Recovery of *Oplopanax horridus* (Sm.) Miq., an Important Ethnobotanical Resource, after Clearcut Logging in Northwestern British Columbia

Carla M. Burton and Philip J. Burton

Research

Abstract

The persistence and recovery of devil's club (*Oplopanax horridus* (Sm.) Miq., Araliaceae) after clearcut logging in northwestern British Columbia, Canada, is investigated through a series of retrospective surveys. This species remains important to the traditional culture of many First Peoples of western North America and is being studied for its biological abilities by medical researchers. Based on observations in 16 clearcuts that had been logged 3 to 37 years earlier, it is clear that devil's club can survive and grow in these disturbed habitats and appears to take at least 10 years for sizes to recover to those found in old-growth forests. The most successful populations of post-logging devil's club probably escaped damage during logging operations, showed no recent signs of fire, and were associated with loose piles of dead branches, tree tops, and rotten logs. Consideration of these factors in forest management, in combination with the time since logging, should facilitate the resilience and sustainability of this species.

Introduction

Devil's club (*Oplopanax horridus* (Sm.) Miq., Araliaceae) has long been an important plant to indigenous people wherever it is found (Compton 1993, Gottesfeld 1992, 1994, Gottesfeld & Anderson 1988, Johnson 2000, Lantz 2001, Lantz *et al*. 2004, Moerman 2002, 2009, People of 'Ksan 1980, Smith 1929, 1973, Smith *et al*. 1997, Turner 1982, 2004, Turner & Thompson 2006). More than 34 broad categories of medicinal use and eight categories of spiritual use of devil's club have been distinguished from across 38 linguistic groups of northwestern North America (Lantz 2001, Lantz *et al*. 2004, Turner 1982).

Ancient stories, oral communications, and written records confirm that the roots and/or stems of devil's club were widely used by First Nations in northwestern British Columbia, primarily for medicinal and spiritual purposes (Barbeau & Beynon 1987, Compton 1993, Gottesfeld 1994, Ryan 1929, Smith 1973). The first written record of medicinal use in the area is from 1842 when Eduardo Blaschke, chief physician for the Russian American Company, described the use of devil's club ashes mixed with the resin of conifer trees as a treatment for sores (Blaschke 1842:74). In 1888, George Emmons described the Tlingit use of devil's club for treating wounds, infections, and sprains (Emmons 1991).

Medicinally, the inner bark from the stem and/or roots was applied externally as a poultice to an ailing or injured area of the body. For internal use, an infusion or decoction of the inner bark was prepared as a drink to treat many medical conditions and for use as a general daily tonic (Burton 2012, Compton 1993, Gottesfeld 1992, Gottesfeld & Anderson 1998, Turner 2004, Turner & Thompson 2006).

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Vapors of the simmering inner bark were inhaled by some people to treat lung conditions. Sometimes a concoction of the bark or roots was mixed with other medicinal plants (Burton 2012, Compton 1993, Turner & Thompson 2006). Table 1 provides some typical medicinal uses for devil's club by northwestern First Nations.

Today, many people prepare and use devil's club in similar ways for medicinal purposes, usually in conjunction with western medicine (Burton 2012, Turner & Thompson 2006). Beyond current First Nations use, the herbal and dietary supplement industry offers commercial preparations of devil's club in the form of teas, tinctures, and capsules that are used to treat many of the same ailments. These supplements usually contain devil's club root bark as the main ingredient (Lantz *et al*. 2004). There is ongoing research with respect to the medicinal efficacy of devil's club. Physiologically relevant constituents include calcium oxalate crystals (which can cause a burning sensation in the mouth but can be broken down by cooking) and at least 18 complex secondary compounds, primarily terpenoids (Sun *et al*. 2010). The active ingredients contained in the inner bark of devil's club have been found to inhibit the growth of certain bacteria and fungi that cause a variety of illnesses, e.g., tuberculosis and fungal pneumonia (Kobaisy *et al*. 1997, McCutcheon *et al*. 1994, 1997). More recent studies suggest that devil's club extracts may be effective in preventing the further growth of several types of human cancer cells and have benefits as a tonic and for the treatment of arthritis, rheumatism, and perhaps adult-onset diabetes (Li *et al*. 2010, Tai *et al*. 2006, 2010, J. Tai pers. comm. 2011).

Traditionally, a decoction of devil's club was used to wash the body to mask human odor when hunting or fishing, and small pouches of dried bark were carried to bring good luck. Today, many people still use devil's club as a wash before hunting or fishing as well as before sporting competitions and various cultural events for good luck (Burton 2012, Compton 1993, Gottesfeld 1994, Smith 1973, Turner & Thompson 2006). Devil's club bark was put in the corners of dwellings and camps or burned on stoves to bring good luck and ward off bad spirits; this practice continues today in private homes, cars, and public buildings. Some individuals wear jewellery made with parts of devil's club stems for protection and good luck (Burton 2012, Turner & Thompson 2006).

Table 1. Examples of medicinal uses for *Oplopanax horridus* (Sm.) Miq. by peoples living in northwestern British Columbia, Canada, and adjacent Alaska, U.S.A. STDs = sexually transmitted disease. *= external applications. References: 1 = Emmons 1911; 2 = Emmons 1991; 3 = Garfield & Wingert 1966; 4 = Gottesfeld 1994; 5 = Hebda *et al*. 1997; 6 = Justice 1966; 7 = Kari 1995; 8 = McGregor 1981; 9 = PSCC 1973; 10 = Smith 1929, Smith *et al*. 1997; 11 = Smith 1973; 12 = Turner 2004; 13 = Turner & Thompson 2006; 14 = Compton 1993.

