth System Model version 5 (CanESM5) Swart et al., (2019) in conjunction with the Shared Socioeconomic Pathway (SSP) as the basis for climate modeling. The analysis uses five different scenarios, SSP1–SSP5, based on projected global socioeconomic changes (used as a predictor for variability in greenhouse gas emissions) from the present day through to the end of the 21st century. SSP126 represents current conditions in 2022 with approximately 420 ppm atmospheric carbon, which was used as the baseline for the current conditions and an increase of 1.7° C by 2040. For the predictive habitat modelling, I used the scenarios SSP245, intermediate GHG emissions: CO₂ emissions remain around current levels until 2050, then falling but not reaching net zero by 2100, with an expected increase in temperature ranging from 2.0° C to 3.5° C by the end of the century. For the worst-case scenario I selected SSP585, very high GHG emissions:

CO₂ emissions triple by 2075, which leads to predicted global temperature increasing from 3.3° C to 5.7° C (CarbonBiref.org 2018). By using the species distribution models generated from the previous section and then employing future scenario simulations SSP245 and SSP585, I provided predicted future habitat suitability for devil's club. The presence-absence data collected during the fieldwork in June 2021 were used to construct the models for Madii Lii and presence data obtained from GBIF repository for British Columbia (GBIF.org, 2022) with the current condition SDM, the BIOCLIM model was used to generate the first model and allowed me to evaluate which of the 19 variables contributed the most influence over the presence of devil's club. The model was then assessed using the AUC value. Using the data obtained from the BIOCLIM model, I then ran the Random Forest (Breiman, 2001) and MaxEnt models, and performed evaluation using the AUC score to determine which model performed best. Random Forest was then selected to produce the predictive SDM modelling for the climate scenarios. I then created predictive habitat suitability models for both (SSP245 and SSP585) for each 20-year period, 2021–2040, 2041–2060, 2061–2080 and 2081–2100 using the Random Forest model.

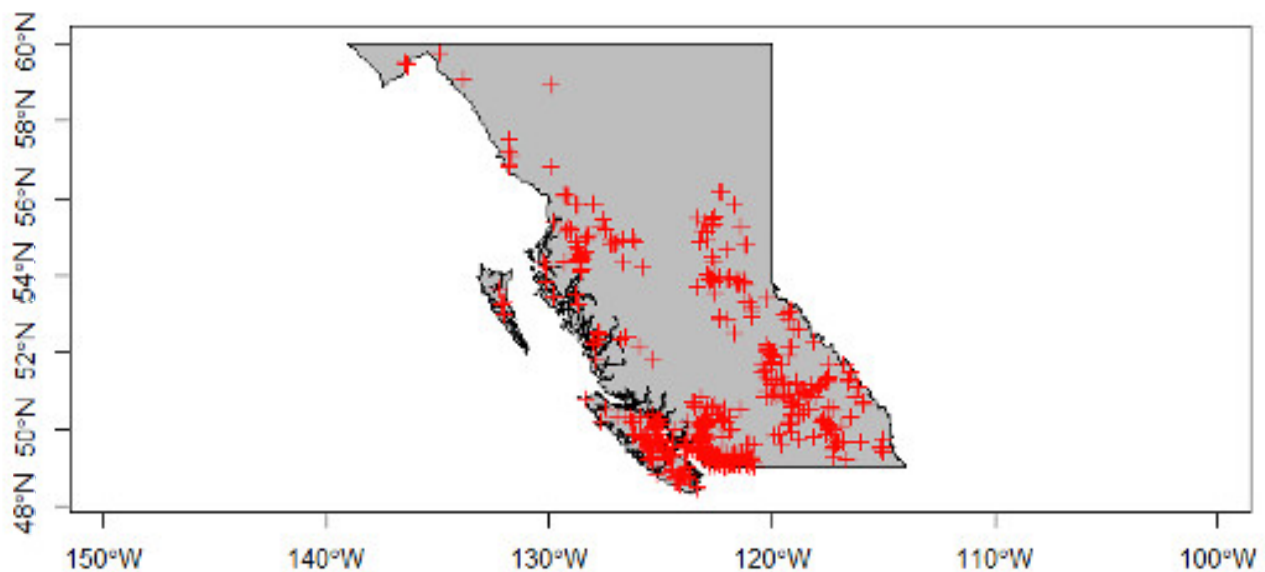


Figure 7. British Columbia recorded locations of devil's club within the province (www.gbif.org, 2022).

2.6.2. British Columbia Predictive Habitat Model

Species distribution and habitat suitability models were generated to illustrate where devil's club can be expected to persist and/or change distributions within the Province of British Columbia under two predicted climate change scenarios. As with the climate change predictive models generated for Madii Lii, I employed the moderate carbon increase level scenario SSP245 and the worst-case scenario model SSP585. First, I defined the British Columbia boundary in ArcMap 10.8.1 and obtained devil's club presence data from the Global Biodiversity Information Facility (GBIF) (www.gbif.org) (submitted by iNaturalist membership, and concentrated around population centers) within that geographical territory (3642 occurrences within North America). I then clipped the species occurrence data to include only presence data that occurred within British Columbia (1600 occurrences) (Figure 7). The 19 bioclimatic variables were employed to generate the testing and training model and to generate the dataset using the k-fold cross-validation. For the devil's club predictive model to be accepted as being applicable, a rigorous k-fold test was performed. This technique ensured that each observation from the training and testing dataset which determined the presence or pseudo-absence (otherwise known as background data points) had a reasonable probability of appearing in the k-fold cross-validation. For this scenario, 5-fold cross-validation (k=5) was used. The test and train dataset were then applied to the base SSP126 (2021–40) climate scenario using the BIOCLIM profile to produce a base model for current conditions for British Columbia. The next operation was to generate the Maxent environmental bioclimatic variable contribution table/graph, and the derived environmental bioclimatic variable response plots for the Maxent predictive habitat model for SSP126 (2021–40). The MaxEnt model was then evaluated for accuracy using the AUC output value.

To ensure that the research produced the most accurate predictive model possible, both the Random Forest (Breiman, 2001), and Support Vector Machine (Vapnik, 1998) profiles were tested and compared using their AUC scores as indicators for best model fit. As Random Forest returned the best performing model, it was then used to complete the predictive habitat suitability models for both scenarios. Predictive habitat suitability models were generated for both (SSP245 and SSP585) for each 20-year period, 2021–2040, 2041–2060, 2061–2080 and 2081–2100 using the Random Forest model profile.

Chapter 3

3.0 RESULTS

In this chapter, results are summarized in two sections. In the first, I present results of field data collection and analyses, including comparisons of devil's club habitat and morphology across sites with different land-use histories. Second, I present a series of predictive habitat models for devil's club in Madii Lii and across British Columbia. These models are meant to evaluate where suitable devil's club habitat will persist and occur under various climate change scenarios at both a regional and continental scale.

3.1 Devil's Club Morphometric Analysis

Devil's club was present in all three site types: traditional use sites, timber harvest sites, and unlogged control sites. The Shapiro-Wilks test reveal that values for devil's stem abundance, stem length and stem diameter at all sites were not normally distributed (Appendix 3). As non-parametric analyses were required for these data, the one-way Kruskal-Wallis test was combined with the Dunn post-hoc test for multiple comparisons of groups. Furthermore, the Kendall-Theil Sen Siegel non-parametric linear regression models were favoured for evaluating devil's club stem abundance, stem length and stem diameter throughout the analysis.

3.1.1. Abundance, Stem Length, Stem Diameter

The results shows there is a significant difference ($p = 0.0019$ H -test = 18.985, $df = 5$) in devil's club stem abundance across the three sampled site types (timber harvest, traditional use, and controls). Devil's club stem abundance was not significantly different across the five decades of timber harvest sites. The plot shows there is fewer stems in the 1970s sites than in the 1980s then there was a gradual decrease in the abundance of stems from timber harvested sites in most

recently logged cutblocks in the 2000s. The Dunn's post-hoc test indicates devil's club stem abundance is significantly greater (Table 3) in traditional use sites than in all timber harvest sites. There is no significant difference between the control sites and timber harvest sites, but there is between the control sites and traditional use sites (Table 3). The traditional use sites group showed a median abundance of 15 stems/100 m² plot, which is considerably more than that of the harvested and control areas (Figure 8).

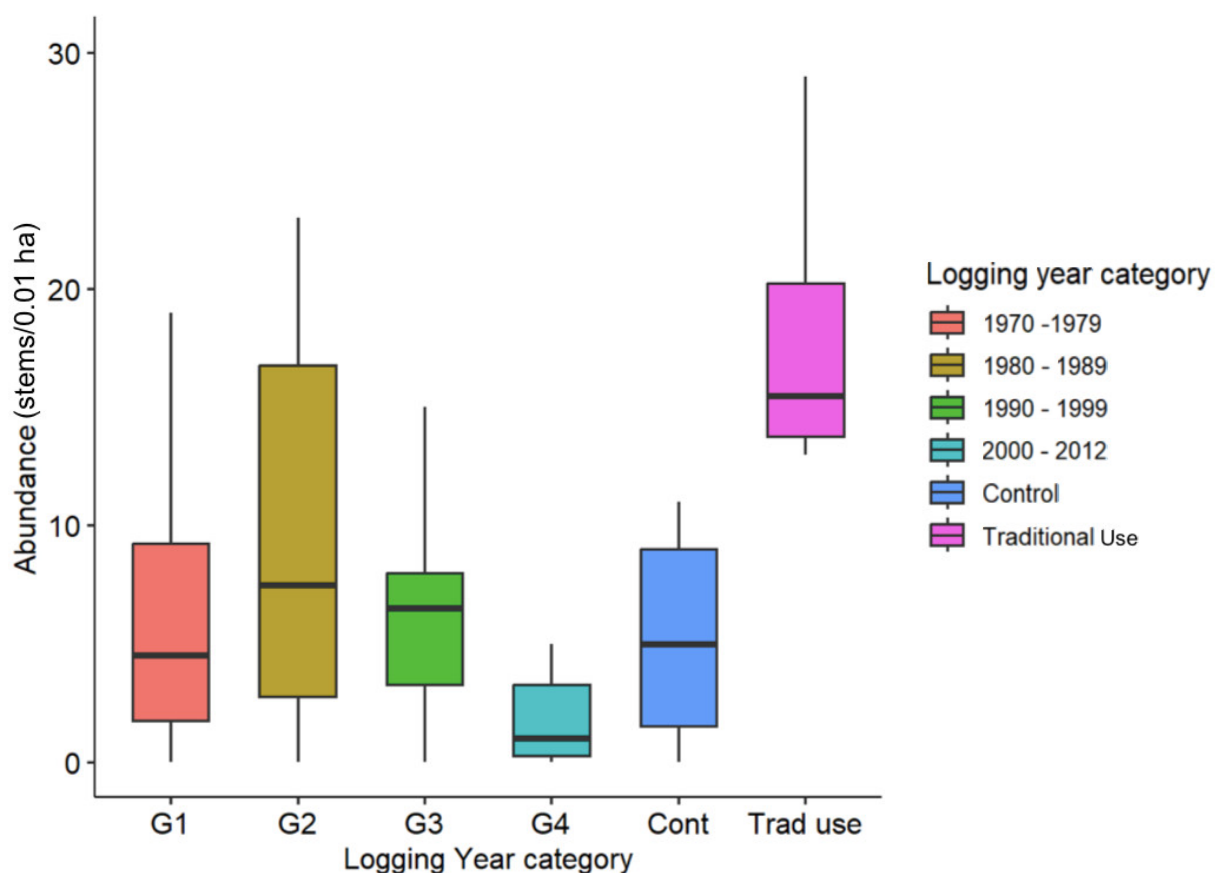


Figure 8. Distribution of stem abundance per 100 m² (0.01 ha) devil's club at each type of site. The bold line within the boxplot represents the median value of the variable. The box represents the interquartile range. The lines extending parallel from the interquartile range. The lines extending parallel from the boxes are known as the "whiskers," which are used to indicate 1.5 x the 25th or 75th percentile values.

Table 3. Pairwise results from Dunn post-hoc tests (with Bonferroni adjusted p-values) comparing devil's club stem density at traditional use sites with harvested sites and control sites. Time periods in parentheses indicate the period of logging.

Comparison	Z - statistic	P. unadjusted	P. adjusted
Control - Traditional use	-3.0101	0.0026	0.0339
G1 - Traditional use (1970–1979)	-3.3179	0.0009	0.0127
G2 - Traditional use (1980–1989)	-2.0449	0.0409	0.1170
G3 - Traditional use (1990–1999)	-2.3607	0.0182	0.2030
G4 - Traditional use (2000–2012)	-3.6950	0.0002	0.0032

The Kruskal-Wallis test reveals that devil's club stem length is significantly different ($p=0.0155$ $H = 14.019$, $df = 5$) among all sampled sites (timber harvest, traditional use, controls).

When comparing between the unlogged and logged sites stem length differs most significantly between the most recently logged sites, 2000–2012 and the traditional use sites ($p=0.0282$), and when comparing between logged-sites from different decades the most significant difference is between Group 2, logged 1980–1989 and Group 4, logged 2000–2012 ($p = 0.0061$), where in both cases the former was significantly longer than the latter. Generally, the median devil's club stem length from the earlier logged sites is greater than from the more recently logged sites, except for Group 2 (1980–1989) stems, which were longer than Group 1 (1970–1979) stems (Figure 9).

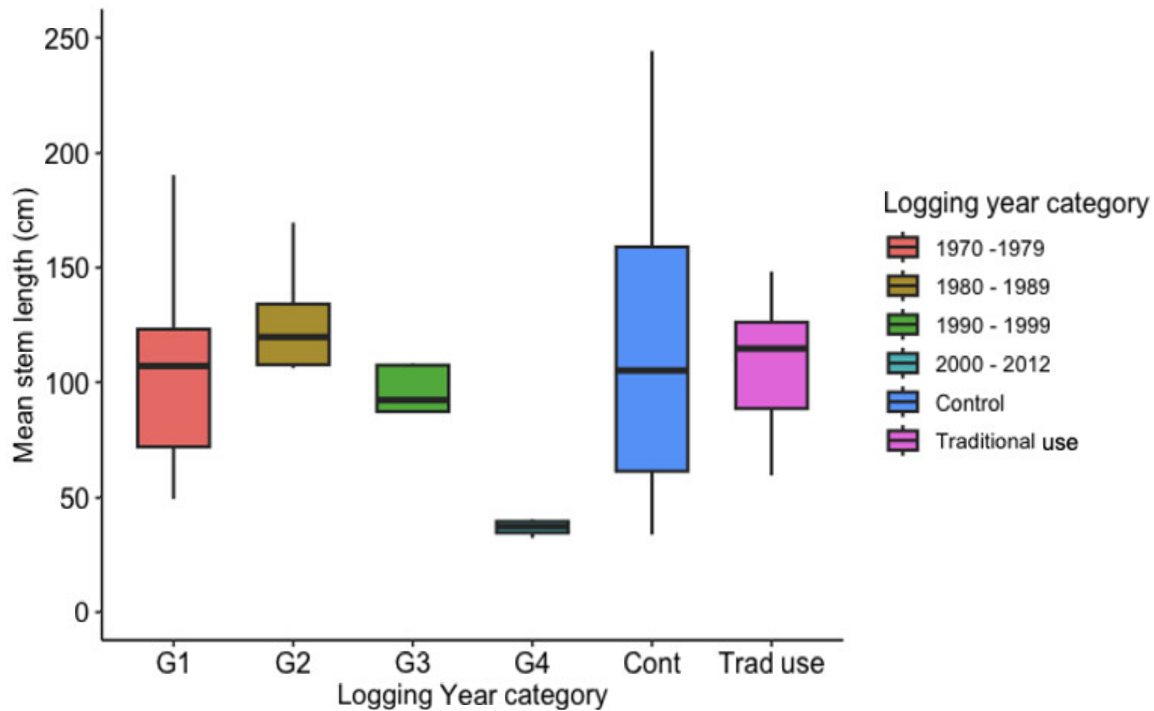


Figure 9. Distribution of median stem length of devil's club plants in different stand ages of forest harvest, control group and traditional-use sites.

Data analysis results from the Kruskal-Wallis test reveal that devil's club stem diameter is significantly different ($p = 0.0102$, $H = 15.036$, $df = 5$) among all sampled sites (timber harvest, traditional use, controls). Though not significant, the analysis shows that stem diameter differs the most between traditional use sites and the control sites ($p = 0.0504$), closely followed by the traditional use sites and Group 4 (2000–2012) ($p = 0.0566$). The largest median stem diameter is found on the traditional use sites (16.4 mm), and the smallest median diameter from those sites harvested from 2000–2012 (12.4 mm) (Figure 10).

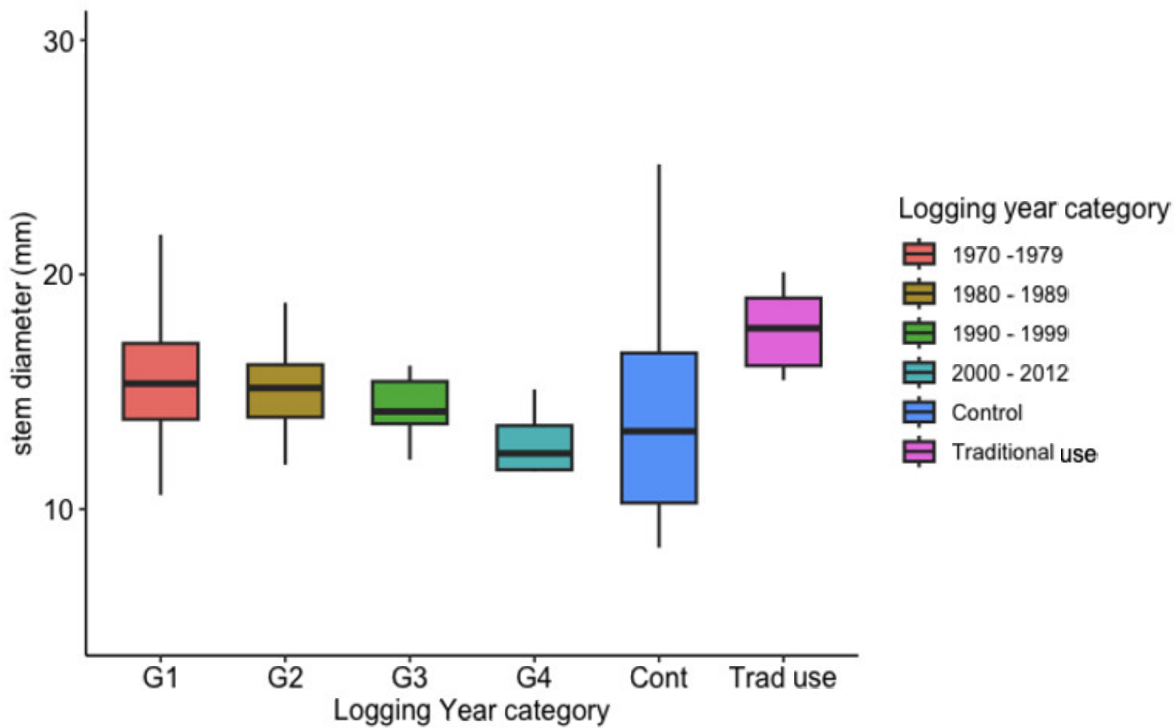


Figure 10. Distribution of median stem diameter of devil's club plants found growing in different stand ages after forest harvest, including control sites and traditional use sites.

3.1.2. Examine Relationship Between Shade and Leaf Area on Stem Length

The results of the Kendall-Theil Sen Siegel non-parametric linear regression indicates that both shade ($p < 0.0001$) (residual standard error: 46.78 on $df = 59$), and leaf area ($p < 0.0001$) (residual standard error: 117.3 on $df = 59$) shows a significant positive correlation between stem length and shade (Figure 11). The scatter plot indicates that as the shade increases, the stem length also increases. Also, a positive correlation can be seen between stem length and leaf area. This shows that as the leaf area increases, the stem length also increases (Figure 12).

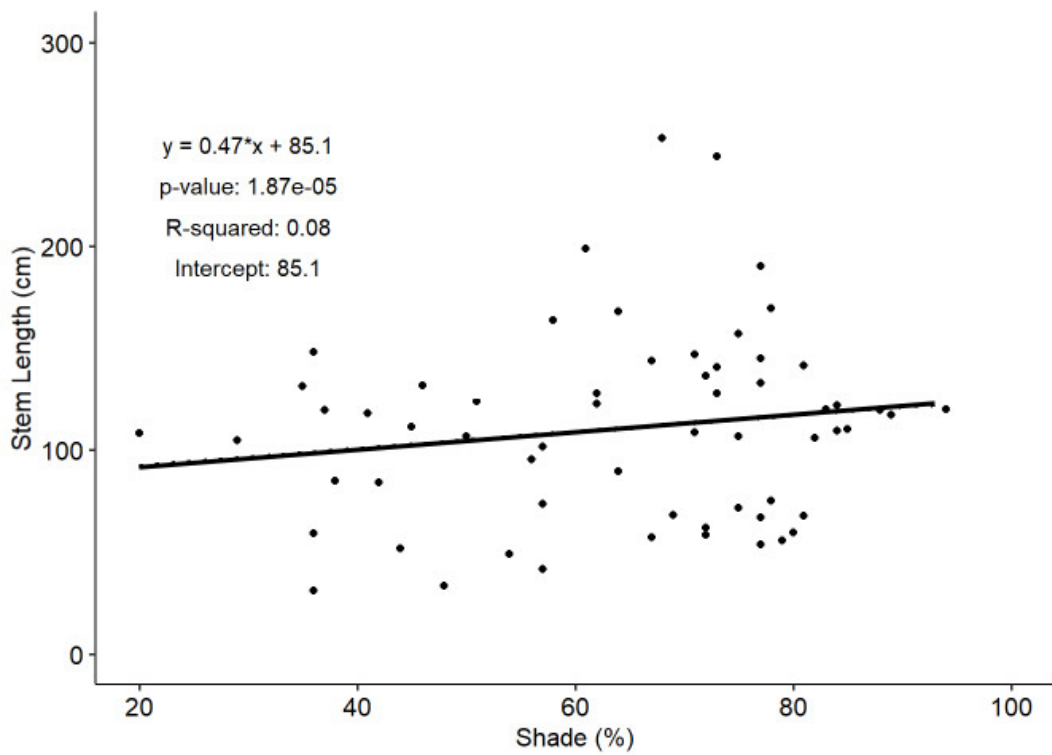


Figure 11. Relationship between devil's club stem length and canopy closure.