	Medicinal uses (Literature references)												
Nation	**Chest**	**Cough & colds**	**Purgative & emetic**	**General**	**Ulcer**	**Pregnancy & birth**	**Cancer**	**Dermatological & cuts**	**Abscesses**	**Tonic**	**Arthritis & rheumatism**	**Diabetes**	**STDs**
Nisga'a	√	√	√	√		√	√	√	√	√	√		
Carrier				6		10					6		
N. Carrier			10	10									
S. Carrier						10							
Gitxsan	10	4	4	10	10		4	4		4	10	4	10
Tlingit	2		2	2				2,6	2		6		2
Wit'suwit'in	4		4				4	4		4	4	4	
Haida			8	6,8	6		6	12	8		6,12		8
Haisla	14		14					14					
Tahltan				1									
Tsimshian	8	8	3	8			8				4		8
Gitga'at	13	13	13	13				9		13	13	13	
Tainina	7	7	7	7					7	7			
Aleut								11*			11*		

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Historically, there is evidence for the traditional use of devil's club stems for technological purposes. The woody stems were cut into segments and used to make fishing lures; whole stems were made into spears, and the berries, bark shavings, and charcoal were used for dye and as pigment for facepaint (Compton 1993, Gottesfeld 1992, Moerman 2002, Turner 1982). There are few references to its past use for food, but early spring buds were boiled and eaten by some peoples (Compton 1993).

Species description

Three distinct taxa are recognized and accepted by the World Checklist of Selected Plant Families (Govaerts *et al*. 2014) as belonging to the genus *Oplopanax*, including plants indigenous to Japan, the Korean Peninsula, northern China, and the Russian Far East. However, other authorities treat these three taxa as subspecies of *O. horridus*. This variation in nomenclature, coupled with use of the common name "devil's club" for all three species or subspecies, can lead to confusion, especially when interpreting research results related to the medicinal potential of North American devil's club.

In this paper, devil's club refers only to the North American *Oplopanax horridus* (Sm.) Miq.; synonymies sometimes found in the older literature include *Echinopanax horridus* (Sm.) Decne. & Planch. ex Harms and *Fatsia horrida* (Sm.) Benth. & Hook. f. ex W.H.Brewer & S.Watson (Klinkenberg *et al*. 2013). This species is found throughout northwestern North America from coastal Alaska southward to central Oregon and eastward to the Yukon, northeastern British Columbia, northwestern Alberta, Montana, and Idaho. There are also several disjunct populations near Lake Superior in Michigan and Ontario (Hitchcock *et al*. 1961, Lantz *et al*. 2004, Viereck & Little 1972, Voss 1985). It is a shade-tolerant understory shrub associated with very moist, nitrogen-rich sites in semi-open mature and old-growth forests, on water-receiving floodplains, in well aerated seepages, along stream edges, water-collecting sites, and even occasionally on water-shedding sites if soils are calcareous (Beaudry *et al*. 1999, Klinka *et al*. 1989, Lantz *et al*. 2004). Young foliage is often damaged by late frosts, but plants regenerate quite well; they are fully hardy in winter (Tumiłowicz & Banazczak 2006). Devil's club stems are upright to decumbent and can reach heights up to 6 m (Lantz 2001, Lantz *et al*. 2004, Roorbach 1999). The leaves are large (up to 35 cm across) and maple-shaped. The stems, petioles, and leaf veins of devil's club are covered with a dense armor of yellowish needle-like spines up to 2 cm long. The flowers are small and whitish, in terminal pyramidal clusters, and ripen to shiny, flattened, bright red berries. Devil's club forms large sprawling clones that expand laterally through the rooting of decumbent stems, which tend to develop when tall plants topple and put the stem in contact with the soil. The growth behavior of devil's club is such that it likely achieves a maximum height of 4–6 m, after which stems collapse and become recumbent and may or may not retain the root stalks as the recumbent stems sprout adventitious roots to initiate what appear to be new individuals (Lantz 2001).

Objectives

Previous research into the population structure of devil's club in forests of different ages on Vancouver Island suggests that devil's club plants take >50 years for stems to attain lengths typically found in undisturbed forests (Lantz 2001, Lantz & Antos 2002). Based on the high regard that many First Nations have for devil's club and their continued desire to use it for medicinal and/or spiritual uses and the potential impact of logging on this important species, a pilot study was designed and undertaken to examine the following questions:

- Does devil's club persist after clearcut logging, given enough time and suitable microsites?
- If so, what site, vegetation, and disturbance attributes are associated with larger plants, given that the preferred stem diameter for traditional harvesting is "about one inch" or 2.5 cm (A. Azak pers. comm. 2007, D. Smith pers. comm. 2008)?
- If not, what conservation, management, and restoration measures might be appropriate to promote this species?

Methods

The length and diameter of living, upright devil's club stems were measured in 16 clearcuts of various ages (time since logging) in northwestern British Columbia. Stems were also measured at two old-growth forest locations that are actively used to harvest devil's club to serve as control or reference sites.

Selection of sites

The clearcuts chosen for sampling were all located in the Nass Valley on the traditional territory of the Nisga'a First Nation north-northwest of Terrace, British Columbia, and were limited to sites that were easily accessible by road (Table 2). An effort was made to sample a wide range of clearcut ages, with time since logging initially estimated on visual assessment of the regeneration status of each site. Exact periods since disturbance (logging) were determined later based on GPS (global positioning system) co-ordinates taken at sample sites, cross-matched to associated databases maintained by the Nisga'a Lisims Government, B.C. Ministry of Forests, Lands and Natural Resource Operations, and Northwest Timberland Ltd.

Data collection

A total of 180 individual devil's club stems at 18 sites, representing 10 stand ages (16 clearcuts and two old-growth forest sites) were sampled over a two-year period (Table

Table 2. Locations within northwestern British Columbia, Canada, sampled for devil's club. *UTM Zone 09. **Clearcut dates from records of the British Columbia, Ministry of Forests, Lands and Natural Resource Operations, Nisga'a Lisims Government, and Trevor Jobb of Northwest Timberlands, Terrace, British Columbia. BEC Zone (Biogeoclimatic Zones of British Columbia).

Site	Location	Easting*	Northing*	Elevation (m)	BEC Zone	Age** (years)
Site 1	Branch 234600, N. Kwinhak	476141	6102821	326	CWHws1	17
Site 2	Branch 234600, N. Kwinhak	474994	6104103	24	CWHws1	5
Site 3	Ksedin Creek Main line,	479473	6105153	538	CWHws1	17
Site 4	Ksedin Creek Main Line	481238	6105138	617	CWHws2	18
Site 5	Ksedin Creek Main line	478266	6105550	387	CWHws1	5
Site 6	Beaupre Ck. km. 8.7	498842	6107006	703	CWHws2	20
Site 7	Beaupre Ck	499745	6105656	686	ICHmc2	16
Site 8	Beaupre Ck	500027	6104607	711	CWHws2	14
Site 9	Beaupre Ck	498003	6113055	269	ICHmc2	37
Site 10	Old Growth Gingolx 1	439669	6095286	254	CWHwm	295
Site 11	Gitwinksihlkw	486676	6121954	356	ICHmc2	11
Site 12	Gitwinksihlkw	487570	6122185	273	ICHmc2	11
Site 13	Gitwinksihlkw	488204	6121710	235	ICHmc2	11
Site 14	Gitwinksihlkw	488164	6120997	212	ICHmc2	11
Site 15	Kitsault	508735	6147287	236	ICHmc2	3
Site 16	Kitsault	508426	6144599	304	ICHmc2	3
Site 17	Kitsault	508643	6144395	251	ICHmc2	3
Site 18	Gingolx Old Growth 2	439694	6095466	258	CHWwm	296

2). In both years, sites were chosen on the day of sampling by slowly driving along logging roads looking for sites that would be recognized as characteristic of devil's club ecosystems (Banner *et al*. 1993): i.e., lower slope positions or depressions with rich vegetation. When sites were selected, GPS coordinates, along with site and habitat features (detailed below), were recorded from the center of a patch of devil's club. Starting from the point where GPS coordinates were collected, the ten nearest specimens of devil's club were measured for basal diameter of each living stem, leaf diameter of the four to five largest leaves on each plant (at the widest point), and main upright stem length (from the ground to the base of the terminal bud). For each devil's club patch or population the following site features were also noted: (1) slope position, (2) evidence of fire, (3) presence of slash (logging debris), (4) identity of all associated plant species or species groups, and (5) the degree of shading from trees or overtopping shrubs.

Data analysis

Measurements from individual devil's club stems sampled at the 18 sites were summarized for each sample site, with the means statistically analyzed by linear regression and one-way analysis of variance (ANOVA) to test for the influence of stand age on devil's club attributes.

Statistical analysis evaluated the response of the following descriptions of devil's club stem size to time since logging: (1) stem diameter (cm); (2) stem length (cm); and (3) useable bark area (cm^2), estimated as the surface area of a cylinder based on stem circumference and 80% of its length (diameter * π * 0.8 * stem length), based on observations that entire stems are traditionally harvested, but the narrow taper at the top of the stem is typically not used.

Overall relationships among these three variables in individual stems were explored using Pearson's correlation coefficient (SAS procedure CORR; SAS Institute 2004). Results are presented primarily for stem diameter as the diameter of stems was considered a crucial criterion for harvesting good devil's club.

Linear regression analysis was conducted separately for each of the three response variables described above. With stand age serving as a continuous independent (predictor) variable, one statistical analysis was conducted with all sites, including old-growth forest nominally denoted as being 295 and 296 years old as per forest cover mapping (Table 2). Because this analysis spanned three orders of magnitude in stand age, regressions were also conducted to test for relationships with the logarithm (base

Table 3. Correlation of individual stem attributes (n = 180) from sampled sites in northwestern British Columbia, Canada.

Stem attribute	Diameter	Length	Bark area
Diameter	r = 1.000	r = 0.765, p < 0.0001	r = 0.933, p < 0.0001
Length		r = 1.000	r = 0.899, p < 0.0001
Bark area			r = 1.000

10) of stand age. A third analysis was conducted without the old-growth sites, thereby being more directly informative of devil's club recovery after logging. All regression analysis was conducted using SAS procedure REG (SAS Institute 2004).

Visual inspection of scattergrams plotting plant size against clearcut age revealed the possibility for some sharp thresholds or categorical differences in the size of devil's club in stands of different ages. Although sampling was not designed to test for thresholds in devil's club performance among stand age classes, analysis of variance (ANOVA) was used to better define the existence and location of any categorical differences. Separate ANOVA runs were conducted for stand means of each of the above attributes to evaluate variation among:

- those five stand ages for which more than one cutblock was sampled (and treating both old-growth sites as approximately equal in age);
- four stand age classes, with individual sites grouped by decadal intervals, as ages <10 years, 10–19 years, 20–40 years, and old growth (>250 years old);
- three clearcut age classes, with individual sites grouped by decadal intervals as <10 years, 10–19 years, and 20–40 years; and
- two clearcut age classes, <10 years and >10 years since logging.

Rather than testing among individual stand ages using ANOVA, these broad age classes were required in order to have at least two replicate stands in each age class. In these analyses, SAS procedure GLM was used for the ANOVA because the same number of stands was not sampled for all stand ages. When ANOVA results revealed a significant effect (p < 0.05), a Tukey post-hoc multiple comparison test (an option in SAS procedure GLM; SAS Institute 2004) was conducted to identify significant differences among individual stand ages and/or stand age classes.

The analyses revealed high variability in stem sizes among and within the sites sampled. Therefore, the sources of this variation were further evaluated for the stems growing in clearcuts. Separate one-way ANOVA runs were used to test the variation of devil's club stem diameter (for example) growing on mesic sites compared to hygric sites (i.e., site moisture regime), in the shade or in the open, on south-facing slopes vs. other aspects, on sites with and without evidence of fire, and on sites with and without other individual plant species or species groups.