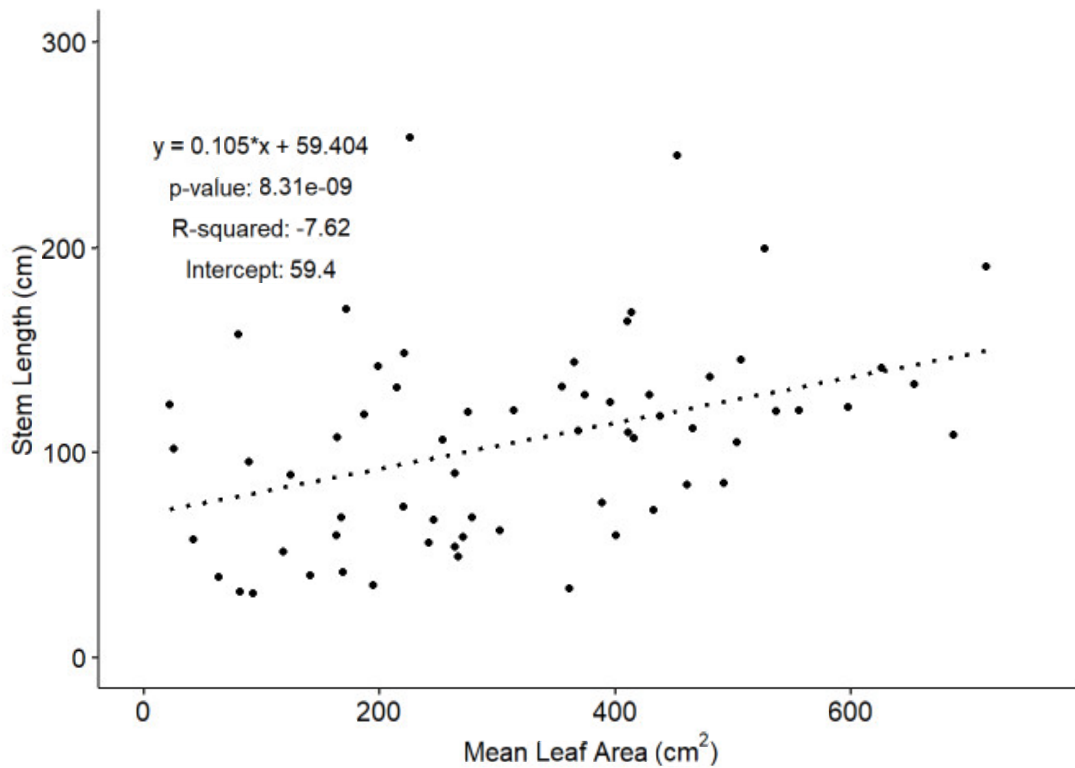


Figure 12. Relationship between devil's club stem length and devil's club leaf area. Dashed line indicates a relationship but not a cause and effect.

3.1.3. Examine Relationship Between Shade and Leaf Area on Stem Diameter

The results from the Kendall-Theil Sen Siegel non-parametric linear regression show that there is significant relationship between shade and devil's club stem diameter ($p = 0.0391$; residual standard error: 3.866 on $df=59$). The analysis indicates an overall negative correlation between shade and stem diameter; as shade increases, stem diameter decreases. The scatter plot, shows that many of the smallest diameter stems are growing in $>75\%$ shade (Figure 13). Conversely, there is a significant positive association of leaf area and stem diameter ($p<0.0001$; residual standard error: 10.34 on 59 degrees of freedom). The analysis indicates a relationship between leaf area and stem diameter, such that when the leaf-area increases, the stem diameter also increases (Figure 14).

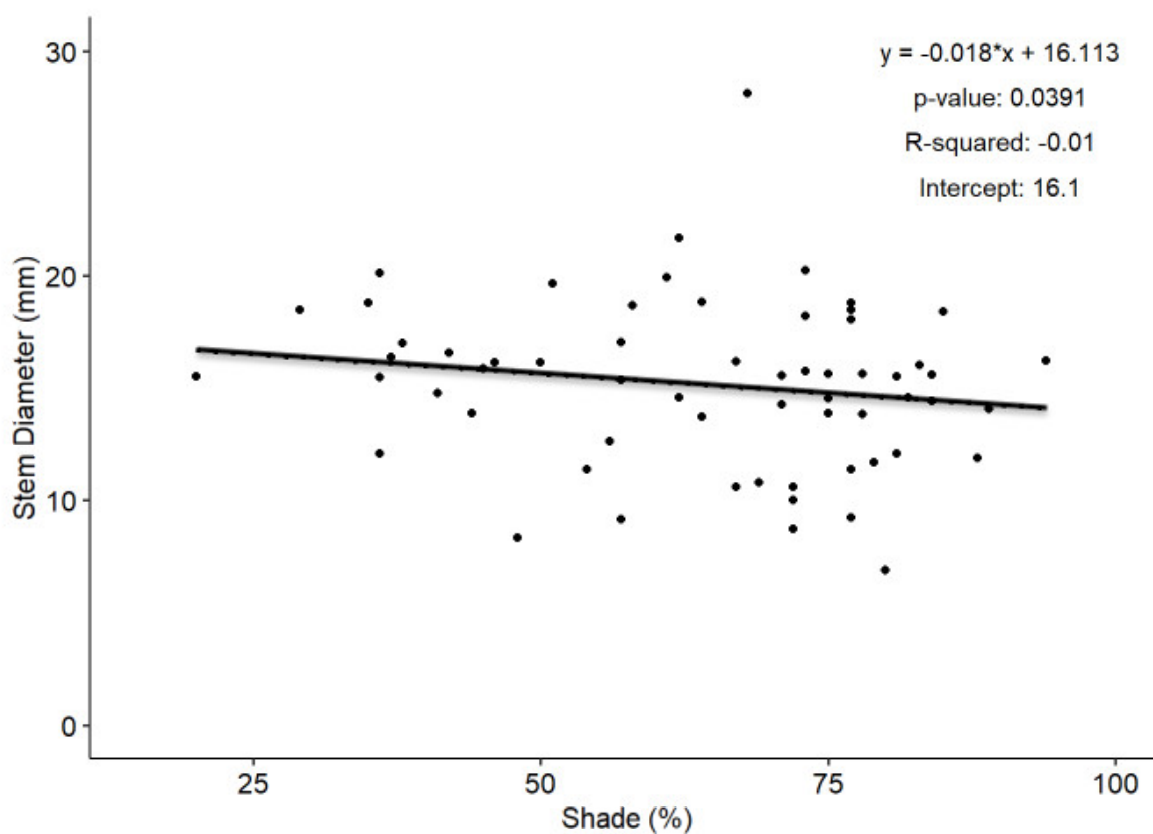


Figure 13. Regression analysis indicating relationship between devil's club stem diameter and canopy shade.

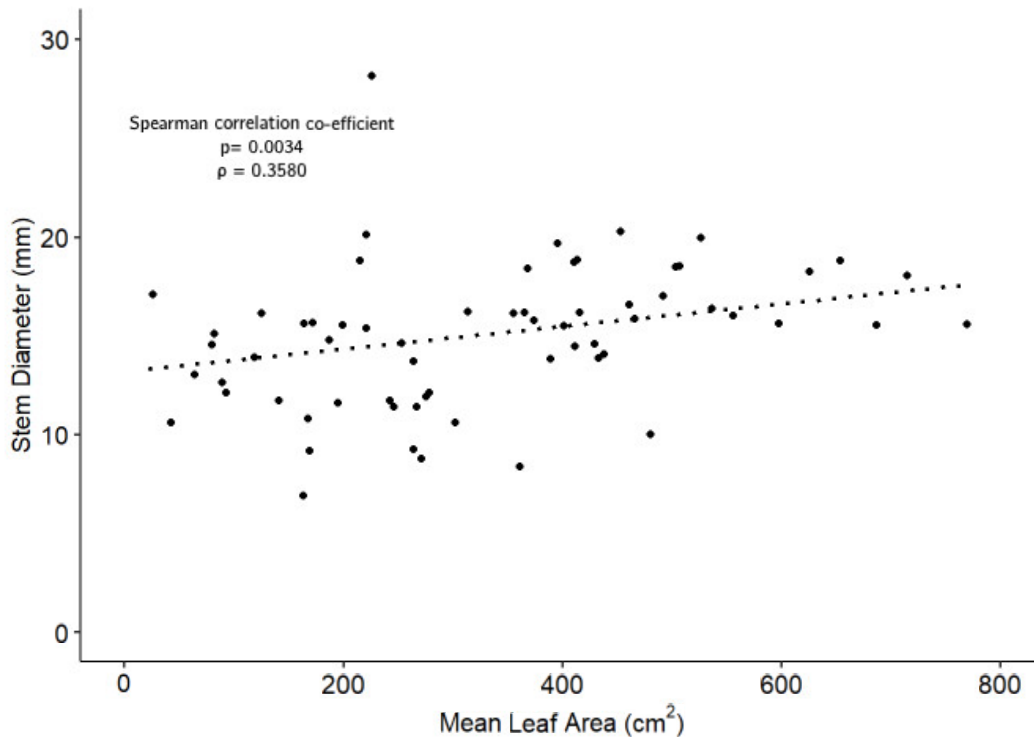


Figure 14. Relationship between devil's club stem diameter and devil's club leaf area. Dashed line indicates a relationship but not a cause and effect.

3.1.4. Relationships Between Devil's Club Metrics

Across all sites, the Spearman's rank correlation test reveals a strong correlation between stem diameter and stem-length, indicating that as devil's club stems increase in length, they have a relatively proportionate increase in their basal diameter (p-value < 0.0001, $\rho=0.6436$). In addition, the relationship between stem diameter and stem abundance also shows a significant correlation (p-value < 0.0001 $\rho = 0.4678$), and likewise stem length and stem abundance show a significant positive correlation (p-value < 0.0001 $\rho= 0.4396$).

3.1.5. Relationship Between Elevation and Devil's Club Metrics

In order to control for the variation in elevation across all sampled sites, a Kendall-Theil Sen Siegel regression analysis was used to examine devil's club stem abundance, stem length, and stem diameter as related to site elevation. The regression analysis shows that stem abundance had a significant relationship with elevation across all sites ($p < 0.0049$; residual standard error: 7.318 on $df = 59$). The analysis indicates that as the elevation increased, the stem abundance decreased, and consequently, the most productive areas were found at lower elevations, approximately 400 m to 500 m above sea level, which corresponded with the location of the traditional use sites situated in the Suskwa River drainage (Figure 15)

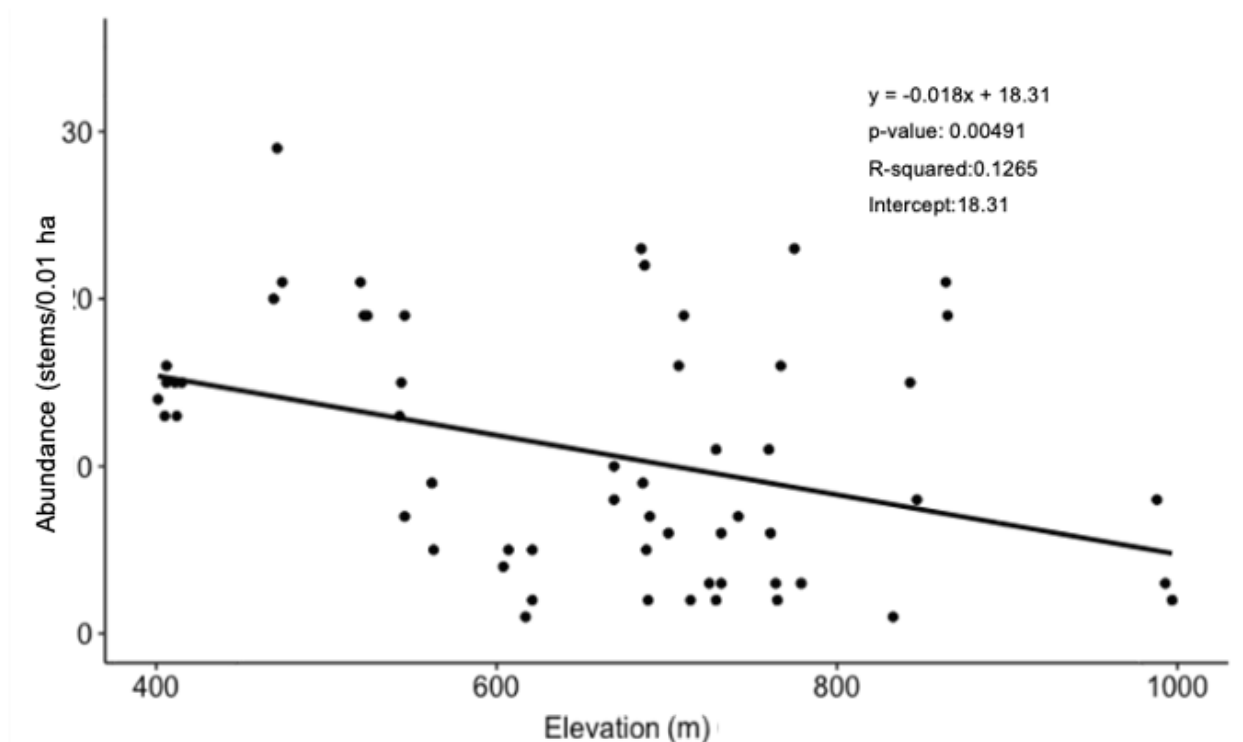


Figure 15. Relationship of devil's club stem abundance (stems/100 m² plot) and elevation using Kendall-Theil Sen Siegel regression analysis.

The regression analysis show that stem length has no significant relationship with elevation across all sites ($p = 0.698$; residual standard error: 46.96 on $df = 59$). Though a linear trend was not significant, many of the sites with the longest stems are found at mid-elevations,

approximately 600 m to 800 m, above sea level (Figure 16), which corresponded to harvested sites from the earliest harvested periods during the 1970s and also the control sites.

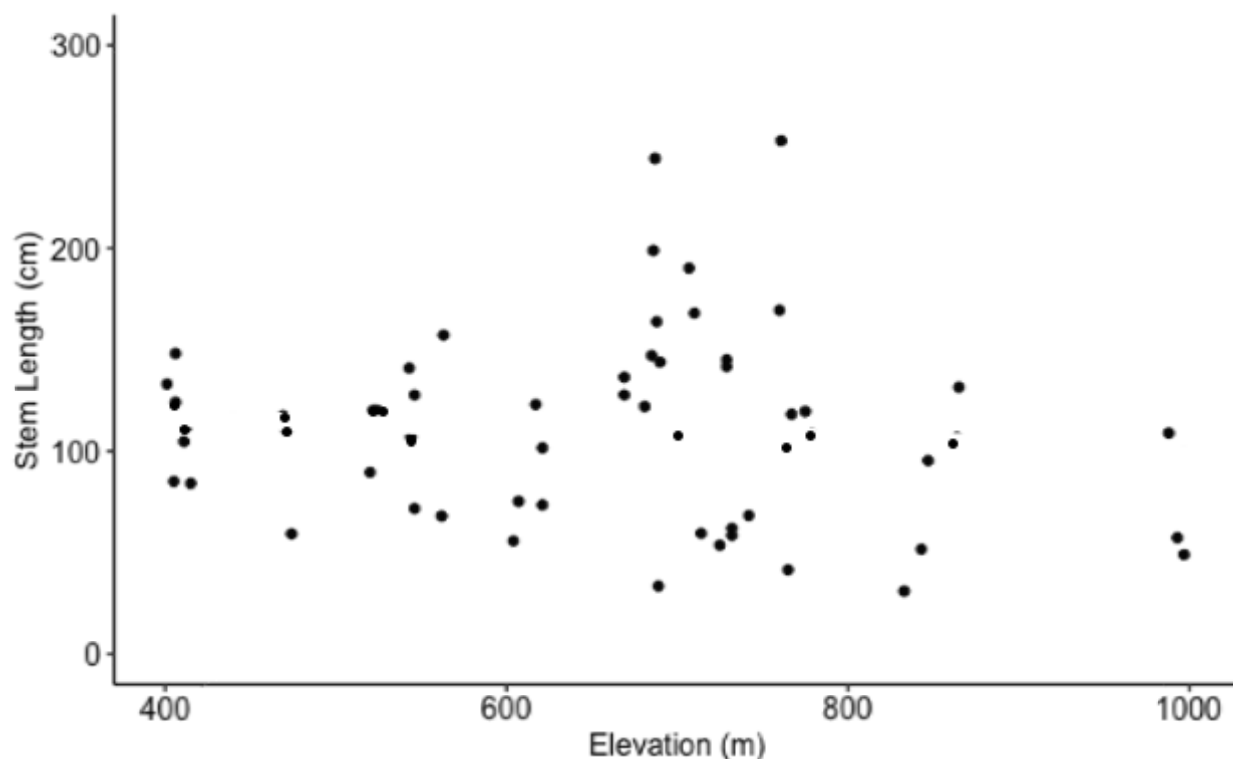


Figure 16. No significant relationship of devil's club stem length (cm) and elevation using Kendall-Theil Sen Siegel regression analysis ($p>0.05$).

Regression analysis further indicates that stem diameter has a significant relationship with elevation across all sites ($p=0.002$, residual standard error: 3.575 on $df=59$). The analysis indicates that as the elevation increases, the stem diameter decreases, and overall, the thickest stems were found at lower elevations, many of which were located in the traditional-use area, with numerous patches containing more than 20 stems over 25 mm diameter. In contrast, at higher elevations, above 900m, there are few sparsely scattered, large diameter stems. However, several large, thick-stemmed specimens found in sites located between 600 m and 800 m elevations corresponding with sites logged during the 1970s and 1980s (Figure 17).

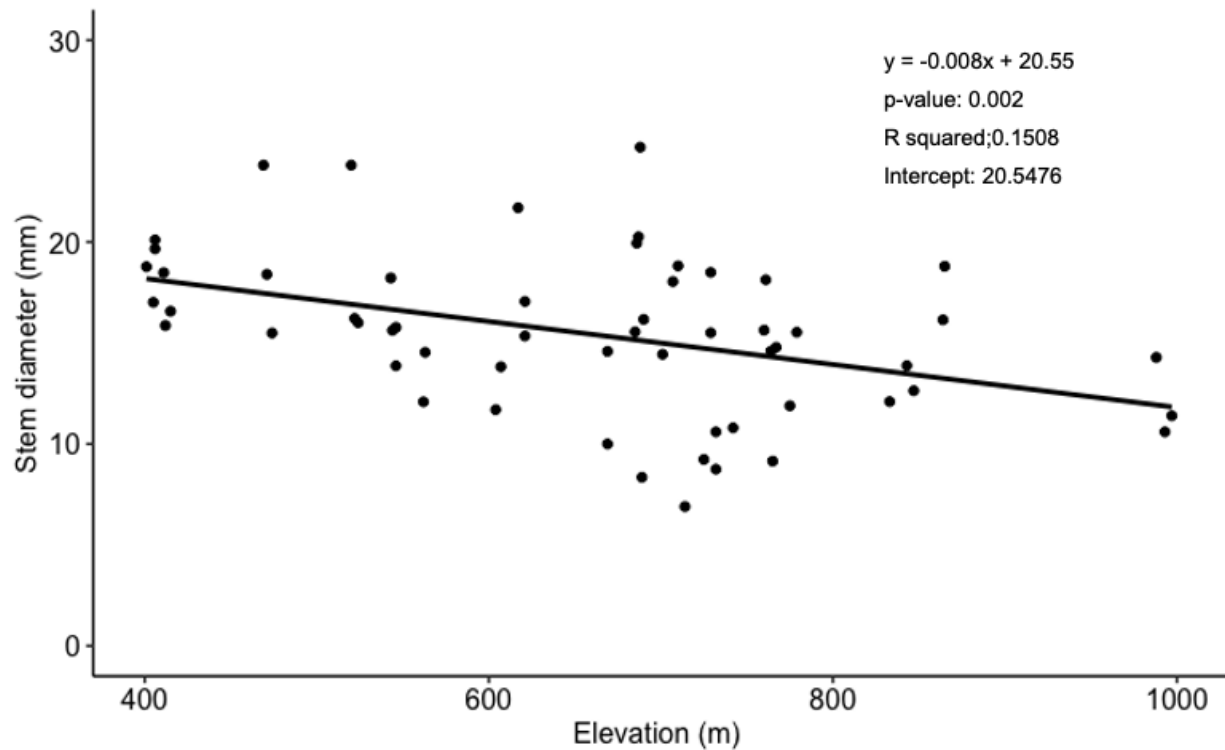


Figure 17. Relationship of devil's club stem diameter (mm) and elevation (m using Kendall-Theil Sen Siegel regression analysis).

When comparing devil's club stem abundance, stem length and stem diameter with site history, Time Since Logging for stands < 60 years old or Stand Age/Time Since Disturbance for those areas traditionally logged or initiated by natural disturbance (e.g., fire) for all sites while controlling for the influence of elevation, the results show a significant relationship between stem abundance and TSL ($p = 0.0009$; residual standard error: 7.805 on 59 degrees of freedom; Figure 19). The results for stem length show no significant relationship between the TSD across all sites, even when the effect of elevation was removed ($p = 0.1700$; residual standard error: 46.19 on 59 degrees of freedom) (Figure 18). However, for stem diameter with TSL there is a significant relationship between ($p = 0.0002$; residual standard error: 4.015 on 59 degrees of freedom). The results from the analysis show that as TSL increased, both stem abundance (Figure 19) and stem diameter increase (Figure 20).