Results

Overview

Generally, it was not difficult to find devil's club growing in disturbed forest stands of all ages. It was found in a wide range of open and shaded conditions but with some plants growing in open areas showing signs of stress (smaller leaves, leaves sometimes curled and edges browned). Living stems were especially prevalent on sites with no evidence of fire (96% of stems sampled), with northerly aspects (74% of stems sampled), on moist or mesic sites (87% of stems sampled), and in nearly equal numbers on sites with and without shade from other vegetation (54% and 46% of stems sampled, respectively). Dead devil's club stems were observed on a number of sites. Living stems on all sites must have either survived logging or resprouted from damaged stems since logging (rather than established from seed), as evidenced by the fact that all stems were robust, most with basal diameters greater than 1.0 cm.

Stem diameter, length, and bark area were all significantly correlated, with diameter a good indicator of the estimated amount of bark available (Table 3). Means and standard errors for stem diameter, stem height, and estimated bark area of devil's club at each of the sites (16 sites ranging in age from 3 to 37 years since logging and two old-growth stands with nominal ages of 295 and 296 years) are presented in Table 4. The largest stems with the most material with which to make medicine came from a stand 11 years old (Gitwinksihlkw 12). The means and standard errors of diameter for these stems and those found in the old-growth stands near Gingolx overlapped with each other. The smallest stems were from a stand that had been logged 3 years earlier (Kitsault 17).

Regression results

When considering the average growth of devil's club at each site sampled (n = 18), linear regression of mean stem attributes showed no significant relationship to stand age (p = 0.1631 for stem diameter, p = 0.8423 for stem length, p = 0.5196 for bark area) or to $\log_{10}$ of stand age (p = 0.0830 for stem diameter, p = 0.3262 for stem length, p = 0.2489 for bark area). When all individual stem measurements were treated as independent observations (n = 180), a significant though very weak relationship was detected for stem diameter as a function of stand age (p = 0.0019, R^2 = 0.06). Significant relationships emerged

Table 4. Mean and standard error results for devil's club stem diameter, height, and usable bark area for individual stands in northwestern British Columbia, Canada, ordered by age.

Location ID	Stand age	Stems measured	Diameter		Height		Bark area	
			Mean	Standard error	Mean	Standard error	Mean	Standard error
	(years)	(number)	(cm)	(cm)	(cm)	(cm)	(cm^2)	(cm^2)
Kitsault 15	3	10	1.68	0.07	41.7	6.5	180	31
Kitsault 16	3	10	1.30	0.08	24.1	3.1	82	16
Kitsault 17	3	10	1.18	0.12	21.7	4.3	77	25
Ksedin 5	5	11	1.25	0.23	31.8	9.5	236	71
Kwinhak 2	5	10	1.49	0.14	51.2	6.1	204	38
Gitwinksihlkw 11	11	10	2.57	0.20	121.1	4.1	780	65
Gitwinksihlkw 12	11	10	3.29	0.27	135.9	5.7	1136	121
Gitwinksihlkw 13	11	10	2.57	0.17	131.7	4.3	854	68
Gitwinksihlkw 14	11	10	2.33	0.19	119.6	10.0	728	112
Beaupre 8	14	10	1.46	0.15	81.9	9.6	330	68
Beaupre 7	16	10	1.69	0.20	78.1	10.0	372	92
Ksedin 3	17	10	2.38	0.41	84.1	12.6	612	201
Kwinhak 4	17	10	1.54	0.20	85.6	9.8	371	82
Ksedin 1	18	10	1.35	0.10	41.5	4.2	145	20
Beaupre 6	20	10	1.43	0.11	59.0	4.1	219	34
Beaupre 9	37	10	1.71	0.15	42.5	5.6	196	40
Gingolx 1	295	10	2.67	0.29	88.9	10.7	639	105
Gingolx 2	296	9	2.30	0.19	64.6	2.5	471	48

when individual stem size was regressed against the log of stand age: p = 0.0001 (R^2 = 0.08) for stem diameter (Figure 1), p = 0.0001 (R^2 = 0.08) for stem length, and p = 0.0010 (R^2 = 0.06) for bark area.

Although the trends exhibited by these three variables suggest that stem size increases with stand age to a certain extent, the regression relationships explain only 6% to 8% of the variance observed. Further analysis of the data was therefore carried out in order to confirm thresholds observed upon visual inspection of the data shown in Figure 1. For example, it appears that stands less than 10 years old rarely support devil's club with stem diameters greater than 1.8 cm, stem lengths greater than 60 cm, or estimated bark area per stem greater than 300 cm^2.

Analysis of variance (ANOVA) results for stem diameter

Assessment of stem diameter differences using ANOVA and Tukey multiple comparison tests revealed some significant relationships among the five stand ages for which replicate cutblocks were available (F = 7.89, p = 0.0070). But those differences (results not shown) were not consistently related to increasing stand age: devil's club in the 11-year old clearcuts had, on average, the largest mean stem diameters, which were not significantly different from those of devil's club in the old growth but were significantly different from the 3- and 5-year old sites.

When data from all the cutblocks sampled were combined into four decadal age classes, significant differences among stand age classes also emerged (F = 3.45, p = 0.0459). Due to either the high variability within the four age classes (Figure 2) or the unequal number of stands within age classes, Tukey tests were unable to identify which means were significantly greater or less than others.

Evaluating only the logged (<40 year old) stands in three age classes generated similar results for stem diameter: ANOVA F = 3.53, p = 0.0597. However, stem length differences were significant (F = 10.72, p = 0.0018), with stems in the 10–19 year age class averaging 98 cm in length, compared to 51 cm in the 20–40 year age class and 34 cm for those less than 10 years old. These differences were accentuated when testing for stand age effects around the 10-year threshold after disturbance, i.e., testing for significant differences between plants growing on clearcut sites <10 years old and >10 years old. ANOVA

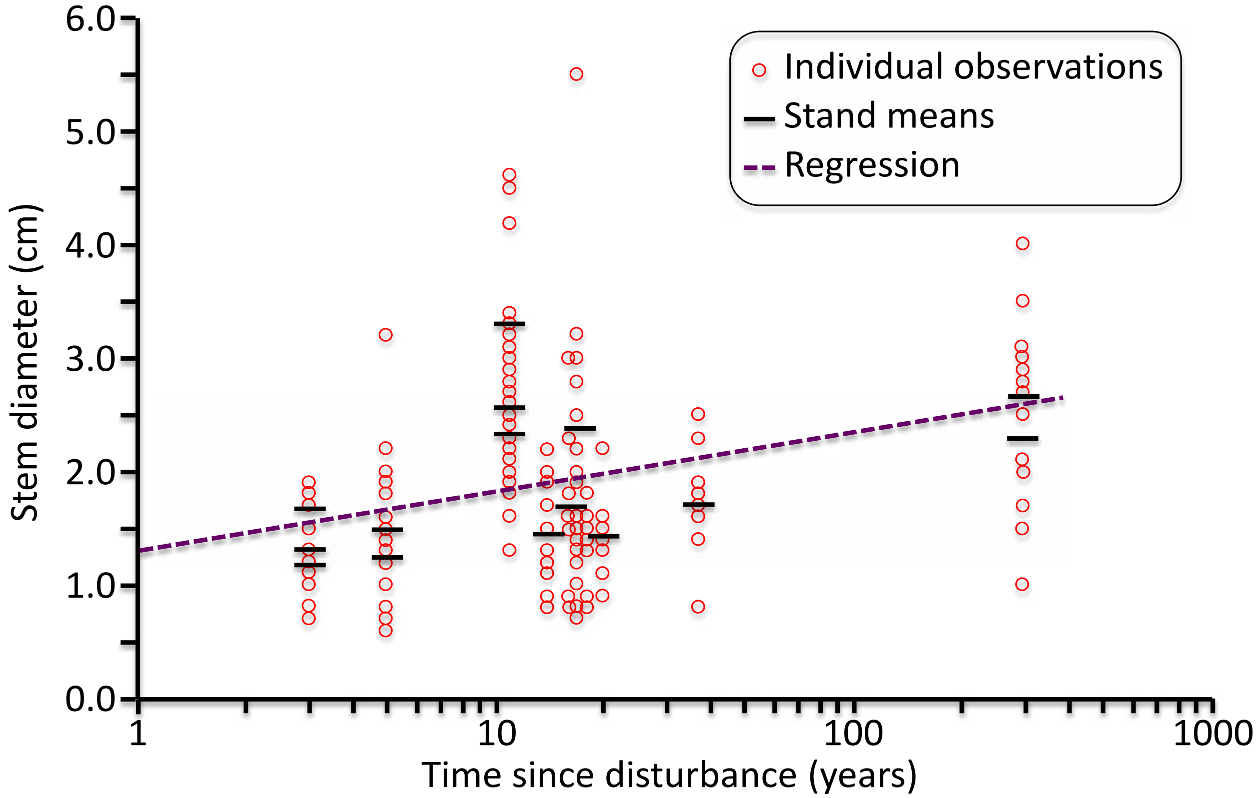

Figure 1. Relationship of individual devil's club stem diameters to time since disturbance in British Columbia, Canada, showing means for each site sampled and the regression line derived for individual stem diameters: diameter = 1.29862 + 0.53186 log10(stand age).

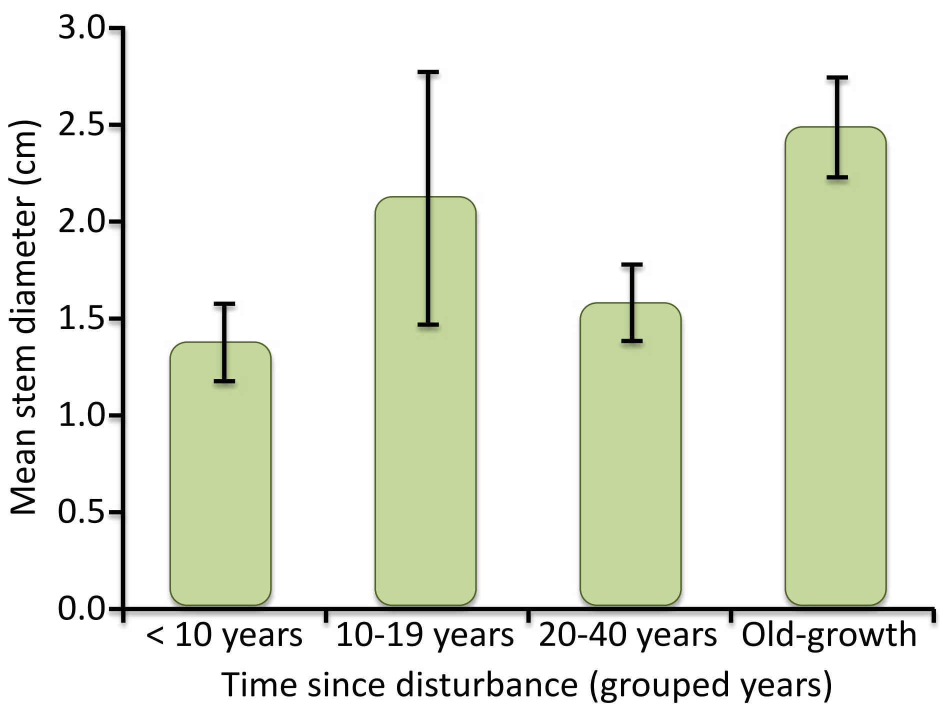

Figure 2. Mean devil's club stem diameters in multiple stands from northwestern British Columbia, Canada, grouped into four age classes; error bars are standard deviations for stand means (not individual stem measurements).