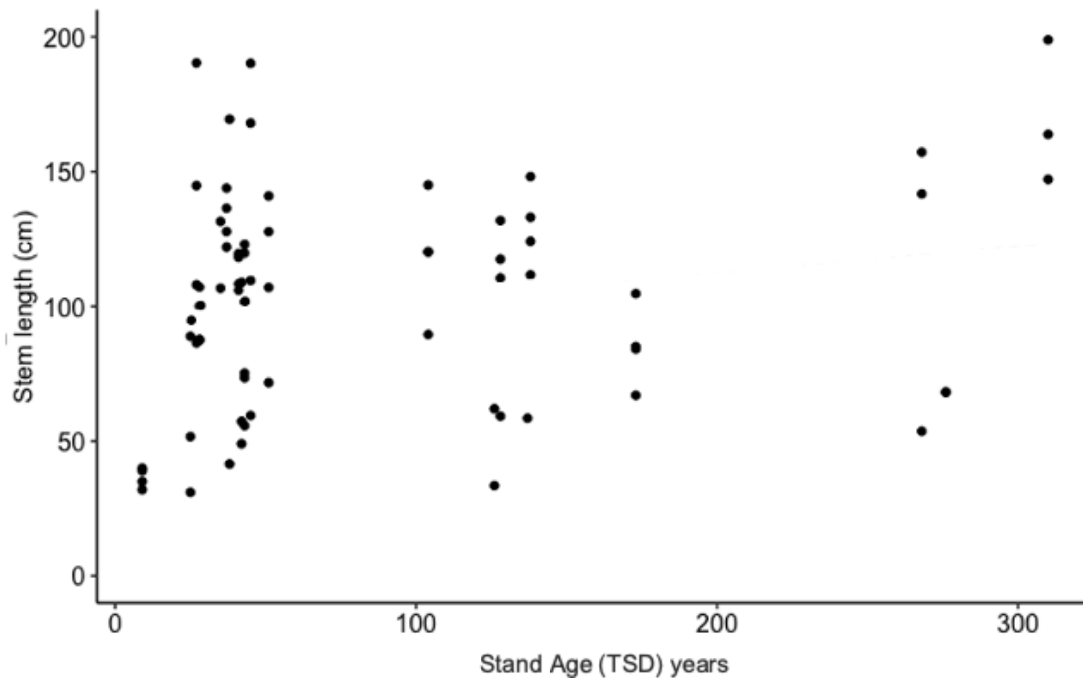


Figure 18. Regression analysis plot shows the relationship between devil's club stem length and the Stand Age or Time Since Disturbance (TSD)Time Since Logging while controlling for the influence of elevation ($p > 0.05$).

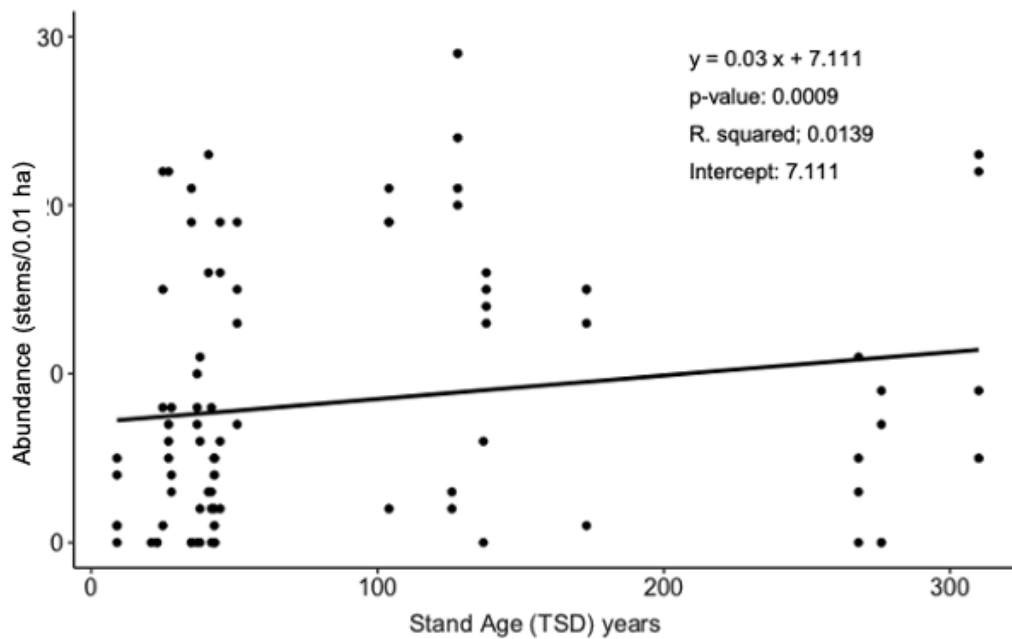


Figure 19. Regression analysis plot shows the relationship between devil's club stem abundance and the Stand Age or Time Since Disturbance (TSD)using a multi-regression to control for the influence of elevation.

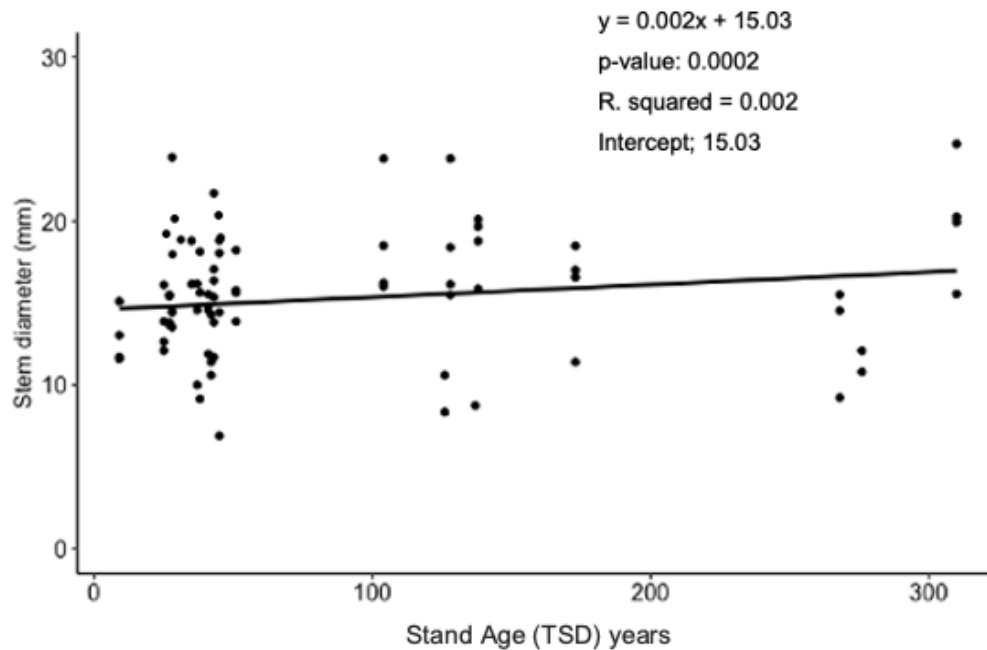


Figure 20. Relationship of devil's club stem diameter and the Stand Age or Time Since Disturbance (TSD) using a multi-regression to control for the influence of elevation.

3.2 Canopy Openness and Leaf Area Analysis

The removal of tree canopy from timber harvesting may or may not affect the size of devil's club leaves (leaf area), which in turn may affect their health and vigour (Dawe et al., 2017). To test the relationship between canopy openness and leaf area across all three stand history categories, I use a Spearman's rank correlation test. Results indicate that, across all sites there is no significant relationship between canopy openness and the area of individual devil's club leaves ($p = 0.1412$, $\rho = 0.1845$). However, evaluating leaf area across all sites a Kruskal-Wallis non-parametric test show that there was a significant relationship between leaf area. And TSL ($p = 0.0028$, $H = 18.111$, $df = 5$). Specifically, these data reveal that median leaf size was greatest on traditional use sites, with the oldest timber harvest site, Group 1 (1970-1979) having larger leaf area than the rest of the timber harvest sites. These data also indicate that the specimens with

the largest median leaf area are in areas which has the most time to regenerate since logging events (Figure 21).

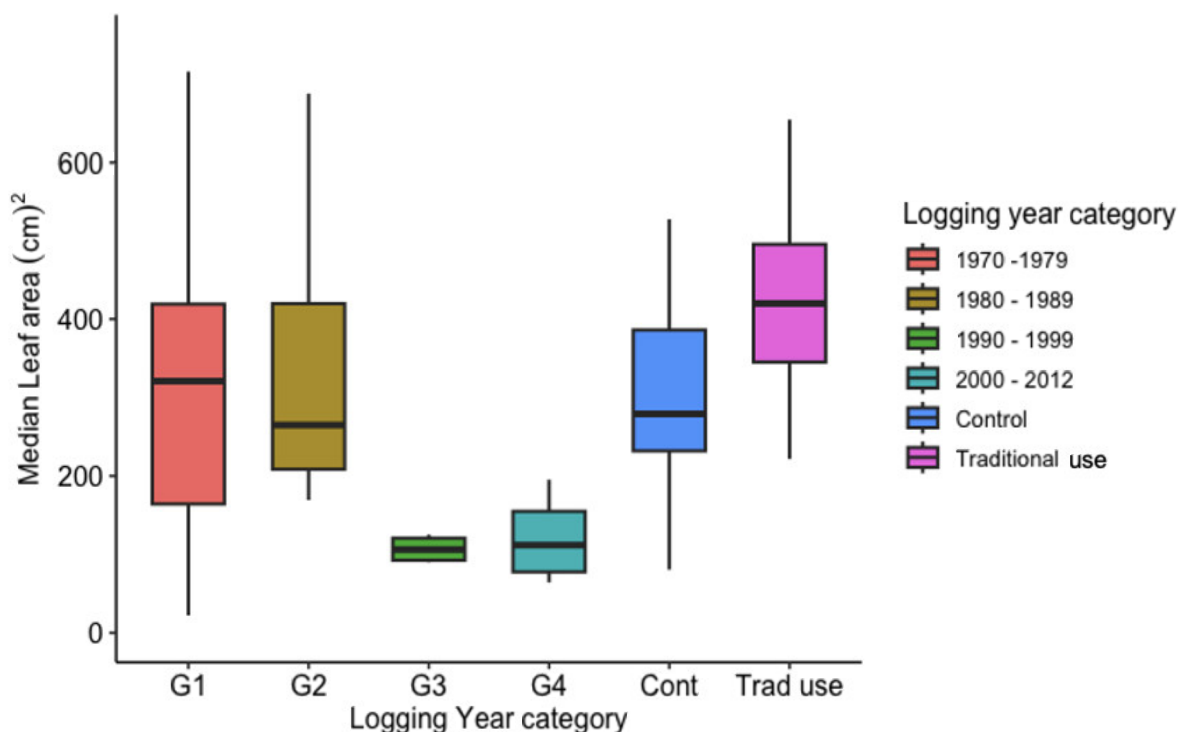


Figure 21. Distribution of the median leaf area (cm²) of devil's club plants found growing in different stand ages of forest harvest.

3.2.1. Effect of Shade and Leaf Area on Abundance

The results of the Kendall-Theil Sen Siegel non-parametric linear regression model demonstrates that shade does not have a significant relationship on devil's club stem abundance (stems/100 m² plot ($p=0.0566$, residual standard error: 8.299 on 86 degrees of freedom; Figure 22), on the other hand there is a significant correlation from leaf-area on the abundance of devil's club stems (stem/100 m² plot) ($p<0.0001$, residual standard error: 20.78 on $df= 86$). The analysis shows a positive relationship between leaf area and abundance. The regression line (Figure 23) suggests that on sites where the leaf area increases, devil's club stem abundance also increases.

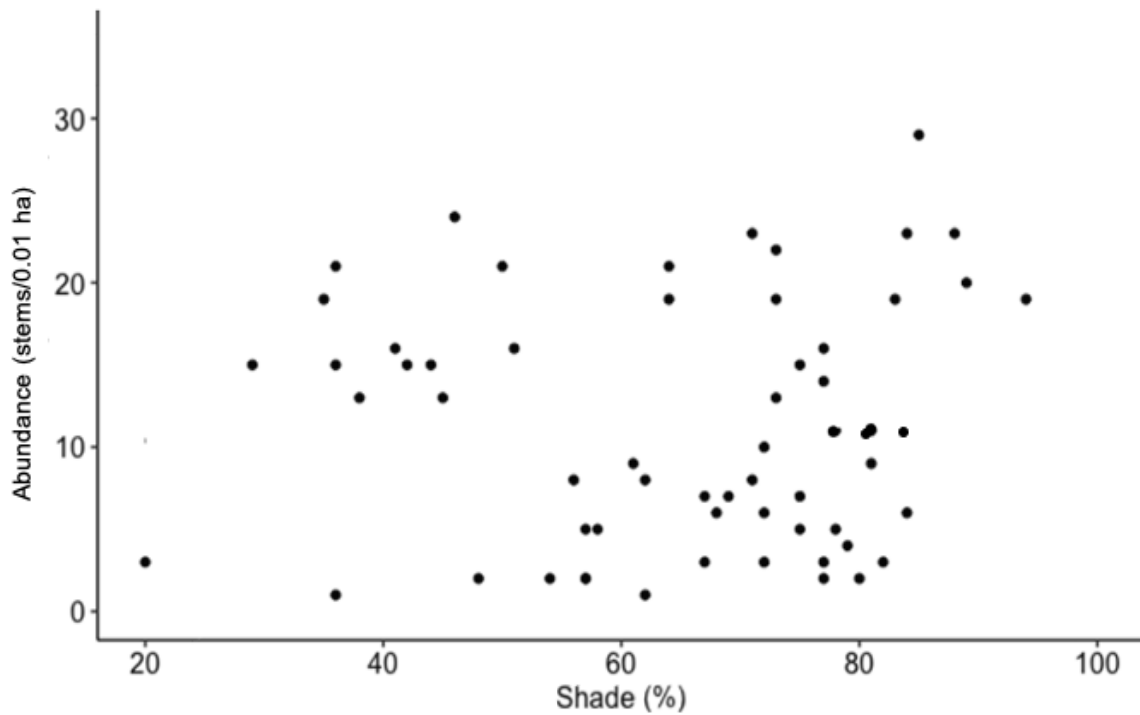


Figure 22. Relationship between devil's club stem abundance and available shade ($p > 0.05$) using regression analysis.

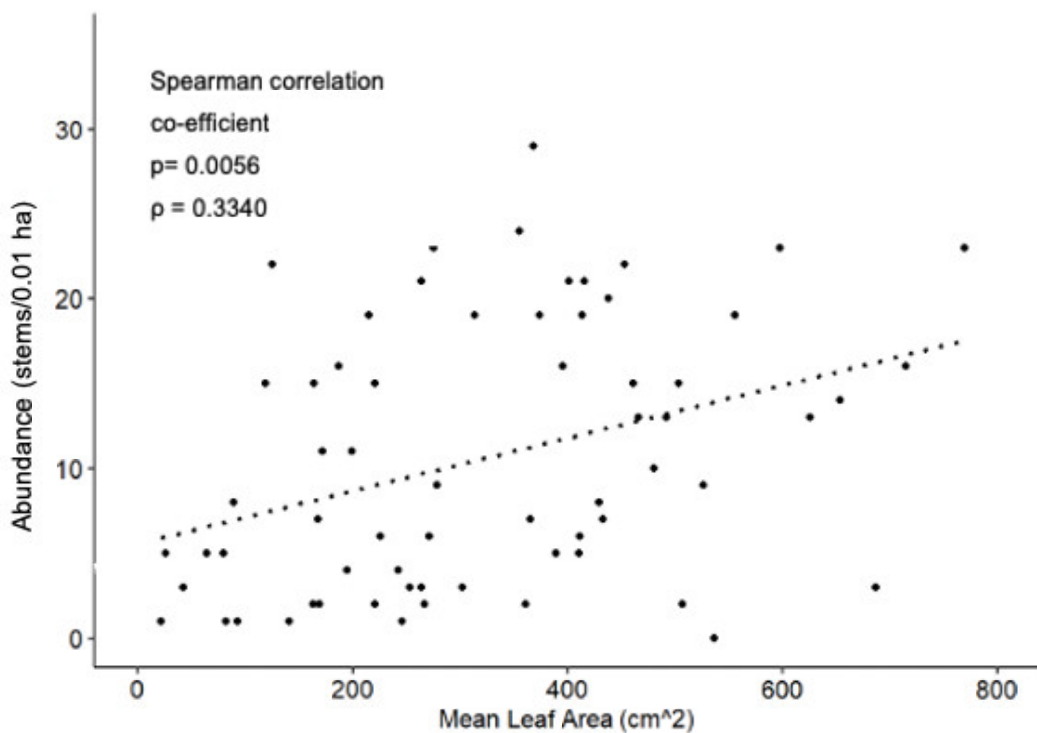


Figure 23. Relationship between devil's club stem abundance and devil's club leaf area. Dashed line indicates a relationship but not a cause and effect.

3.3 Tree Cover analysis

The relationship of devil's club abundance to tree cover is presented in the bar chart below (Figure 24). Of the 10 tree species encountered mountain alder had the lowest number of occurrences at locations where devil's club was present (n=6). In contrast, the most frequently occurring tree species on sites where devil's club was present (n=50) was spruce (various natural hybrids) . The analysis showed that across all sites, spruce (*Picea* spp.) (30.1%) was the most frequently occurring species where devil's club was present, followed by western redcedar (15.7 %) and paper birch (10.2 %).

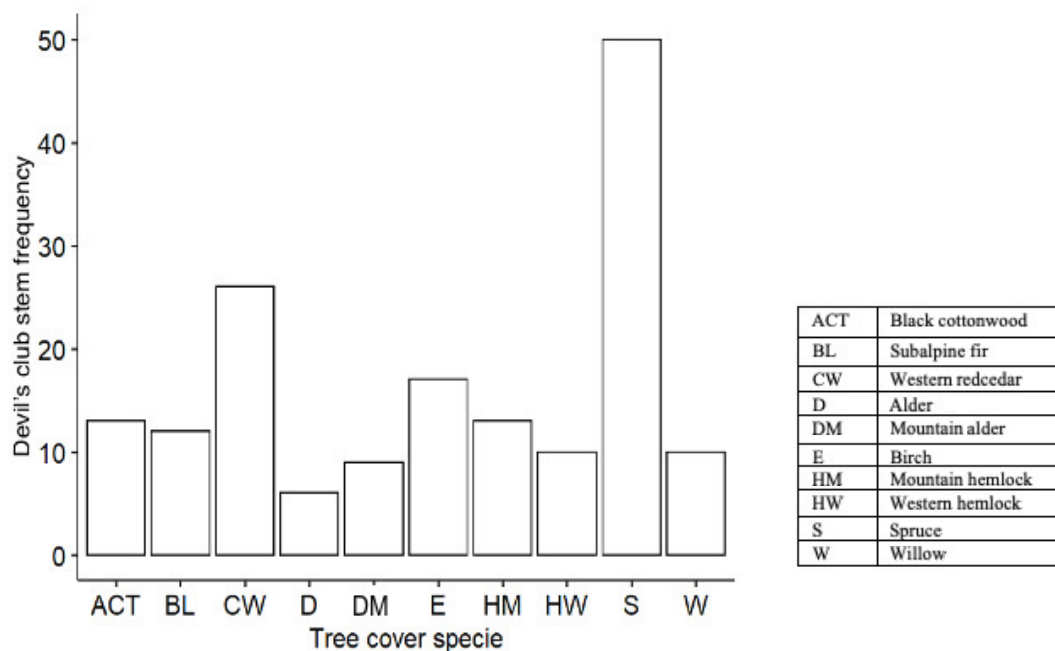


Figure 24. Frequency of occurrences of tree species where devil's club was present.

3.4 Species Distribution Modelling Results

The development of the species distribution model for devil's club in Madii Lii successfully followed the stepwise workflow as described in the methods section of this research. The BIOCLIM profile used the 17 bioclimatic variables to produce the base model and determine which variable had the most influence over the occurrence of devil's club. These data were then also used to generate the devil's club testing and training data points (Figure 25). For model evaluation calculations the BIOCLIM algorithm generated 18 species presence data-points and 144 species absence data-points from the 88 presence-absence data-points (plots) obtained during the field data collection (Table 4). The model also generated "background points" which were created to characterize the environmental qualities of the study region. The model algorithm was then able to determine which conditions the target species (devil's club) would most likely need to persist without manufacturing absence locations.