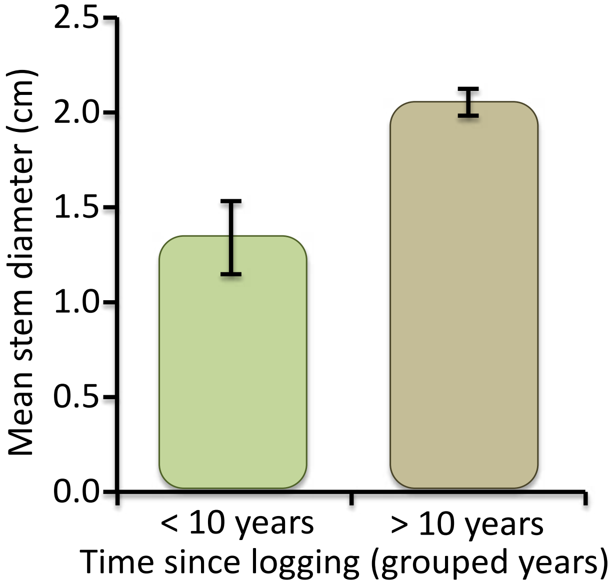

Figure 3. Mean devil's club stem diameters in stands from northwestern British Columbia, Canada, grouped into two age classes, clearcuts less than or greater than 10 years old since logging; error bars are standard deviations among stand means. ANOVA indicates that the means are significantly different at the 95% confidence level.

results for stem diameter demonstrated significantly larger stems in the older stands (where they averaged 2.1 cm) compared to the younger stands (averaging 1.4 cm; $F = 6.56$, $p = 0.0209$, Figure 3). Even more pronounced results were found for stem length (averaging 87 cm compared to 34 cm; $F = 12.08$, $p = 0.0025$) and for bark area (averaging 528 cm^2 compared to 139 cm^2; $F = 8.25$, $p = 0.0110$).

ANOVA results for site and species association factors

Given the widespread variability in plant size revealed in the above analyses (especially in the cutblocks 10 to 40 years old), it appears that stand age alone is not the defining factor for determining the size of devil's club stems. One-way ANOVA to examine the relationship between stem diameter and stand age classes did not reveal a more consistent relationship than did regression analysis, although there seems to be some sort of threshold between 5 and 11 years of age. To further understand the variability observed in stem sizes, individual one-way ANOVAs were run to evaluate individual site factors that might contribute to differences in devil's club growth. Microsite factors such as evidence of fire, soil moisture regime, shading, aspect, and the presence of various plant species or species groups were evaluated for their ability to predict stem diameter. For this analysis, only stems from the logged sites were evaluated (n = 161) because the goal of this part of the study was to evaluate factors contributing to devil's club recovery after clearcut logging.

Site factors

Analysis of the data with respect to the recovery of devil's club after logging showed that stems on slash-burned sites were significantly smaller than stems on unburned sites ($F = 11.15$, $p = 0.0011$). There were also significant effects when comparing open vs. shaded sites ($F = 6.36$, $p = 0.0127$) and gross site moisture regime ($F = 12.86$, $p = 0.0004$). Figure 4 shows mean stem size was significantly greater when stems were growing in the open and on slightly drier sites.

Some of the largest stems ($F = 16.75$, $p < 0.0001$) were found growing in and among "dead shade" (i.e., shade cast by logging slash or wood waste).

Species association

There were 25 frequently encountered plant species or species groups growing in association with devil's club in clearcuts of all ages. Highlighted data (Table 5) show that there were ten species or genera for which their presence or absence was associated with significant (ANOVA, $p < 0.05$) differences in the size of devil's club stems.

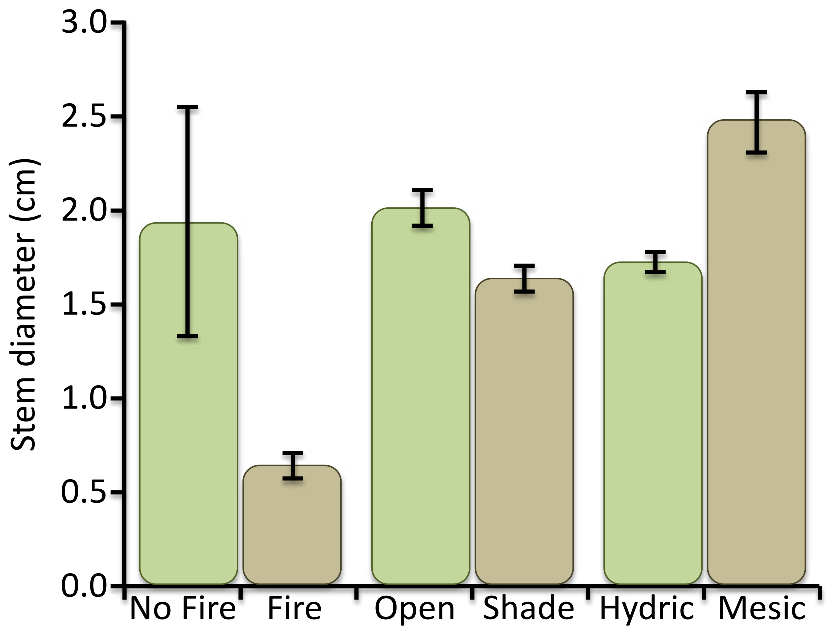

Figure 4. Significant differences (p < 0.05) for devil's club stem diameters under contrasting microsite conditions in northwestern British Columbia, Canada. Error bars are standard errors of individual stem measurements.

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Table 5. Mean and standard error for devil's club stem diameters associated with the presence or absence of plant species (or species groups) observed growing with devil's club in all clearcut age classes within sampled sites in northwestern British Columbia, Canada.