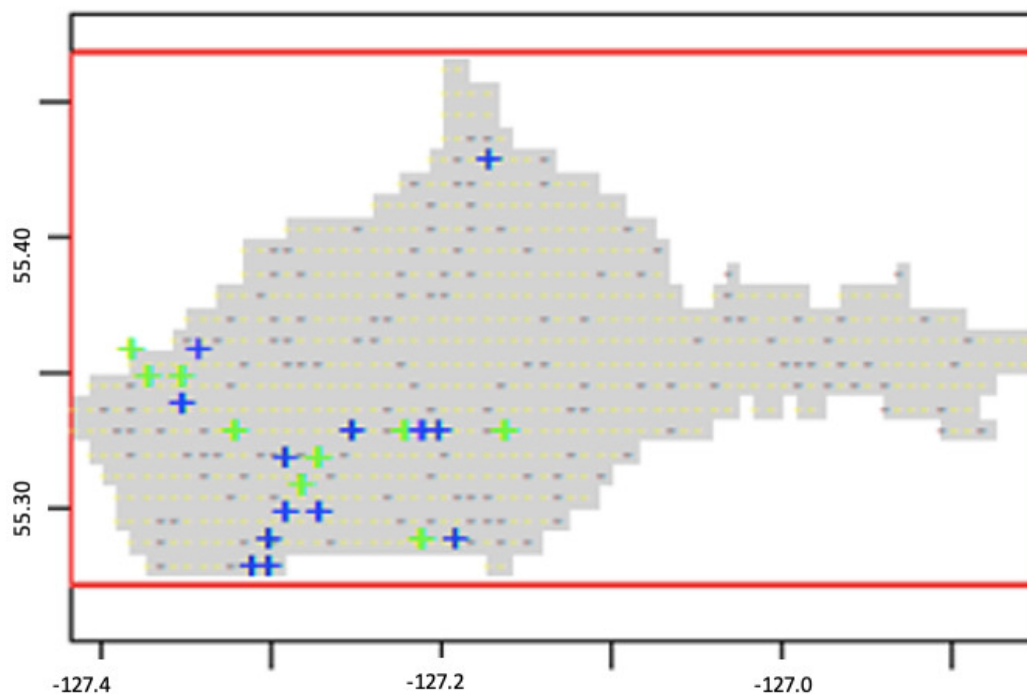


Figure 25. Training and testing points generated to produce a BIOCLIM species distribution model. The blue points represent devil's club present training locations and the green points denote devil's club absence locations, yellow are background testing.

3.4.1. Response Plot

The results from the bioclimatic variables are illustrated as response plots for each individual variable. The response plot for devil's club provides the range of values in each predictor variable based on the fitted models for the SDM. By using the presence-absence data gathered during the fieldwork, a bioclimatic response graph can be generated for each variable. Each plot indicates the relationship between the probability of occurrence for devil's club with respect to each individual environmental variable (Figure 26).

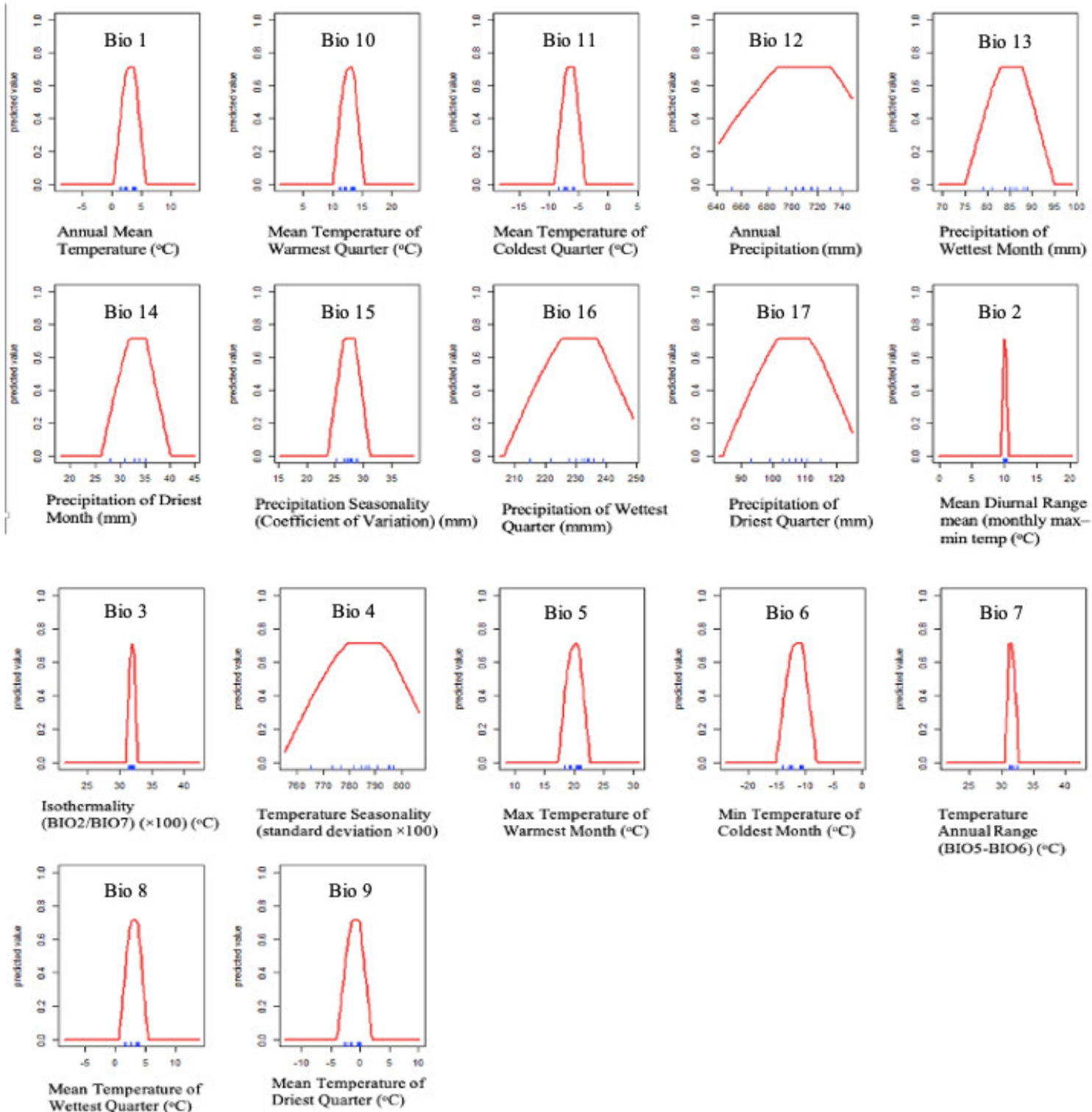


Figure 26. Multiple response plots for devil's club probability of occurrence in relationship to all bioclimatic variables evaluated on the basis of training data. The x-axis represents the range of values of the environmental variable, and the y-axis provides the probability of incidence on a scale from 0 (low probability) to 1 (high probability) (Worldclim, 2021).

3.4.2. Interpretation of Response Plots

The results from the generated response plots showed the relationship between the probability of occurrence of devil's club relating to each environmental variable. For each response plot, the output was generated for one environmental variable. The response plots for Bio(s) 1,5,6,8,9,10,11,14,15 all displayed similar shaped profiles. The response curves for these plots showed that the probability of occurrence of this species follows an optimum curve. For example the response curve for Bio 1 Mean Annual Temperature, indicates a high probability of species presence in areas that maintain a temperature between ~0 and 4 °C. The response plot curves for the Bio(s) 4, 12,16, and 17 indicate the probability of species presence over a wide range of values. For example, Bio 12, Annual Precipitation, the curve shows that devil's club prefers wetter climates up to a maximum of 730 mm per annum, then as precipitation becomes too excessive the probability of occurrence declines. Finally, the response plot curves indicate that for Bio(s) 2, 3, and 7, all have a very steep and narrow response mean, indicating that devil's club has a small tolerance for variations in these variables, for example, Mean Diurnal Range, the mean of monthly (max temp–min temp).

3.4.3. BIOCLIM Model Evaluation

This BIOCLIM model indicated an AUC value of 0.8951 which suggested a very reliable model. The AUC of 0.8951 value translates to 89.51% chance that the model will reliably differentiate between positive and negative classes (Table 4). In addition, the model evaluation relies on two variables, (p) presence and (a) absence, and uses these values to calculate the correlation coefficient value (0.453). Furthermore, the max TPR+TNR value also provides an alternate model evaluation. The True Positive Rate (sensitivity) and the True Negative Rate (specificity) across the range of the threshold probability values can be calculated/plotted to provide a complementary model evaluation. The value represents the probability threshold at which our

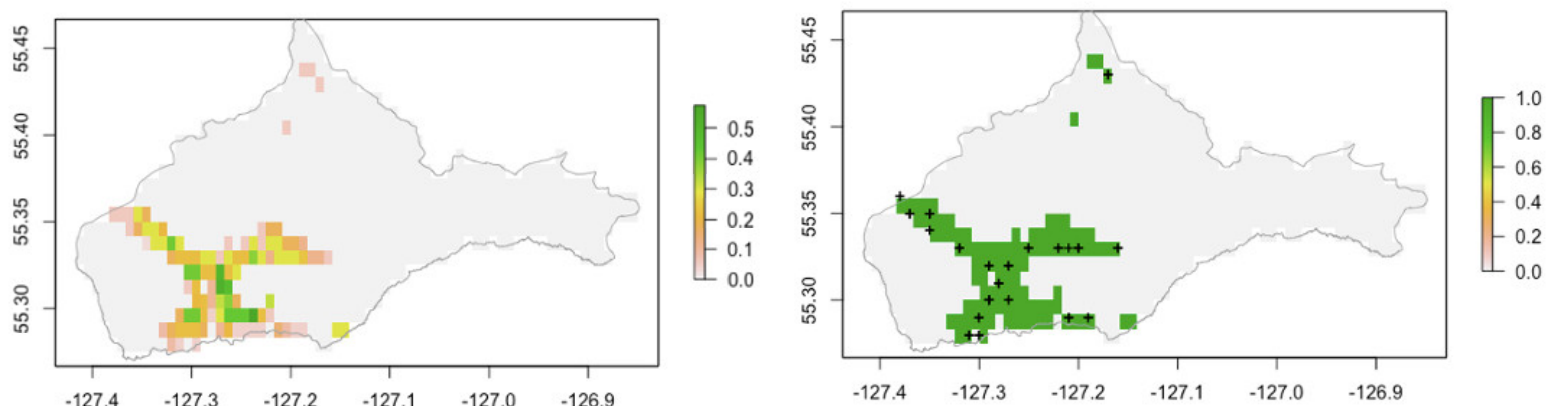
model maximizes the True Positive Rate (TPR) and the True Negative Rate (TNR). The greater the value for both figures, the likelihood of a more reliable model

Table 4. Summary of BIOCLIM model evaluation

Class	Model Evaluation
n presences	18
n absences	144
AUC	0.895
correlation coefficient	0.453
max TPR+TNR	0.293

The interpretation of the predicted map is quantified as the suitability of a grid cell (n-row 24, n-column 68, n-cell 1632, 6889 m² cell) on a scale from 0 to 1, where 0 refers to very low suitability, and one refers to very high suitability. The model based on BIOCLIM layers combined to generate a predicted presence-absence for devil's club in Madii Lii (Figure 27).

Figure 27. Left: species distribution model with continuous habitat suitability values determined from the BIOCLIM layer model. Right: binary presence/absence model used by applying a threshold, derived from the max TPR+TNR value.



3.4.4. General Linear Regression Method for the SDM

The General Linear Regression/Gaussian model results produced another set of predicted habitat suitability and presence-absence maps (Figure 28). The suitability map shows current conditions, with the green (darker) area where the most suitable habitat for devil's club is more likely to be

found. The yellow areas are moderately suitable, the pink-orange are low suitability, and the beige/white are non-suitable habitats for devil's club. The presence-absence diagram highlights in green the region to the south where devil's club is expected to proliferate.

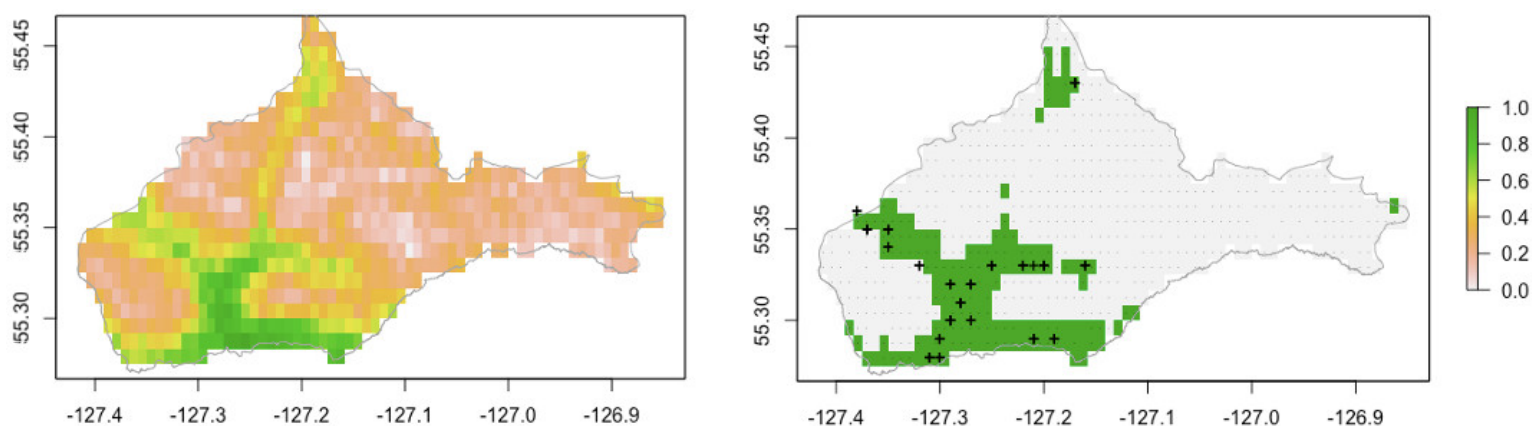


Figure 28. Left: species distribution model with continuous habitat suitability values for the Generalized Linear Model/Gaussian model. Right: binary presence/absence model used by applying a threshold, derived from the max TPR+TNR value.

3.4.5. Average Score Model

The process of model generation was then completed for the Domain, MaxEnt and SVM models and the AUC scores compared for likelihood of best fit for each model (Appendix 4). By merging the results of four models (BIOCLIM, Domain, GLM and SVM; Figure 29) an “average model” was calculated by employing a mean score of predicted probability of devil's club occurrence from each of the individual contributors to provide a single average model prediction (Figure 30).

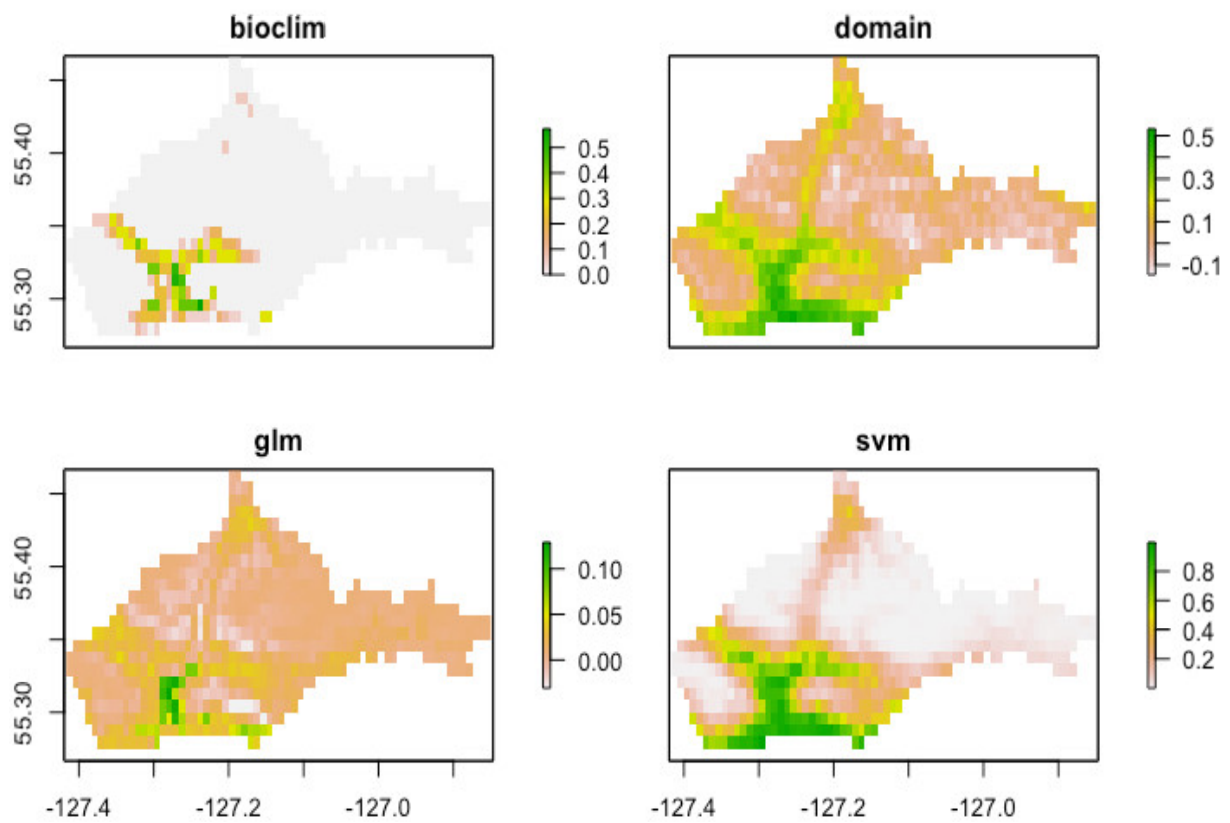


Figure 29. SDM using BIOCLIM, Domain, GLM and SVM model profiles

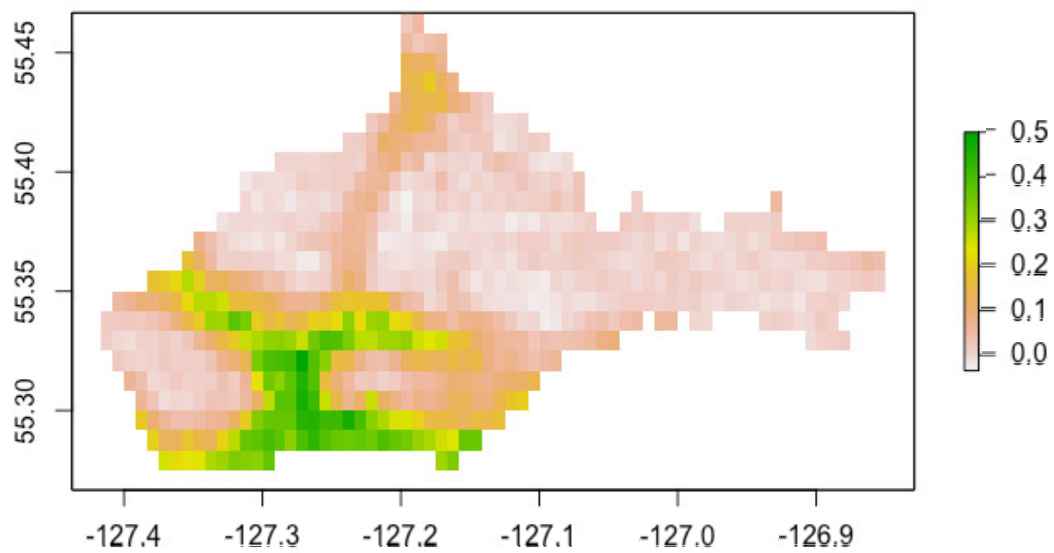


Figure 30. Madii Lii devil's club Average Score SDM compiled from: BIOCLIM, Domain, GLM and SVM models.

All four models (BIOCLIM, Domain, GLM and SVM; Figure 29), as well as the Average Score model (Figure 30), suggest that the southern portions of the study area (green coloured area) provide the most suitable habitat for devil's club, and much of the northern portions of Madii Lii predicted to be less suitable or unsuitable habitat. The favourable conditions found in the southern and western region of the territory corresponds with the lower elevations within the valleys formed by the various watercourses that flow through the territory and join the Suskwa River adjacent to the southern boundary.

3.5 Madii lli Predictive Habitat Suitability Generation

3.5.1. Baseline BIOCLIM SDM Model

Though the research had previously created an SDM for existing conditions, to generate a predictive habitat model encompassing the effects of a warming planet, an alternative baseline model was constructed using the SSP126:2021–2040 climate model scenario. This BIOCLIM base model also incorporated the predicted effects of the imminent change in global climate

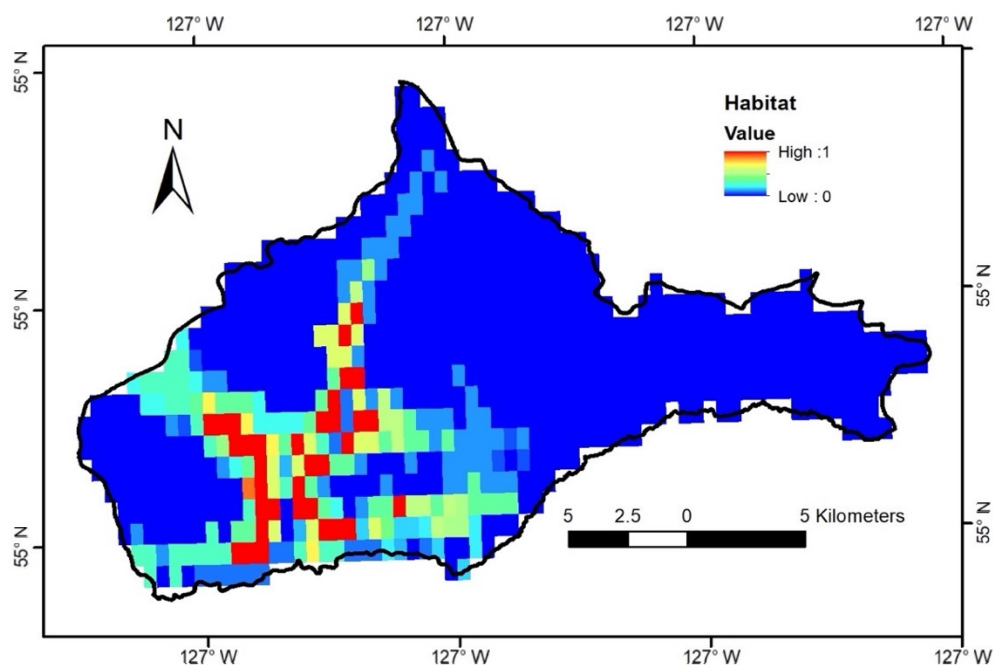


Figure 31. Madii Lii predicted habitat suitability for devil's club under current conditions using BIOCLIM model for the SSP126 2021-2040 climate scenario.

temperatures. Comparable to the previous methods the BIOCLIM predictors generated presence and absence points which then could be used to develop the test and train datapoints (Figure 31). The BIOCLIM model evaluation (Figure 31) illustrates the training and testing model data points. Here, the presence (n=18) constitutes the training set which was generated from field data and are divided into two selections: training and testing. The absence data is pseudo-absence model evaluation data-points (n=144) data constructed by the software algorithm for measuring model accuracy. The test-train model received a poor score for the Area Under Curve (AUC) values of 0.7853 (Table 5).

Table 5. Summary of model evaluation for the BIOCLIM test-train model.

class	Model Evaluation
n presences	18
n absences	144
AUC	0.7853
correlation coefficient	0.1941
max TPR+TNR at	0.0293

3.5.2. *MaxEnt Model*

The BIOCLIM profile method only considered 'presence' data. The MaxEnt model, on the other hand, used machine learning to consider data points from presence, absence and background data. The maximum entropy model predictors were applied to the 17 bioclimatic variables, which then generated the variable-contribution percentage score for each variable that in turn were ranked in order of most influence. The results from the contribution plot showed that the top-ranked environmental variables were Min Temperature of Coldest Month and Mean Temperature of Coldest Quarter. These two variables provide the most reliable indicator of the probability of devil's club presence. These data were then used to generate a series of response plots for each environmental variable.

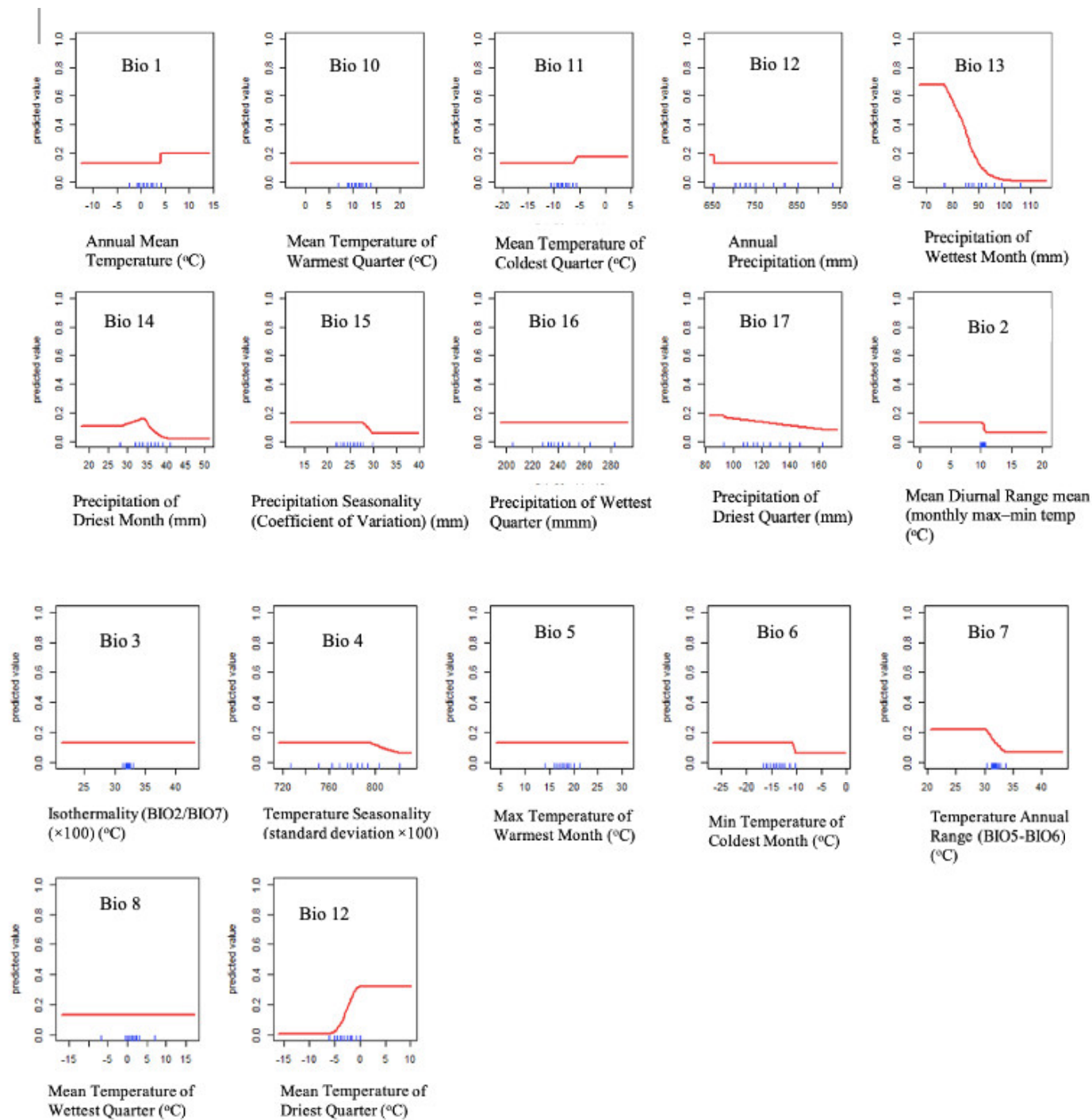


Figure 32. Multiple response plots for the environmental variables for MaxEnt model generation.

These results from the response plots (Figure 32) illustrate the relationship between the probability of occurrence of devil's club and each environmental variable. For each plot, the response is modelled for one environmental variable while the other environmental variables are held constant at their mean. For example, the largest response is for Bio 13 = Precipitation of Wettest Month, the probability of devil's club presence decreases from 70% at 80 mm to 10% at 90 mm precipitation. While for Bio 1 = Annual mean temperature, the response function is a straight line meaning its effect is negligible and does not affect the model. The results from the MaxEnt model perform better than the BIOCLIM model, with an AUC of 0.8493 (Table 6). The AUC of 0.8493 value means there is an 85% chance that the model will reliably distinguish between positive class and negative classes (Figure 33).

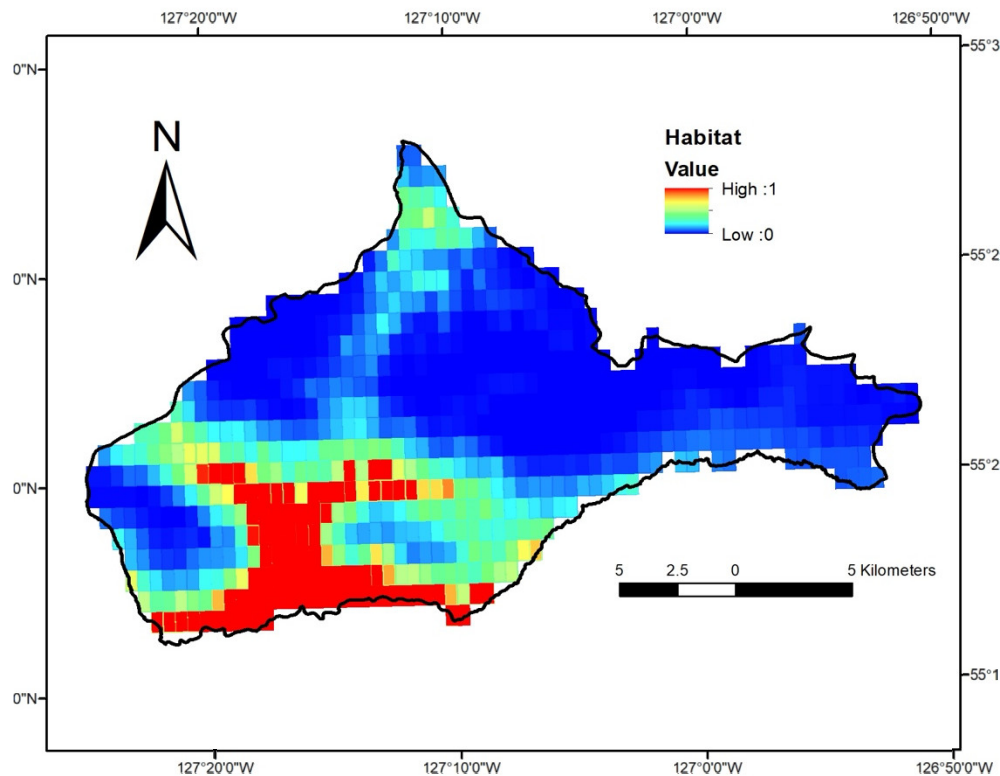


Figure 33. Predictive habitat suitability for devil's club in Madii Lii for the SSP245:2021–2040 model using MaxEnt model.

Mapped projections of the MaxEnt model output provides a suitable set of model predictions. Next, the Random Forest model was tested, and output compared with the MaxEnt model to determine the best model algorithm to use for climate change prediction.

Table 6. Summary of model evaluation scores for MaxEnt model.

class	Model Evaluation
n presences	18
n absences	144
AUC	0.8493
correlation coefficient	0.4485
max TPR+TNR at	0.2341

3.5.3. Random Forest Model

The ROC plot for the Random Forest profile provided an AUC value of 0.9371, (Table 7). In addition to the MaxEnt and Random Forest, Support Vector Machines models were also applied to the data. However, the AUC score was only 0.8741, still very good, however for this scenario Random Forest produced the best performing model and was used to generate the predictive habitat models for climate change scenarios.

Table 7. Summary of model evaluation scores for Random Forest model.

Class	Model Evaluation
n presences	18
n absences	144
AUC	0.9371
correlation coefficient	0.6199
max TPR+TNR at	0.0612

3.6 Predictive Habitat Suitability for Devil's Club in Madii Lii 2021–2100

The mapped results from the predictive habitat suitability modelling for Madii Lii for SSP245 2021–2100 (moderate/stabilized increase in GHG emissions) are shown below (Figure 34). The maps depict the expected changes in devil's club habitat from present-day conditions to the end of this century in Madii Lii. When comparing 2021–2040 with 2081–2100, it is apparent how habitat suitability is changing. The plot displaying 2081–2100 has fewer suitable red, yellow, and green colour. indicating that habitat suitability has declined over the 80-year period. The most apparent change seen between the 2041–2060 model and the 2061–2080 model. However, there appears to be an improvement with the amount of suitable habitat in the latter decades of the 21st century.

When observing the model output for the SSP585:2120–2100 (Figure 35), the red area (best quality habitat) is considerably reduced when comparing the 2021–2040 map with the 2081–2100 map. From the map it is evident that there is a consistent, gradual decrease in areas of suitable habitat (red, yellow, and green), which also become more fragmented over time. Conversely, the areas of poor quality (turquoise) and unsuitable habitat (blue) increase over the 80-year period to the end of the century.

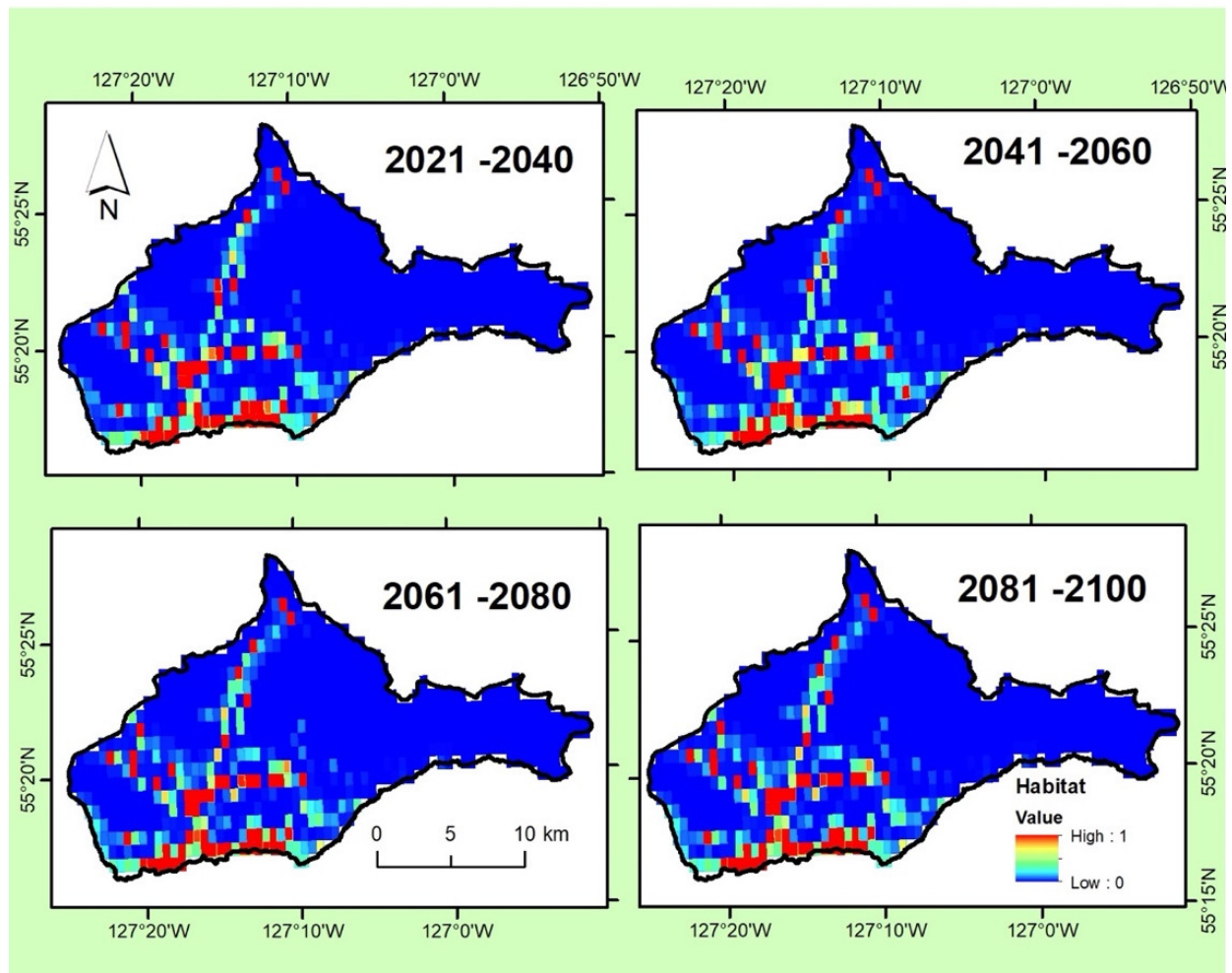


Figure 34. Predictive suitability habitat for devil's club in Madii Lii illustrates the SSP245:2021–2100 climate.

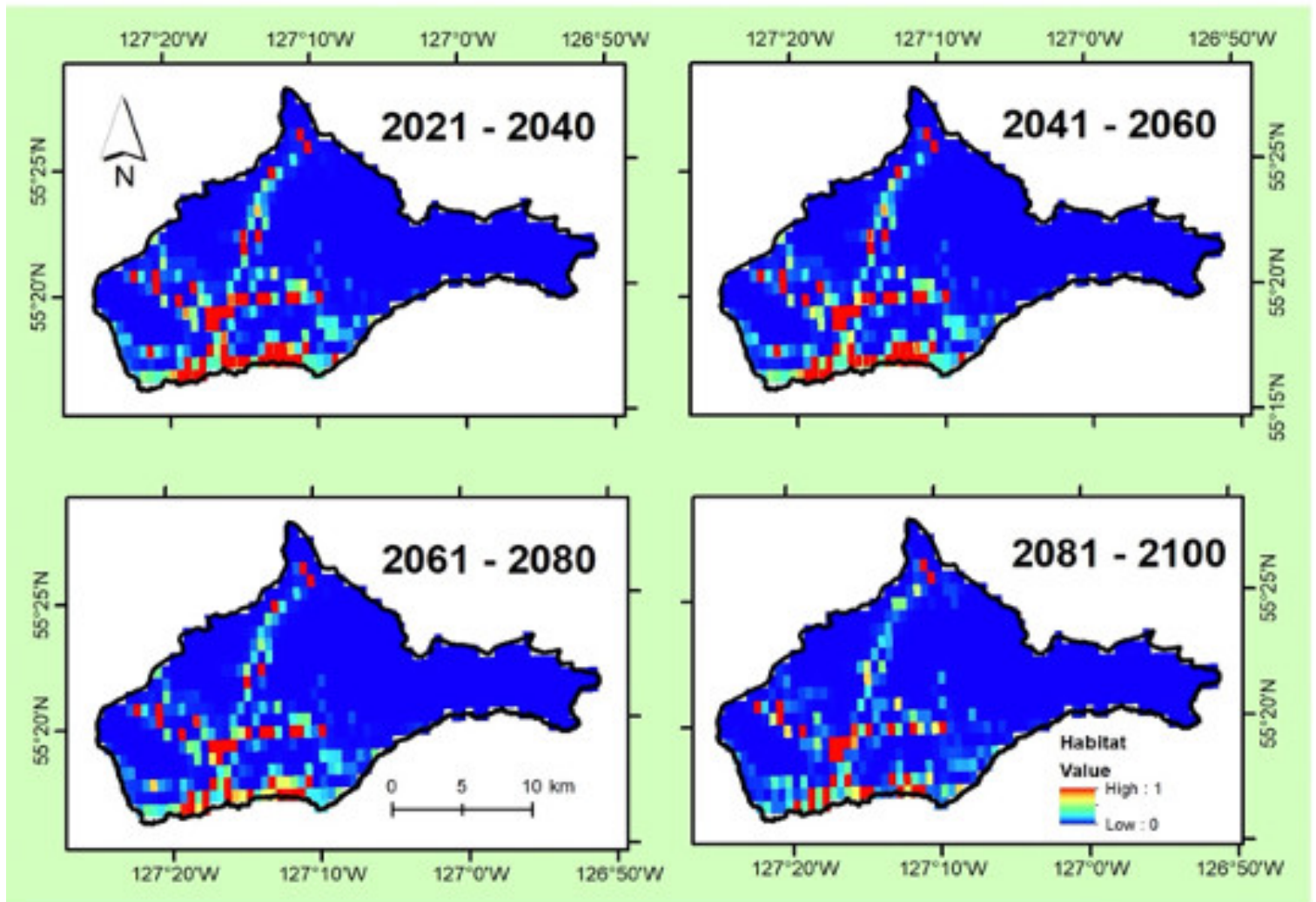


Figure 35. Predictive suitability habitat for devil's club in Madii Lii illustrates the SSP585:2021–2100 climate.

3.6.1. Training and Testing Datapoints with BIOCLIM Model

As well as examining current and future access and availability to devil's club within Madii Lii, this research also examined predictive habitat suitability throughout British Columbia. The result from the BIOCLIM model was used to develop a training and testing presence-absence algorithm for devil's club (Figure 36). The model evaluation generated 318 devil's club present data-points and 1000 species absent data-points, from the 1600 data-points derived from the GBIF download for devil's club locations in BC. The AUC value was 0.8460, providing satisfactory model to construct the predictive habitat suitability model (Table 8)

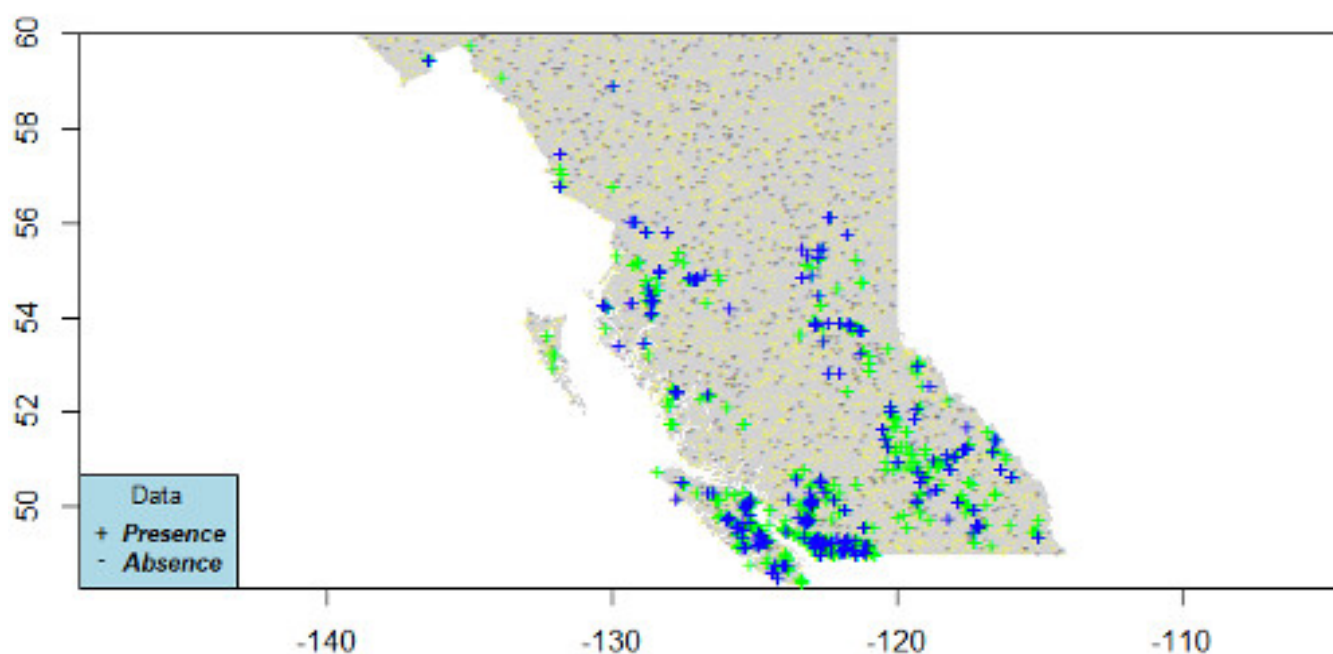


Figure 36. British Columbia testing and training points generated to produce BIOCLIM species distribution model. The blue points represent the species present training data-points and the green the species present testing data-points, yellow are background training points.