Scientific name	English name	Present			Absent			ANOVA results	
		n	Mean	S.E.	n	Mean	S.E.	*F*	*p*
Abies amabilis (Douglas ex Louden) J.Forbes	Pacific silver fir	10	2.55	0.16	168	1.86	0.07	6.46	0.0119
Athyrium filix-femina (L.) Roth	lady fern	64	1.85	0.09	114	1.92	0.09	0.33	0.5644
Cornus canadensis L.	bunchberry	62	1.85	0.10	116	1.92	0.08	0.26	0.6114
Corylus cornuta Marshall	beaked hazelnut	10	1.54	0.20	168	1.92	0.07	1.87	0.1734
Epilobium angustifolium L.	fireweed	94	1.71	0.08	84	2.10	0.11	10.08	0.0018
Equisetum spp.	horsetail	30	1.49	0.08	148	1.98	0.08	8.59	0.0038
Geum macrophyllum Willd.	large-leaved avens	19	2.62	0.22	159	1.81	0.07	16.59	<.0001
Gymnocarpium dryopteris (L.) Newman	oak fern	21	1.47	0.15	157	1.95	0.07	6.26	0.0133
Mnium, *Plagiomnium*, and/or *Rhizomnium* spp.	leafy mosses	10	1.69	0.20	168	1.91	0.07	0.62	0.4316
Linnaea borealis L.	twinflower	10	1.71	0.15	168	1.91	0.07	0.51	0.4777
Lysichiton americanus Hultén & H.St.John	skunk cabbage	50	1.71	0.11	128	1.97	0.08	3.38	0.0678
Menziesia ferruginea Sm.	false azalea	41	1.68	0.13	137	1.96	0.08	3.64	0.0581
Polypodium glycyrrhiza D.C.Eaton	licorice fern	19	2.62	0.22	159	1.81	0.07	16.59	<.0001
Populus tremuloides Michx.	trembling aspen	4	2.58	0.41	174	1.88	0.07	2.63	0.1063
Ribes sp.	currants	20	1.70	0.12	158	1.92	0.07	1.20	0.2748
Rubus idaeus L.	red raspberry	10	1.71	0.15	150	1.84	0.07	0.22	0.6426
Rubus parviflorus Nutt.	thimbleberry	61	1.98	0.12	117	1.85	0.08	0.95	0.3317
Rubus spectabilis Pursh	salmonberry	29	2.59	0.13	149	1.76	0.07	26.68	<.0001
Salix sp.	willows	21	1.59	0.14	157	1.94	0.07	3.21	0.0747
Sambucus racemosa L.	elderberry	16	1.41	0.10	162	1.94	0.07	5.85	0.0166
Thuja plicata Donn ex D.Don	western red cedar	27	2.51	0.22	151	1.79	0.07	18.54	<.0001
Tsuga heterophylla (Raf.) Sarg.	western hemlock	82	1.93	0.09	96	1.86	0.09	0.28	0.5943
Vaccinium membranaceum Douglas ex Torr.	black huckleberry	71	1.92	0.11	107	1.88	0.08	0.11	0.7361
Vaccinium ovalifolium Sm.	oval-leaved blueberry	71	1.92	0.11	107	1.88	0.08	0.11	0.7361
Veratrum viride Aiton	false hellebore	20	1.39	0.07	158	1.96	0.07	8.32	0.0044

The presence of a particular plant species or genus growing in association with devil's club stems could denote larger or smaller devil's club stems. Figure 5 shows that of the ten species or genera with significant relationships to devil's club stem size, only five were associated with an increase in devil's club stem diameters. These include the two coniferous species *Abies amabilis* (Douglas ex Louden) J.Forbes (Pacific silver fir) and *Thuja plicata* Donn. ex D.Don (western hemlock), the single shrub *Rubus spectabilis* Pursh (salmonberry), and the herbaceous plants *Geum macrophyllum* Willd. (large-leaved avens) and *Polypodium glycyrrhiza* D.C.Eaton (licorice fern). In contrast, smaller than average devil's club diameters were associated with the presence of the shrub *Sambucus rac-*

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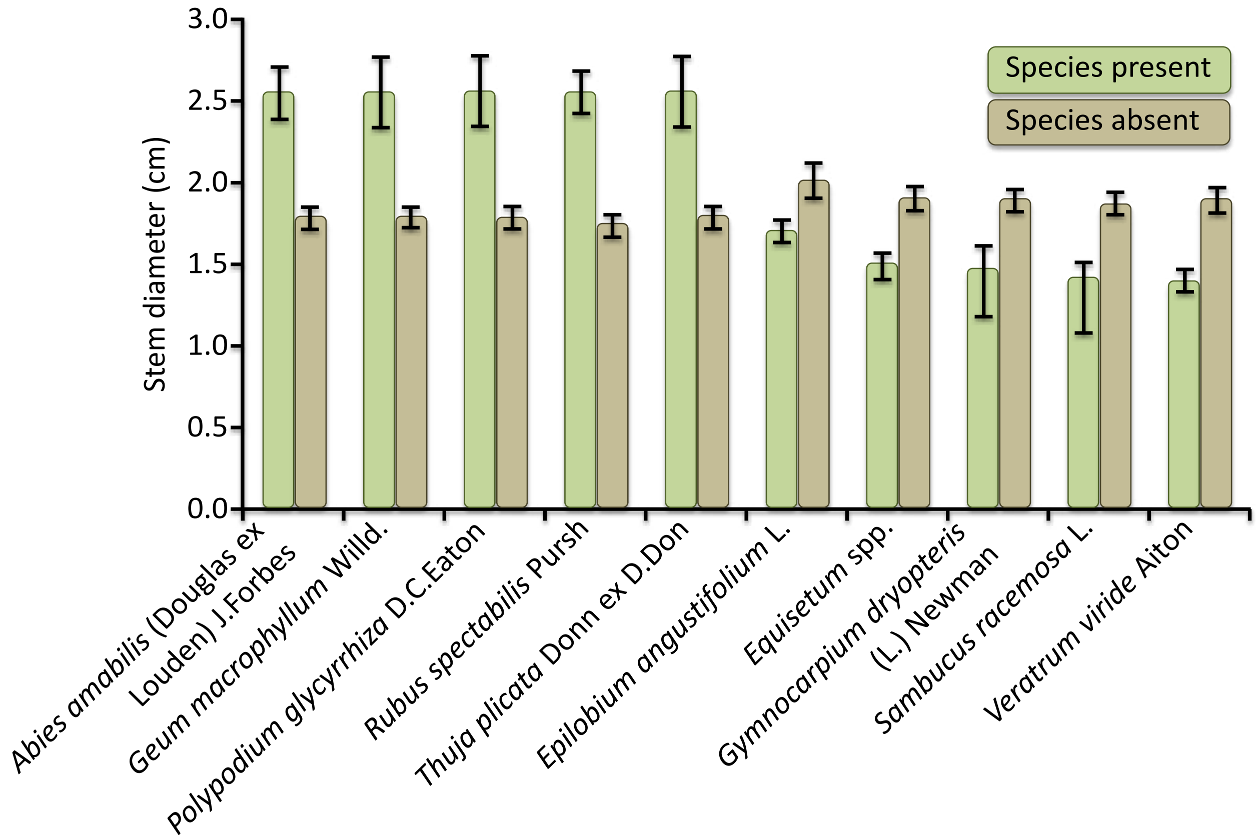