Table 8. Summary of model evaluation scores for BIOCLIM model evaluation.

class	model evaluation
n presences	318
n absences	1000
AUC	0.8460
correlation coefficient	0.4395
max TPR+TNR at	0.0228

This model is then used to produce the predicted habitat suitability for British Columbia using the current climate scenario SSP126:2021–2040, (Figure 37).

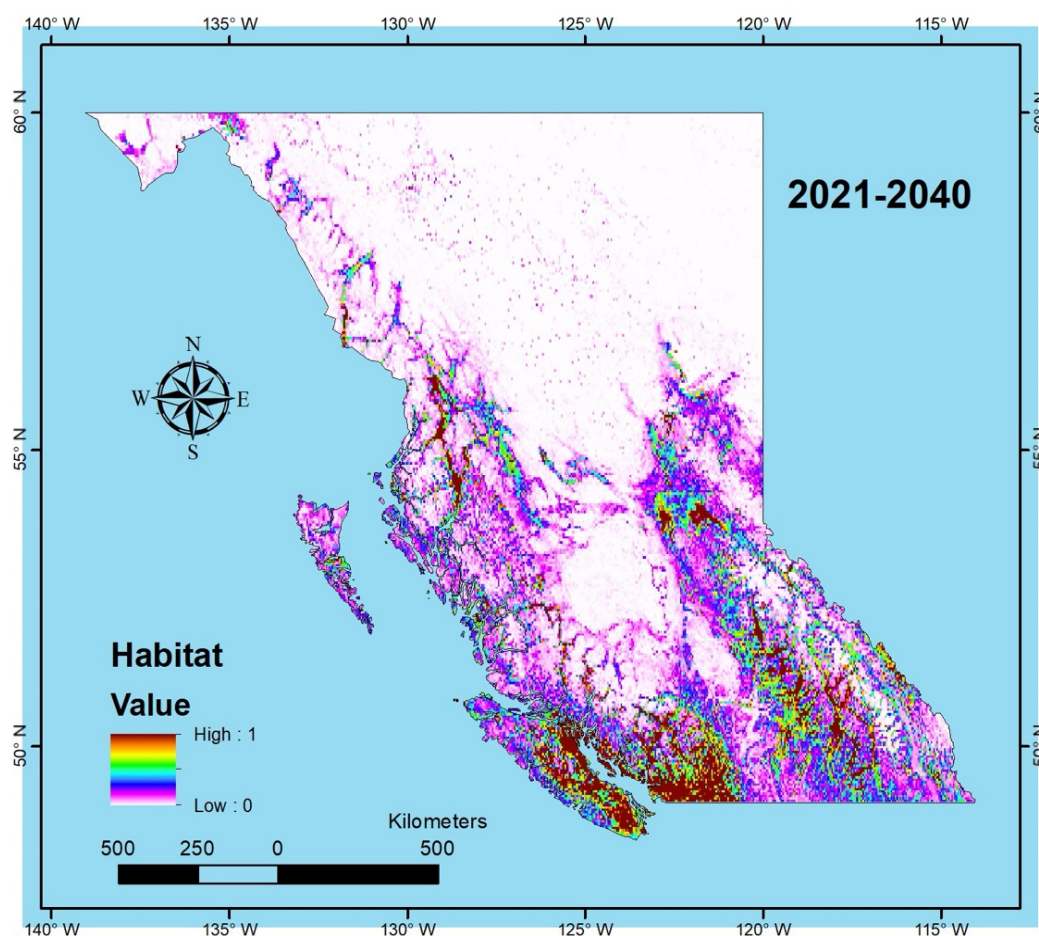


Figure 37. British Columbia devil’s club suitability habitat using BIOCLIM using current and predicted near-future conditions for the (SSP126:2021–2040) climate scenario.

3.6.2. *Maxent Suitability Model*

The BIOCLIM profile method only considers “presence” data. In contrast, the MaxEnt model profile can generally produce more reliable models using machine learning methods that consider all data points from presence, absence and background data. The maximum entropy model was applied to the eighteen environmental variables, which generated predictors that produced a ranked-percentage variable contribution table. The results from the plot indicate which environmental variables are the most sensitive to the MaxEnt model. These data showed

that the environmental variables, Bio_1 (AMTemp, Annual Mean Temperature) with a 23% contribution and Bio_2 (MTempD, Mean Temperature of Driest Quarter) with a 22% contribution, were ranked first and second, respectively, and were the most sensitive to the model. The results for the variable contribution graph (Appendix 7) and response plot for the British Columbia Maxent model (Appendix 8). Having determined which contributing environmental variables influence the predicted likelihood of species presence, the MaxEnt model was then evaluated for accuracy using the ROC and AUC output. Here the AUC value produced a value of 0.9176 (Table 9), which is excellent for predicting habitat suitability. When compared, the BIOCLIM (Figure 38) and the MaxEnt (Figure 39) models showed quite distinct differences. Overall, the MaxEnt model predicted considerably more suitable habitat across the region, of which a substantial amount was shown to be good quality devil's club habitat, indicated by the red, yellow, and green bands.

Table 9. Summary of MaxEnt model evaluation.

class	model evaluation
n presences	318
n absences	1000
AUC	0.9176
correlation coefficient	0.6870
max TPR+TNR at	0.3892

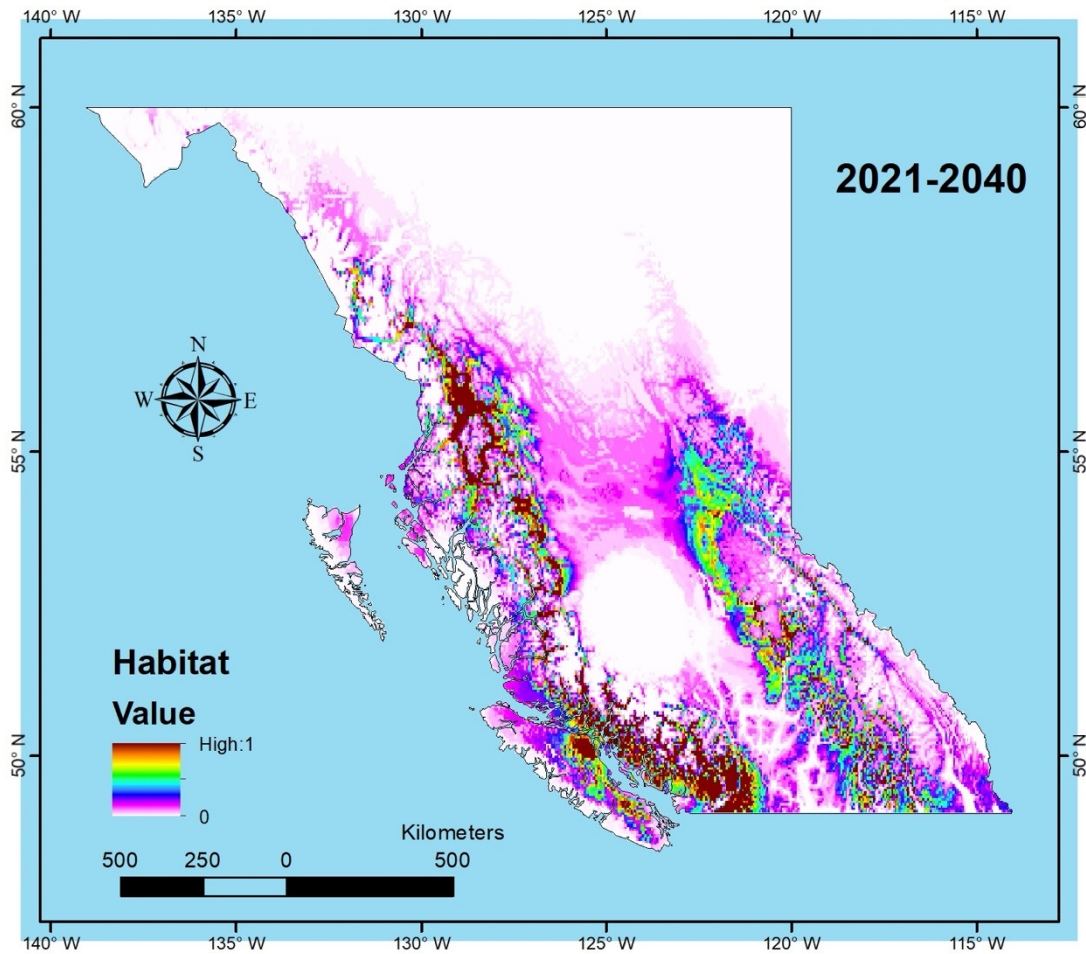


Figure 38. British Columbia devil's club suitability habitat using MaxEnt layer for SSP126:2021–2040.

3.6.3. Random Forest and SVM Model

The results from the Random Forest and Support Vector Machine model profiles were also tested and compared using their AUC scores as indicators for best model fit (Appendix 4). The Random Forest model achieved an AUC score of 0.9720 (Table 10), and SMV received 0.9000.

Therefore, the Random Forest profile was used to complete the predictive habitat suitability modelling for the SSP245:2021–2100 and SSP585:2021–2100 scenarios. When comparing the MaxEnt and Random Forest model output maps, the Random Forest model shows smaller

scattered areas of high-quality habitat shown in red and suitable areas in yellow, than predicted by the MaxEnt model.

Table 10. Summary of Random Forest model evaluation.

class	Model Evaluation
n presences	318
n absences	1000
AUC	0.9725
correlation coefficient	0.8573
max TPR+TNR at	0.4173

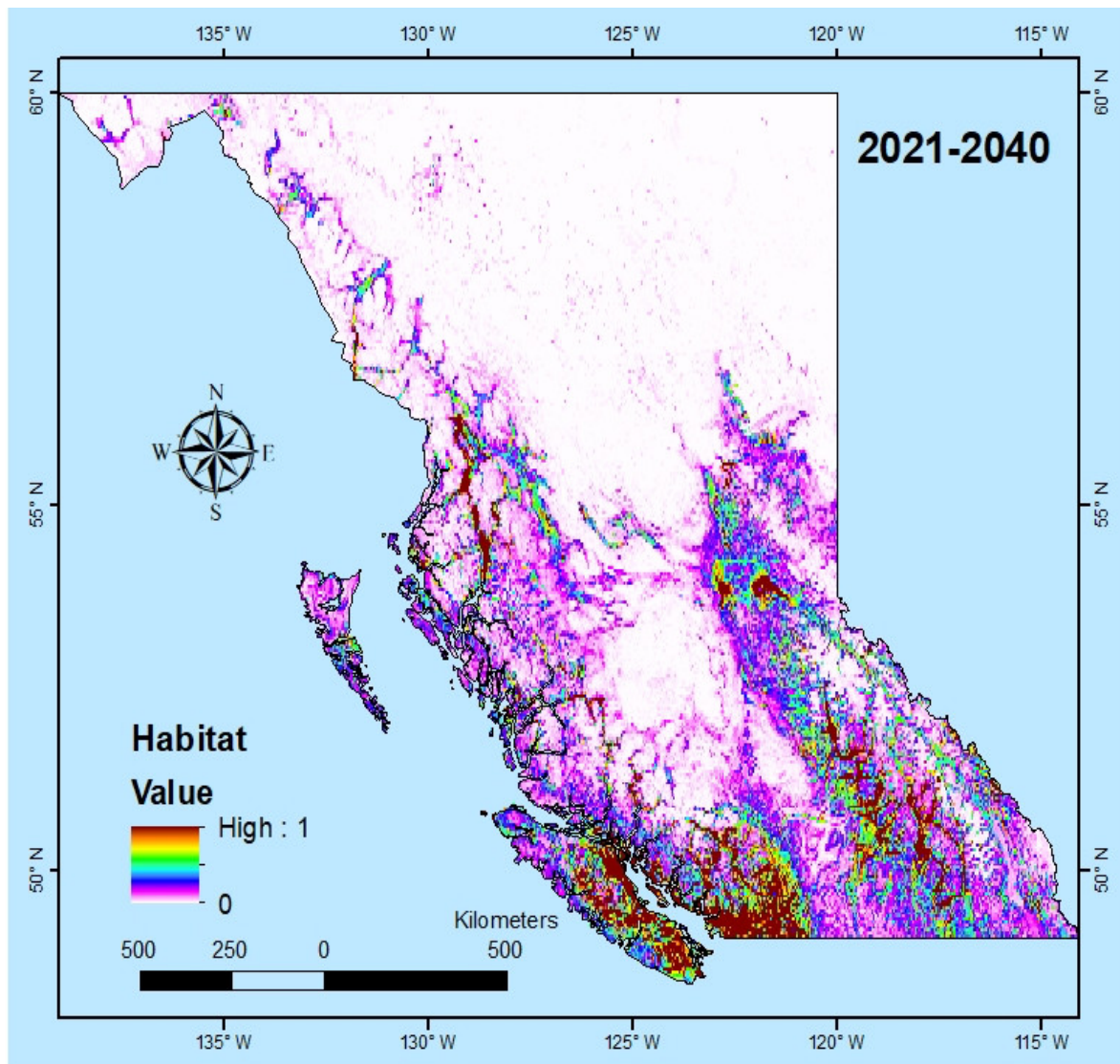


Figure 39. British Columbia devil's club suitability habitat using Random Forest layer for SSP126:2021–2040.

3.6.4. Random Forest Predicted Habitat Suitability Model 2021–2100

In the first scenario SSP245:2021-2100, there is only a modest reduction in the amount of the highest quality habitat shown in red and yellow colour over the four time periods (Figure 40). The most noticeable change is the decline in the moderate quality habitat (turquoise), which is replaced with more low-quality habitat (magenta), and there is considerably greater area of non-suitable habitat (white). Similar to the Madii Lii SSP245 model, the British Columbia PHM indicates an increase in suitable and highly suitable habitat for devil's club for the latter part of the 21st century, possibly due to the plateauing of GHGs in the mid-21st century. SSP245 states that there will be an incremental use of green technologies, and therefore a reduction in fossil fuels emissions. The effect of these improvements will likely take some time to take effect on the warmer climate, and consequently, devil's club habitat.

For the second scenario (Figure 41) SSP585:2021–2100, the decline in suitable habitat for devil's club is severe. In this sequence, there is even less quantity of the highest and very good habitat (red, yellow, and green) from the outset, and maintains a few very small areas in the southwest of the province, around the Vancouver area. The loss of mediocre and poorer quality habitat is quite evident. The scattered area of magenta that runs parallel to the coastline becomes completely fragmented, leading to infrequent areas of low-quality habitat being replaced by increasingly large areas of unsuitable habitat as the area of white increases.

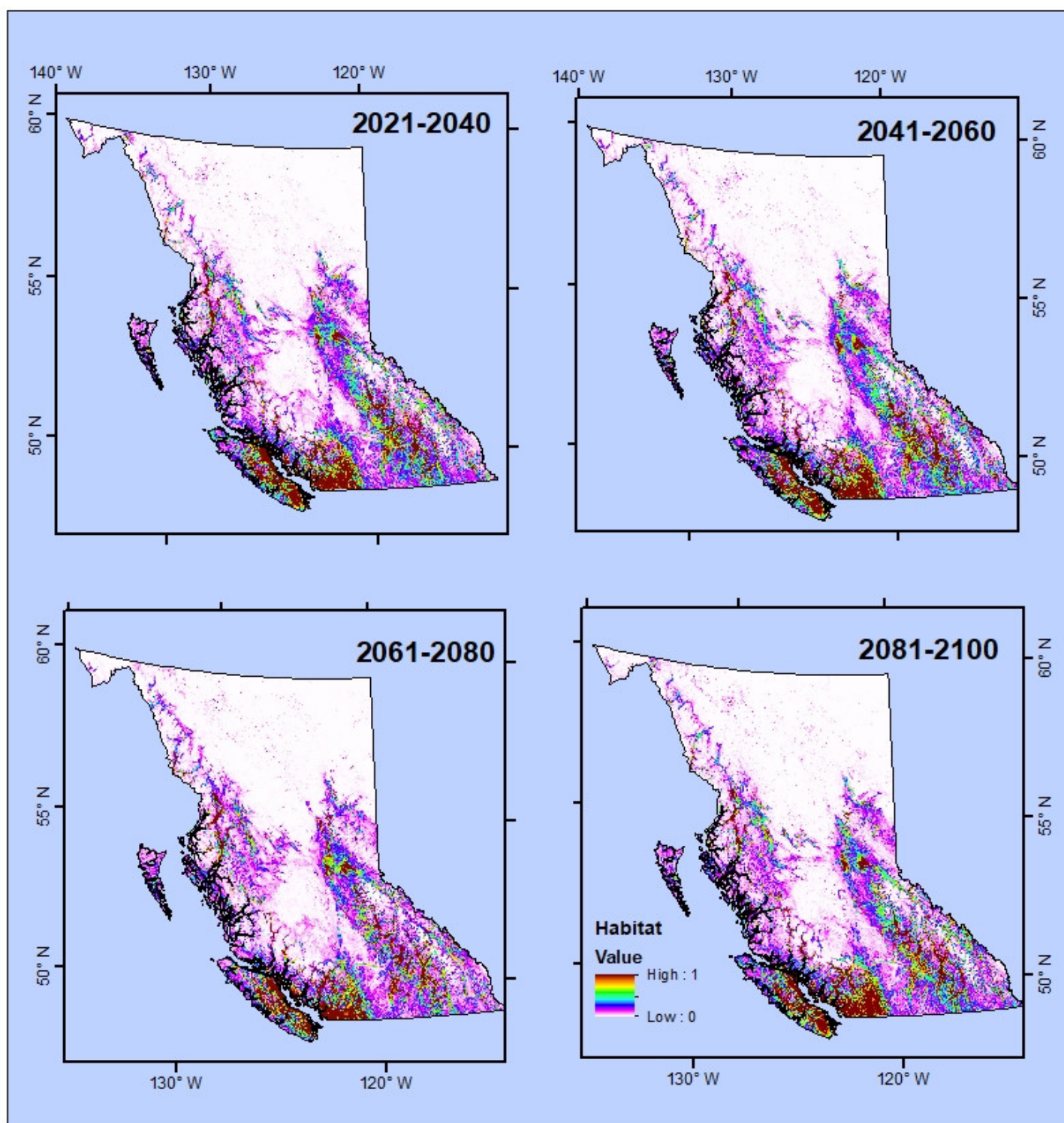


Figure 40. Predictive habitat suitability models using Random Forest layer for SSP245:2021–2100.

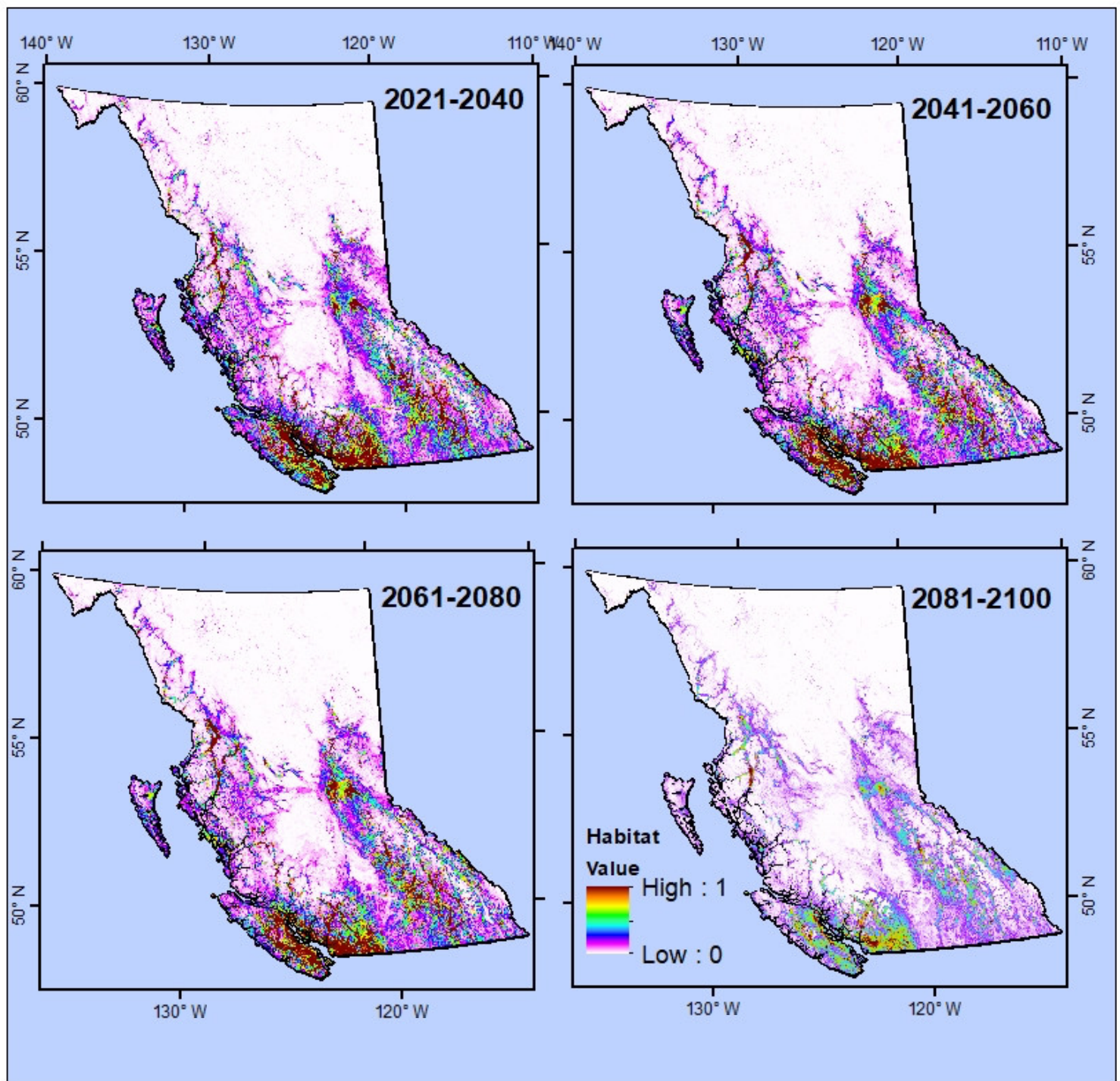


Figure 41. Predictive habitat suitability models using Random Forest layer SSP585:2021–2100.

Chapter 4

4.0 DISCUSSION

4.1 Looking Back

Madii Lii has been heavily logged for more than sixty years, starting with selective cedar pole logging in the late 1950s. Since the 1960s, clearcut logging in Madii Lii has removed all commercial timber from 4169 ha of the landscape, equating to 11.8% of the entire territory—even more when one accounts for unforested areas in the alpine (Rabnett, 2018). Out of the 352 km² of territory, most of the 42 km² of clearcut cutblocks are located within the ICHmc1 and ICHmc2 BEC zones, which is known to be typical devil's club habitat. The logging industry has altered the landscape of Madii Lii, impacting devil's club habitat and impacting the availability of large, sought after specimens suitable for medicinal and cultural use.

Research findings suggest that certain types of land use histories significantly affects devil's club growth patterns, both in the vigour of individuals and the abundance of devil's club stems. Devil's club stem abundance and stem diameter were both found to be considerably greater in areas traditionally used and managed by Luutkudziiwus people (i.e., not industrially logged), compared to both unlogged control sites and previously logged sites. This finding is significant for Gitxsan harvesters because the most desirable characteristic for devil's club harvest is usually its size (stem diameter) and abundance (diversity of choice) as harvest preference is often based on plant vigour and abundance (Gottesfeld & Anderson, 1988). The evidence from this study indicates that logging activities are, overall, compromising the availability and quality of devil's club for Luutkudziiwus people.

Using morphological data as a proxy for devil's club health and vigour, combined with stem abundance, the data revealed that devil's club would take about 26 years to regrow to the abundance (quantity) and size (diameter) of previously unlogged (control) sites, but at higher

elevations, with much slower growing, this may increase to roughly 50 or more years to regenerate to a size comparable with the preferred individuals harvested for cultural uses, like those found at the traditional use sites. These data concur with previous research, which suggests that devil's club could persist after disturbance, such as logging or fire, but regrowth takes a significant amount of time (Burton & Burton, 2015; Lantz, 2001b; Lantz & Antos, 2002). The impacts on Luutkudziiwus peoples' harvesting practices could be significantly impinged with possibly between 26–50-year recovery period, which is comparable to two generations of people and therefore affects knowledge transmission. The majority of cultural knowledge regarding medical plants and healing in Gitxsan contexts is transmitted verbally from one generation to the next and is practiced experientially on the land. A two-generation gap in knowledge transfer would likely disrupt the flow of cultural knowledge of traditional medicine (Calixto, 2005). While ethnobotanical floras and written documents about devil's club (and other important plants) are relevant for maintaining knowledge of select plant species, these texts cannot replace the experiences and relational teachings that come from being on the land and taking part in harvesting practices directly (e.g., Geniusz, 2022).

Devil's club growth patterns are not simply a function of the time since logging. As expected, sites with the most recent logging events had shorter, less productive stems. However, stem thickness varied with time since industrial logging. For example, morphometric data in logged sites alone (not in controls or traditionally managed sites) showed that some thicker stems were observed in sites logged between 1980–1989 and not, as hypothesized, in the older logged sites from 1970–1979. Devil's club on sites surveyed from the highest elevations were generally smaller (containing only a few short, small-diameter stems), making these pockets of devil's club especially vulnerable, despite the recovery time. This would suggest that devil's club grows particularly slowly at higher elevations. As a result, this phenomenon of smaller devil's club at

some of the older sites may be explained by differences in elevation, temperature regime, and growing season length. However, these data did also show that some of the 1980-89 logging occurred some of the highest elevations, and that that it is likely there are other factors which could also influence the stem thickness such as change of logging practices between those eras. Or it is also possible that devil's club stem growth is non-linear and may peak at about 40 years, and possibly decline with stand age

Some practitioners prefer stems harvested from higher elevations, as they are reputedly more potent or powerful (Larson, 1988; Turner et al., 2011) and “cleaner” compared with plants harvested from lower elevations (Gottesfeld & Anderson, 1988). Ethnobotanical data suggests harvesters prefer high elevation sites, possibly because the labour involved offers spiritual significance or the slower growth could mean denser tissues and higher concentrations of active ingredients (Armstrong, 2022; Gottesfeld & Anderson, 1988b). This research confirms that even with a 50+ year recovery period, or even longer at higher altitudes, desired devil's club harvest sites are not consistently recovering from logging activities. These findings confirm that forestry regulators and practitioners need to consider devil's club recovery on a site-by-site basis and with regards to cultural preferences. Other research similarly suggests that devil's club is a negatively impacted understory species that takes longer to recover, regardless of the type of logging practiced (Beese et al., 2022; Lilles et al., 2018).

During sample collection in Madii Lii, the site elevation and location was noted to be consistent with the history of logging in the area: intensive high-grading of the most desired species at lower elevation (easily accessible cedar-hemlock stands) began in the 1950s and 1960s, then the practice of clearcutting rapidly advanced into the territory, removing the most profitable and accessible wood fibre. By the 1980s, logging occurred at progressively higher

elevations (~1000 m), with the continued advancement of cutblocks simultaneously degrading characteristic devil's club habitat.

By the later 1990s, loggers in the Kispiox Timber Supply Area (TSA) gradually returned to the lower elevations and further into the territory to access the more challenging terrain to harvest in mixed cedar-hemlock forests. This resulted in further destructive impacts on the remaining devil's club habitat. As more access roads were constructed, the loggers in the TSA removed large volumes of timber from more and more parts of the territory, especially at lower elevations. The rapid construction of access roads and clearcutting meant that most of the easily accessible, high-economic value forest stands were quickly exhausted, and by the end of the 1990s, 85 % of the western redcedar stands were removed (Rabnett, 2018).

This research found that the largest and most productive devil's club patches were located in the lowest elevation sites. Several factors could result in the larger size and greater abundance of devil's club growing at lower elevations. Specimens from lower elevation sites benefit from longer growing seasons, an earlier snowmelt, and a longer duration of warmer temperatures compared with those from higher elevation. In addition, it is possible that localized habitat conditions found at lower elevations such as nitrogen-rich, moist soils with good drainage all contribute to larger devil's club patches. The impacts of the early logging should also be considered. Two different methods of logging, high-grading and clearcutting, both occurred at these low elevation areas, and may have had different impacts. Those low-elevation logging sites have had the longest recovery time of 50+ years, possibly affecting the continuity of devil's club harvesting and knowledge transmission over recent years.

When preparing devil's club for medicinal or spiritual purposes, many practitioners favour the thickest stems for practical reasons: Helen Watkins states "as the labour required to de-bark and process is the same for a large stem, as it is for a small one" (Betcher, 2016). It

makes the task more efficient and produces a greater quantity of medicine for the same amount of work. The most abundant quantities of thicker stems that can be found in Madii Lii are generally located at mid- to lower elevations. For example, the site with the thickest diameter stem (44.9 mm) was collected from an elevation of 471 m within one of the traditional use sites, among a patch of 29 large diameter stems many of which were 20–25mm diameter. In contrast, these data showed that at the highest elevation site (at 997 m, logged in 1979) there were only a handful (13) of stems with a median stem-diameter of 11.4 mm.

Devil's club showed greater health and vigour at Luutkudziiwus traditional use sites, such as those close to Gitxsan village sites, the Babine trail network, managed berry sites, and other cultural sites (e.g., Xsi Nox Nox Loobit). It is likely that these landscapes were managed and maintained by Luutkudziiwus community members for centuries, resulting in desired management outcomes for species like devil's club. Previous research has shown that post-logging slash-burning significantly impaired the regrowth of devil's club (Burton & Burton, 2015; Hamilton, 2006). Factors that impact devil's club regeneration after slash burning include altered moisture regime, competition from faster-growing species and, in most cases, high-intensity slash burning results in large-scale organic soil depletion. The extremely high temperatures generated during slash-burning most likely kill all the basal and below-ground buds and other meristems, severely hindering devil's club regrowth or survival at these locations.

Other post-logging practices such as chemical treatments (e.g., with the herbicide glyphosate), and reforestation with quick-growing commercial crops (e.g., spruce and pine), can also compromise the ability of native species like devil's club to re-establish and persist. Initially, it was thought that glyphosate's direct toxic effects were short-lived and limited to the target species (Grossbard & Atkinson, 1985), however, long-term toxicological studies suggest that

plants sprayed with glyphosates experience delayed flowering and disrupted reproduction patterns (Boutin et al., 2014).

Overall, the logging industry has drastically reduced access to devil's club in Madii Lii for Luutkudziiwus community. One of the major factors contributing to peoples' favourite patches is accessibility. Geospatial analysis indicates that roughly 150 km² of Madii Lii territory lies in the preferred devil's club habitat of the ICHmc1 and ICHmc2 BEC zones. Of that, ~ 40 km² have undergone clear-cut logging (~ 27%), and associated impacts from logging road construction and skidder trails have drastically reduced habitat. Of the remaining 110 km², 15 km² of predicted devil's club habitat is currently inaccessible due to a collapsed bridge that once spanned Natlan Creek. The collapsed bridge, which would have permitted access to a considerable area of devil's club habitat, highlights an important issue that since the forest licensees ceased operating in Madii Lii, they are no longer responsible for maintaining road infrastructure. Once roads are no longer needed for harvesting or silviculture, the repair of forest access roads becomes the duty of the Province, and vehicular access should be provided, where community stakeholder's express the desire to maintain access. Lastly, 13 km² of the remaining predicted devil's club habitat, located at the upper reaches of the Denison Creek and the Upper Suskwa, are also inaccessible due to flooding (likely by a beaver dam).

In addition, the areas of high suitability devil's club habitat found along the Iltzul Creek are very steep and are virtually impossible to access. In reality, there are only a few easily accessible areas of devil's club left in the territory, which are mostly found alongside the Suskwa Forest Service Road and the Babine Trail. Additional devil's club patches, which remain reasonably accessible, are located along the Denison and Iltzul Forest Service Roads. However, both roads are now heavily congested with brush and are only accessible by all-terrain vehicle or by foot for those individuals determined to enter these areas. The compounding impacts to

habitat, the slow-growing nature of devil's club, cultural preferences, and the territory's topography mean that access to readily available and desirable stems is considered low.

Results showed that forest canopy and light dynamics affect devil's club morphology in significant ways. As predicted, shade had a significant effect on stem length. This makes sense, as generally plants are light-deprived and stem growth is directed to finding sun flecks and canopy openings, and therefore, the stems tend to be longer and leggier in areas with less available sunlight. Partly shaded sites, with mixed canopy gaps, produced devil's club plants with large leaves and the thickest diameter stems; the results showed that, where canopy cover exceeds 75%, many of the smallest diameter stems were located. This also makes sense given that devil's club prefers mixed or spotty sun exposure, a characteristic of mature or old growth forests (MacKinnon & Pojar, 1994). These findings do not fully agree with earlier research conducted in the Nass Valley, which found that the thickest stems were found in either open conditions or in the shade created by piles of slash or logs—dead shade (Burton & Burton, 2015). The difference in findings may be attributed to the differing locations for the research; the Nass Valley has a more coastal climate with greater cloud, and their sampling occurred in considerably younger cutblocks where there was more competition with brush or dense trees (Burton & Burton, 2015).

Previous research performed in second-growth boreal mixed-wood forest showed that successful understory species such as velvet leaf blueberry (*Vaccinium myrtilloides*) are able to persist in heavy shade conditions by employing biomass allocation plasticity. Researchers found that this species was able to adjust resources to either specific leaf area, leaf area, individual leaf weight, and the proportion of total biomass in stems, depending on the level of shade (Moola & Mallik, 1998). Likewise, it appears that devil's club possesses a similar plasticity trait (found in most plant species) that induces stem elongation and larger leaf growth under shadier conditions

compared with species in open canopy environments (Givnish, 1988; Power et al., 2021; Valladares & Niinemets, 2008). This research also agrees with previous research which found devil's club will flourish in areas exposed to combinations of dense shade and periodic exposure to bright sunlight, such as found in canopy gaps created by a natural disturbance such as blow-down or lightning strike.

4.2 Looking Forward

The Intergovernmental Panel on Climate Change (IPCC 2018; Masson-Delmotte, et al., 2021) concluded that anthropogenic climate change has caused an increase in global temperature by 1.18°C above pre-industrial levels and is likely to reach 1.5°C between 2030 and 2050. The impacts of global temperature increases will vary in different regions and biomes across the planet. For example, the polar regions are expected to experience increase in average temperatures of between 5°C to 6°C by 2100 (Price et al., 2013) and the boreal forest biome in Canada is projected to undergo the widest range of mean annual temperature increases, between 4°C and 11°C by the end of the 21st century (Gauthier et al., 2015; Price et al., 2013). To understand how these predicted changes may impact devil's club distribution, range, and habitat across varying climate scenarios, this research projected species distribution models for varying climate scenarios with the ultimate goal of predicting how devil's club will fare under uncertain climate futures.

Devil's club SDMs for Madii Lii and British Columbia, combined with climate change predictions, presented areas of suitable habitat and favourable environmental conditions, which indicated the probability of devil's club presence/absence at a particular location. Four high resolution SDMs in 20-year increments at Madii Lii, and four low resolution SDMs for the entirety of British Columbia were generated. By extrapolating my documented devil's club

distribution data obtained during this field research SDMs illustrate where devil's club might persist (and/or thrive), and where habitat will likely change over the course of the next 80 years. These data are instrumental for Luutkudziiwus land-use planning, to help identify where devil's club habitat should be protected.

Based on these data collected during field sampling in Madii Lii, and the subsequent PHMs generated from these data-points the climate change scenarios produced some interesting results. The species distribution models for Madii Lii indicate that steep-sided valleys, toe-slopes, and benches, all associated with three large watercourses that flow through Madii Lii (Natlan, Iltzul and Denison Creeks) and the Suskwa River all continue to provide suitable habitat for devil's club. The models suggest that two significant indicators for devil's club presence/absence are mean annual temperature and mean annual precipitation. The predicted impacts from both climate change scenarios (SSP245 and SSP585) suggest an overall decline in highly suitable and suitable habitat over the next 80 years. However there appears to be a distinct difference in the amount of high-quality habitat at the end of the century between the SSP245 and SSP585 scenarios. The models predict that there will be a considerably larger area of suitable habitat for devil's club in the former scenario, most likely due to the lower GHG emissions as a result of the increased use of green technologies and the decline of fossil fuels during the mid-21st century. Without those transitions, devil's club habitat will decrease significantly in Madii Lii and British Columbia.

The SSP245 model progression shows a decline in habitat through to 2080 but then begins to rebound, and there is an appreciable increase in the highly-suitable habitat along the Natlan Creek and Suskwa river areas when comparing 2080 with 2100. The SSP585 model predicts a steady decline in the areas of highly suitable devil's club habitat are nearly eliminated,

except for a small area by the Suskwa River, and overall, the area of unsuitable habitat increases over time.

Climate models indicated that annual precipitation and precipitation of the wettest quarter and driest quarters all had a maximum tolerance, after which precipitation becomes too excessive, and reduces the probability of devil's club presence. This will become more important as precipitation levels become more erratic, and the frequency of extreme-weather events such as "atmospheric rivers" (ARs) become more common in British Columbia. It is expected that, between 2070 and 2100, extreme AR events will increase in frequency in British Columbia, especially during December (Radić et al., 2015). Climate models project an overall increase in total precipitation over BC, with the increased frequency and intensity of AR-extreme events, and repeated AR-events with precipitation exceeding 20 mm per day (Radić et al., 2015). Furthermore, for Madii Lii, the anticipated path for many of these AR-extreme events is to move northward (from southern BC), bringing more precipitation to the north coast of BC. While Madii Lii is over 200 km from the coast, there is widespread perception and expectation that the northwestern region is becoming similar to a coastal in climate, and the additional precipitation will impact the territory. The northern coastal region of BC is expected to experience annual precipitation increase between 6% and 26% (dependant on climate change scenario) by the end of this century (Haughian et al., 2012). Moreover, when comparing the current condition (SSP126) model with both the intermediate and high-level greenhouse gas emissions scenarios (SSP 245 and SSP585), my model shows significantly fewer areas of the best and high-value habitat for devil's club, with an increasing amount of unsuitable and very low suitability habitats. However, as with many wild species, there is a progressive northerly shift and expansion of some previously unsuitable habitats becoming low-quality but suitable (Hirabayashi et al., 2022). Studies have shown that some species will migrate to higher elevations as the effects of climate

change become more apparent (Breshears et al., 2008; Kelly & Goulden, 2008; Lenoir et al., 2008). Unfortunately, Luutkudziiwus people likely cannot, and will not, have access to these potential northern clusters at the higher elevations given that they are far from home (reducing accessibility) or outside of their territory (which would belie customary governance structures and land-use protocols.). However, it is possible that devil's club populations from the south and coastal areas may migrate further inland as the climate changes to a more coastal, as many researchers are predicting (Haughian et al., 2012). However, with this migration to higher and mid-elevation habitats may become congested, and competition threatens endemic species with increased risk of extinction and homogenization (Gómez et al., 2015; Jurasinski & Kreyling, 2007; McKinney & Lockwood, 2001). In all scenarios, the availability and accessibility of devil's club in this landscape could be considerably reduced over the next 80 years. Furthermore, locations where devil's club clusters persist may be limited to difficult to reach places, such as remote valley bottoms, and therefore the construction of access roads or trails will be needed to allow for harvesting. Conversely, any revitalization of traditional trails could benefit Luutkudziiwus community members as these new trails would possibly serve several purposes such as resource access and future potential eco-cultural tourism.

Two climate scenarios were analyzed including, SSP 245 and SSP585. Scenario one (SSP245) first predicts a moderate increase of GHG emissions with resulting warming of 3.8-4.2°C by the end of the 21st century (Fricko et al., 2017). Scenario two (SSP585) anticipates a continuous unrestrained worldwide economic growth fuelled by unrestricted burning of hydrocarbons, and thereby producing the highest overall GHG emissions by the year 2100 (Fricko et al., 2017). As a result, the predicted global temperature increase is expected to be 4.7–5.1°C. by the end of the 21st century (Fricko et al., 2017). These are graded according to lower impact (SSP245) and highest impacts (SSP585). The anticipated change in weather patterns could have

a profound effect on the access and ubiquity to this vital medicinal and culturally significant plant for First Nations groups across the province of British Columbia. The baseline model illustrates the estimated range of devil's club today across BC, and it clearly shows two distinct regions with good quality habitat, one in the east of the province, on the windward slopes of the Cariboo, Selkirk, Monashee, and Rocky Mountains, and one in the west, which follows the Coast Mountains (Figure 42).

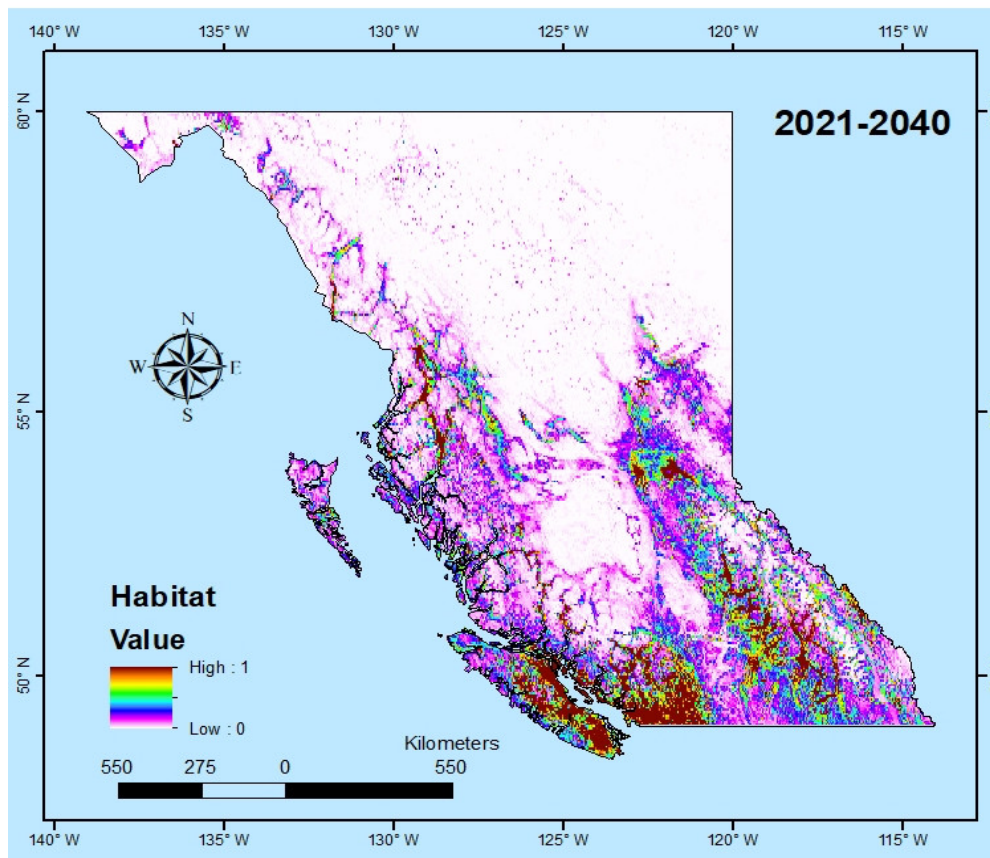


Figure 42. British Columbia devil's club suitability habitat using BIOCLIM using current and predicted near-future conditions for the (SSP126:2021–2040) climate scenario.

For the predicted models, scenario 1 (SSP245) forecasts a moderate increase in GHGs leading to $\sim 1.7^{\circ}\text{C}$ rise in temperatures across BC, while the second scenario (SSP585) predicts a potential increase of 4.75°C , as GHG emissions continue to rise throughout the 21st century (Haughian et al. 2012). Climatologists have generated models that calculated the probability of a

reoccurrence of the record-breaking temperatures that occurred in British Columbia in June–July of 2021. The models indicate that by 2055–2064, the chance of an individual day exceeding a previous record-high is 1-in-1000 years or (0.01%) for the SSP126 (a low emission pathway reaching net zero by 2075, with global temperatures forecast to increase to by 1.7°C by 2040, and to 1.3–2.4°C by 2100; Thompson et al., 2022). In contrast, scenario SSP585 projects the chance of an individual day exceeding a previous recorded high-temperatures (record high) increasing to 1-in-75 years (1.3%) by 2064, and by 2094, the chance rapidly increases to 1-in-6 years (17%) (Thompson et al., 2022). This projected increase in temperatures, during the driest months and throughout the year, could severely impact the viability of a plant that is stressed by prolonged periods of extreme heat. Combined with the excessive and intense precipitation events expected, devil’s club is facing a very uncertain future.

Predictions suggest that over the next eighty years, many plant species (not specifically *Oplopanax horridus*) will be forced into ever-smaller regions and pushed into areas of higher elevation and possible higher latitudes (Higgins et al., 2003; Hirabayashi et al., 2022). For most of BC’s Indigenous peoples, harvesting devil’s club of suitable size and quality will become increasingly challenging. As mean temperatures increase and weather patterns change, many understory plant species that flourish in forested microclimates, having cool moist environments and with lower interannual variability, will experience more pronounced impacts of a warming climate (De Frenne et al., 2021). Prev  y et al. (2020a) examined three culturally-important food-producing species from the northwest USA for several Tribes from Washington, Oregon, northern California, Idaho, and western Montana. These species — beaked hazelnut, Oregon grape, and salal— are expected to experience a reduction in suitable habitat, affecting cultural transmission of use and management, and the livelihoods of people that depend on them. The study also predicts that the projected reduction in climate moisture would cause the southern

regions and lower elevation ranges of these species to disappear by the end of the 21st century. Changes in the thermal regime could also induce a cascade of effects by altering the phenology of many plant species (Prevéy et al., 2020a).

4.3 Limitations of Research

During this research, I endeavoured to produce a thorough and unbiased assessment of the recent impacts of logging on devil's club and the predicted impacts of an uncertain climate future. However, with all research, there are limitations to what was possible due to time and budgetary restraints. A key factor I would have addressed was that I intended to sample over a wider area. A significant section of the ICH/clearcut logging areas was inaccessible, and the subsequent reduction in sampling sites may have skewed my results for both the devil's club abundance and morphology statistical analyses, as well as the species distribution and climate-change modelling predictions. Consequently, the results and conclusions derived from this research should be considered with that caveat in mind. In addition, the Stand-Age/Time Since Disturbance age-data used to date the control and Traditional Use sample sites was retrieved from the Vegetation Resource Inventory (VRI) (FLNROD, 2018a). Therefore, the reliability of results from the analysis when compared with the logged sample sites is dependent on the quality of the VRI data.

Likewise, for the Predicted Habitat Modelling for the Province of British Columbia. The presence data was retrieved from a single repository (GBIF); therefore, relying on the quality of that data could be problematic. The GBIF repository depends on the iNaturalist membership to submit presence data. Consequently, there could be a bias towards recorded presence data points in areas which have greater populations and accompanying large academic institutions such as

universities. Therefore, the areas of highly suitable devil's club habitat seen in the Vancouver metropolitan area may be due to a sampling bias.

There are inherent constraints and assumptions involved with predictive habitat modelling, and model-reliability is derived from the quality of input-data. Models can only reflect their calibration and training-data; therefore, the entire species-range should be applied to the model. If a species subset from a limited area is used, then model prediction usually predicts a contraction of suitable habitat in the future. Another reoccurring issue with PHM is the reliance on, using the Area Under the receiver operating characteristic Curve (AUC) value as the primary indicator of model robustness may be problematic, as different spatial scales can result in higher or lower model fit values (Jiménez-Valverde, 2012; Lobo et al., 2008). However, studies have found that the Random Forest (RF) model algorithm is often the most effective model and consistently performs better than the other algorithms at a large spatial scale (Aguirre-Gutiérrez et al., 2013).

PHMs cannot discriminate the effects of inter-species influences and do not incorporate many other environmental factors such as soil nutrient composition, mycorrhizal relationships, and soil moisture, which could induce either a positive or negative effect on a species distributions and adaptations to climate change. Moreover, SDMs and PHMs also typically fail to take account of population differences in their genetic adaptation to local climates, soils, and biotic stresses. In addition, PHMs do not consider the impact of change of land-use or disturbances such as fire or beetle infestation. Refugia from such disturbances, and locations more likely to provide habitat continuity over time can also offer protection for suitable habitats that otherwise might be lost (Rose & Burton, 2009). Despite these limitations, SDMs and PHMs modelling provide valuable insight into our likely near-future reality and provides a basis for scenario planning and can guide the direction of conservation efforts.

Chapter 5

5.0 CONCLUSION

The primary goal of this master's research was to assess the effects of a history of clearcutting on the *wa'uumst*, or devil's club (*Oplopanax horridus*) resource in the wilp Luutkudziiwus traditional territory known as Madii Lii, and to understand how this impacts the current and future availability of this medicinal plant. I examined whether devil's club can persist and regrow after the logging, and what the effects are on plant abundance and morphology in former clearcuts compared to undisturbed and/or Indigenous managed areas. Predictive habitat models using two climate change scenarios (SSP245 and SSP585) were used to assess local and regional climate change on devil's club distribution in British Columbia.

The results from this research suggest that devil's club has been significantly impacted by clearcut logging practices in Madii Lii over the last five decades, with reduced abundance, size and availability. However, as with previous studies (Burton & Burton, 2015; Lantz and Antos, 2002), this research also indicates that devil's club can persist in cutblocks after logging. Unfortunately, it appears that to reach the preferred sizes (e.g., >25 mm stem diameter, Burton & Burton, 2015) and quantities for medicinal and cultural purposes may take 26 to possibly 50 or more years to recover, depending on elevation. The research also showed that the optimum shade where devil's club can thrive is up to 75%, suggesting post-logging recovery could be impeded where replanted with closely packed commercial crops such as hybrid-spruce replacing the original cedar-hemlock dominated forests.

5.1 Recommendations

Given the cultural significance and the potential impact on Luutkudziiwus and the loss of valuable medicinal knowledge, any future extractive or destructive resource projects should include protective measures for areas where devil's club is regularly harvested and patches of devil's club which exceed a pre-determined size. To protect these valuable patches, I suggest determining a buffer zone of a proportionate size using green-tree retention areas (Bennett & Mulongoy, 2006; Hansson, 2001; Rosenvald & Löhms, 2008). Madii Lii is currently under threat from linear developments such as liquified natural gas (LNG) pipelines and power transmission lines, including the Prince Rupert Gas Transmission project (PRGT) and, more recently, the possible revival of PRGT to service the proposed Ksi Lisims LNG project. If these or similar developments eventually proceed, then it is essential that exclusion zones surrounding productive devil's club habitat should be implemented prior to commencement of any work.

Another concern for continued cultural use is that only a handful of the areas sampled had a plentiful number of stems of the favoured diameter and are possibly vulnerable to over-harvest. Because of the slow-growing nature of devil's club, and the prolonged time required to reach the desired size, the low availability of high-quality devil's club stems may inhibit the flow of cultural knowledge of devil's club. Therefore, by utilizing these data from survey plots and SDMs for devil's club in Madii Lii, it would be possible for Luutkudziiwus Elders or knowledge keepers to regulate the quantity and location of any significantly large devil's club harvest in Madii Lii. Also, in order to prevent a catastrophic loss of adequately sized devil's club, it may be wise to prepare for future scarcity by the initiation of a devil's club cultivation plan. One possibility is to develop a multi-pronged devil's club sustainability plan, based on protection, regulated harvesting, and possibly cultivation to be implemented by Luutkudziiwus community

leaders. Cultivation of devil's club could occur within a forest garden, or in areas specifically designated within Madii Lii. such as proximate to the ancient village site. This may not be the ideal solution, due to the spiritual nature of harvesting but may ultimately be required to ensure the continued availability of this important medicinal plant.

The historic victory in the Federal Supreme Court Decision of *Delgamuukw and Gisday'wa v. the Crown* (S.C.C.44) affirmed Aboriginal title in British Columbia, that it is a right to the land itself, and not only the right to hunt, fish or harvest. The ruling further means that when dealing with Crown land, the government must consult with and may have to compensate title holders whose rights are affected. The duty to consult with First Nations groups affected by natural resource projects, including forestry and pipelines, is often seen as a hurdle by industry rather than an opportunity to understand how these projects and industrial activities will likely impact traditional livelihoods including the gathering of plants for food and medicine, in this case, devil's club. As a plaintiff in the case, Luutkudziiwus has not been effectively consulted in resource management contexts, and this research confirms how impacts from industry directly impact the cultural and ecological health and well-being of house members.

As well as the data regarding the location and size of devil's club patches, this research complements the catalogue of evidence that details how successive provincial governments and their agents have largely ignored the incidental impacts of intensive forest practices such as widespread clearcutting. The detrimental impact of even-aged forest management on devil's club and these effects on Luutkudziiwus members, have been effectively disregarded by forest licensees and the provincial government for the last fifty years. Fortunately, as this research shows, devil's club can recover from the impacts of logging, though it appears that several decades, or two generations of Luutkudziiwus will pass during this time.

In conclusion, possibly the most significant contribution of this study is the documentation of the detrimental effects of environmental change on the culturally salient medicinal plant known as *wa'uumst*, or devil's club in Madii Lii. As the highly suitable devil's club habitat degrades and becomes less available due to the warming climate, devil's club of appropriate size will likely become more challenging to find and harvest, particularly with respect to the SSP585 climate model. Consequently, the flow of cultural knowledge may diminish with the availability of the plant, both in Madii Lii and throughout British Columbia. This environmental degradation has seen immediate impacts in the case of logging, and this degradation may continue over time as a consequence of climate change. The reduction in availability and the impaired access to devil's club has and will continue to harm the transfer of Luutkudziiwus Indigenous and local knowledge.

5.2 Future Research

These results illustrate the time required for devil's club to re-establish post-logging, and, therefore, how this may impact the availability of the plant for Luutkudziiwus cultural use. However, as time, resources and access were limiting factors, for future research I suggest undertaking a greater research area throughout the numerous Gitxsan wilp territories and biogeoclimatic site series locations. As for the question regarding shade, there appears to be varied result regarding the impact of canopy openness on the morphology and vigour of devil's club. Therefore, I suggest a long-term controlled experiment (e.g., 5–10 years), where shade screens control different amounts of shade and the plants' response to the treatment is measured. A similar controlled experimental technique could be used to measure the response for different soil moisture contents and different soil nutrient levels (e.g., nitrogen).

During this research I also examined the relationships between devil's club and the human activities, especially logging, on Luutkudziiwus traditional territory of Madii Lii. The interpretation of the results suggests that devil's club can persist and re-establish post-logging. However, as previously stated, the time required for this process to occur is still variable, which may be a result of influences in elevation and other site attributes. Therefore, a wide-ranging study of different site types from different regions will help determine if there is a definitive time-scale for devil's club recovery after clearcut logging to occur. Possible important factors that have been examined are soil moisture and soil nutrients. I intended to measure the influence of soil moisture on devil's club fecundity, but the soil-moisture sensing equipment failed and this part of the research was made impossible. Therefore, any future research should evaluate the role of soil moisture and soil nutrient levels in the productivity of devil's club within a logged environment. In addition, I suggest that future research should be expanded to incorporate the use and monitoring of the effects of partial cutting and gap-based silviculture, as employed in the Date Creek Experimental Forest near Kispiox, and as described in Lilles et al. (2018).

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Appendix

Appendix 1.

List of Sampling Site Locations

Site #	Group	Site ID	Elevation	Year Logged	Latitude	Longitude
1	1970	1970-01	544	1970	55°17'48"N	127°16'21"W
2	1970	1970-02	701	1976	55°18'0"N	127°17'29"W
3	1970	1970-03	616	1978	55°19'0"N	127°16'0" W
4	1970	1970-04	610	1978	55°19'38"N	127°14'46"W
5	1970	1970-05	988	1979	55°26'0"N	127°10'23"W
6	1980	1980-01	672	1984	55°17'23"N	127°18'0"W
7	1980	1980-02	766	1980	55°19'53"N	127°13'22"W
8	1980	1980-03	760	1983	55°19'49"N	127°12'1"W
9	1980	1980-04	895	1986	55°19'52"N	127°9'32"W
10	1990	1990-01	843	1996	55°20'30"N	127°20'47"W
11	1990	1990-02	816	1993	55°20'46"N	127°20'5"W
12	1990	1990-03	908	1994	55°21'4"N	127°22'11"W
13	1990	1990-04	902	1998	55°21'25"N	127°22'45"W
14	2000	2000-01	668	2012	55°17'51"N	127°17'22"W
15	2000	2000-02	941	2000	55°21'19"N	127°20'14"W
16	2000	2000-03	968	2012	55°25'50"N	127°9'57"W
17	control	3000-01	562	1739	55°18'52"N	127°16'35"W
18	control	3000-02	686	1705	55°18'59"N	127°17'30"W
19	control	3000-03	726	1747	55°19'57"N	127°19'14"W
20	control	3000-04	742	1884	55°19'58"N	127°12'49"W
21	trad-use	4000-01	474	1847	55°17'18"N	127°11'20"W
22	trad-use	4000-02	401	1892	55°16'34"N	127°18'4"W
23	trad-use	4000-03	411	1892	55°16'38"N	127°17'58"W
24	trad-use	4000-04	515	1887	55°17'35"N	127°12'37"W

Appendix 2.

Explanatory list of BIOCLIM ecological variables Bioclimatic variables.

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in species distribution modeling and related ecological modeling techniques. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (quarter of the year). (WorldClim.org 2022)

They are coded as follows:

BIO#	Ecological Variable
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp)
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Appendix 3.

Table showing the results of the Shapiro-Wilk normality test from the values provided from the field sampling data.

	Shapiro-Wilk normality test	
Variable	W - Value	p-value
Stem Length	0.95881	0.01776
Stem Abundance	0.8881	1.55E-06
Stem Diameter	0.97787	0.2273
Elevation	0.97519	0.08917
Shade	0.93147	0.0001693
Leaf Area	0.19857	< 2.2e-16

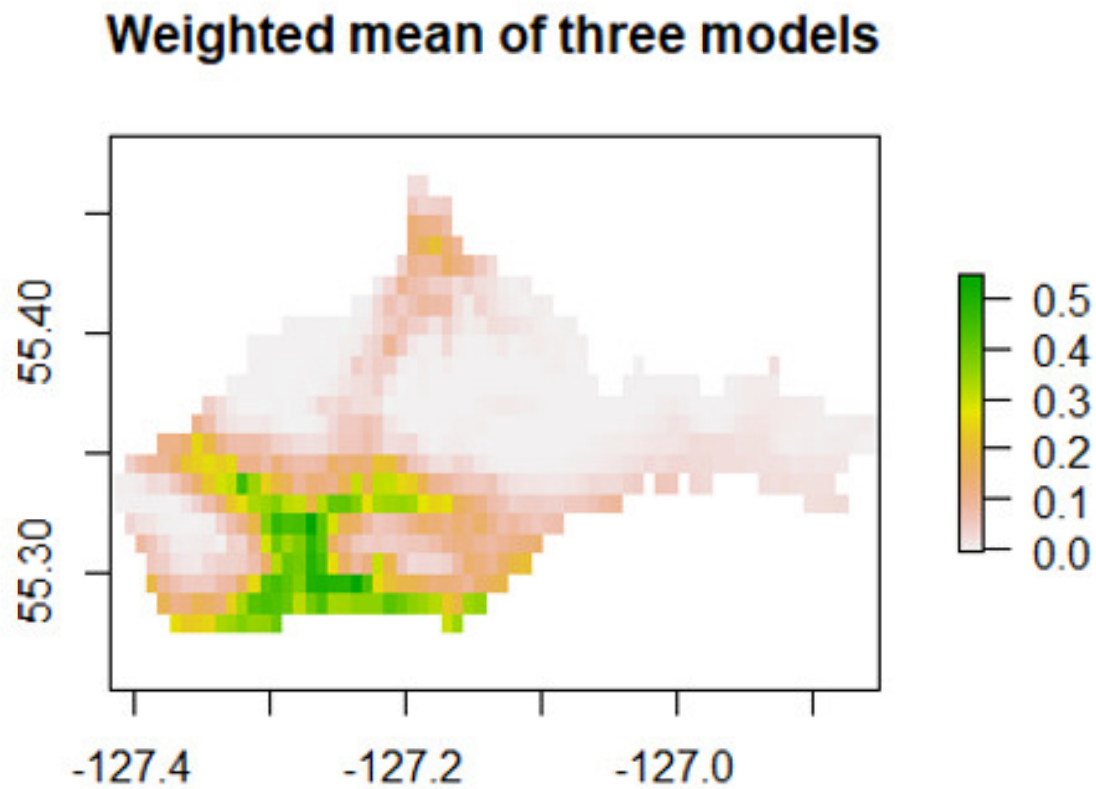
Appendix 4.

Model Evaluation based on AUC scores for Domain, GLM, Gaussian, MaxEnt and SVM model output.

DOMAIN	
Class	Model Evaluation
n presences	18
n absences	144
AUC	0.8572531
cor	0.4198339
max TPR+TNR at	0.2583034
GENERAL LINEAR REGRESSION	
Class	Model Evaluation
n presences	18
n absences	144
AUC	0.8996914
cor	0.3854456
max TPR+TNR at	-1.896563
GAUSSIAN	
class	Model Evaluation
n presences	18
n absences	144
AUC	0.8695988
cor	0.4407287
max TPR+TNR at	0.1809112
SUPPORT VECTOR MACHINES	
class	Model Evaluation
n presences	18
n absences	144
AUC	0.9205247
cor	0.5239749
max TPR+TNR at	0.03078363
MAXENT	
class	Model Evaluation
n presences	18
n absences	144
AUC	0.9085648
cor	0.546431
max TPR+TNR at	0.4980119

Appendix 5.

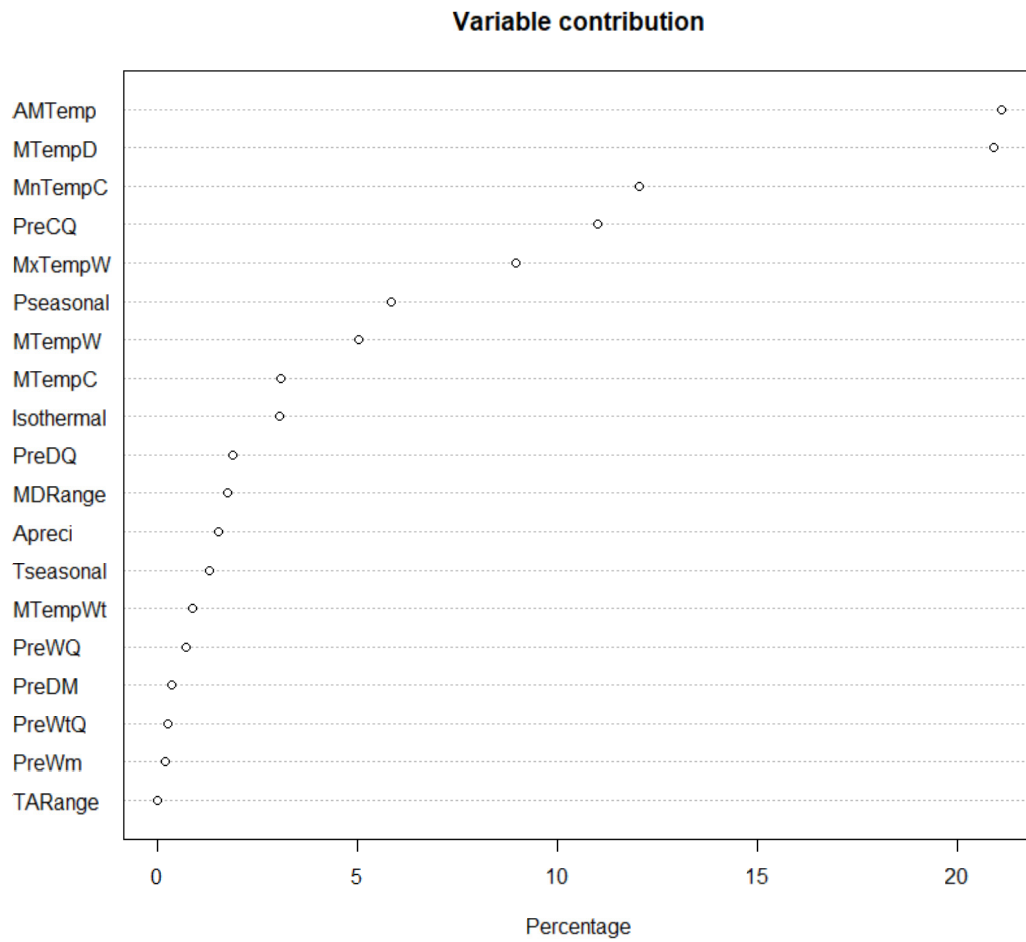
Weighted Mean of Suitability map



Map showing areas weighted mean of GLM, BIOCLIM and Support Vector Machine models. The greener colour indicates the most suitable areas and grey area means least suitable area for devil's club habitat.

Appendix 6

Ecological variable contribution plot for predicted habitat in MaxEnt model for British Columbia



Appendix 7

Maximum Entropy Response plots for devil's club for British Columbia predictive habitat models