Figure 5. Significant results for analysis of variance comparing mean stem diameter of devil's club (*Oplopanax horridus* (Sm.) Miq.) and the presence/absence of individual plant species from sample sites in northwestern British Columbia, Canada. Error bars are standard errors of individual stem measurements.

emosa L. (elderberry) and the herbaceous plants *Epilobium angustifolium* L. (fireweed), *Equisetum* spp. (horsetail), *Gymnocarpium dryopteris* (L.) Newman (oak fern), and *Veratrum viride* Aiton (false hellebore).

Discussion

Many people who use devil's club stems for medicinal or other purposes prefer to harvest them from undisturbed, old-growth forests (Burton 2012). Nonetheless, it appears that many devil's club plants are able to survive or recover through vegetative sprouting of damaged plants after logging. Such survival is to be expected, provided logging practices (e.g., log skidding, slash-burning) don't affect the health of the forest floor to the extent that regrowth and clonal spread of devil's club stems is inhibited (Lantz 2001). Regeneration from seed is rarely encountered in the wild (Lantz & Antos 2002, Roorbach 1999), and none was observed in this study. It is reasonable to expect that old-growth forests would have the largest stems of this slow-growing, shade-tolerant species and that older clearcuts would support larger stems than more recent clearcuts. However, results suggest that although time since logging is a factor in understanding the average size of devil's club after disturbance, other factors are also important. In particular, it is difficult to find large stems in the first 10 years after clearcut logging. The extent of stem damage from logging or fire and microsite factors (e.g., site moisture and nutrient availability, the presence of protective slash) also affect the persistence and recovery of healthy stems. These results are consistent with the literature which describes devil's club as a shade-tolerant species that is sensitive to fire and grows well on moist sites (Alaback 1980, Burton 1998, Howard 1993, Klinka *et al*. 1989, Roorbach 1999).

The significant relationships determined between devil's club plant size (as indicated by stem diameter, stem length, and bark area) and the logarithm of stand age supports the notion that stem size increases with stand age, though in a curvilinear manner. Field observations and subsequent analysis reveal that stand age alone does not predict plant size as many of the largest stems were found in 11 year old stands. In fact, relatively little of the variance (6% to 8%) in plant size was explained by stand age. There is a tendency for stems to increase in size with time since disturbance, but this relationship is not a linear one as the rate of evident size increase in the first decade after logging does not continue indefinitely. Clearly other factors contribute to the persistence and recovery of devil's club after disturbance because the largest stems are not always found in the oldest clearcuts. Under the right conditions, devil's club stems in northwestern BC have been found that measure 6 cm in diameter (data in Burton 1998).

Stem diameters were found to be significantly smaller on sites where slash-burning had occurred than on sites where there was no burning. Devil's club is sensitive to fire (Fischer & Bradley 1987, Hamilton 2006) and is reported to be absent from burned sites for decades after catastrophic fire (Howard 1993). Its cover declines after slash-burns of even low to moderate severity (Hamilton 2006). This response to fire could reflect the fact that devil's club, common on moist sites where fires are infrequent, is adapted to a long fire return interval (Banner *et al*. 1993, Keeley *et al*. 2011, Wong *et al*. 2003). Shortening that interval through slash-burning could affect the ability of devil's club populations to persist on the landscape. Given the long natural fire return interval of ecosystems that support the growth of devil's club, its sensitivity to damage by fire, and the criteria for its establishment and persistence, broadcast burning is not a recommended treatment after logging where maintenance of devil's club is desired. Likewise, burn piles (consisting of logging slash, tree tops, and damaged wood) should not be placed on or near existing stands of devil's club.

Devil's club is a shade-tolerant species (Beaudry *et al*. 1999, Burton 1998, Klinka *et al*. 1989), and it can survive and persist in a forest understory. It can tolerate a wide range of light conditions from open to very low (Lantz 2001), but dominance by devil's club in a plant community may be favored in shade (Roorbach 1999). Devil's club populations sampled by Burton (1998) showed higher plant biomass at light levels up to about 50% of full sunlight; biomass was no greater at higher light levels and was often less. Our observations of dead stems and plants showing signs of stress in recent clearcuts further substantiate these findings. Nevertheless, significantly larger stems were documented under fully open conditions versus shaded conditions, where sunlight is blocked by shade from other living vegetation including juvenile conifer trees, shrubs, and herbaceous plants. Given that devil's club can persist under a variety of light conditions, it is possible that the stems growing in close proximity to vigorous growth of other plants were in competition for moisture and nutrients and so were smaller. In contrast, devil's club stems growing in the shade of slash or logs (dead shade) were bigger because they can grow well in the shade while that shade partially suppresses competition from more light-demanding species (Roorbach 1999).

Formal determination of relative soil moisture regime (as described by Banner *et al*. 1993) at each sampling site was not conducted as part of this study. Nonetheless, observations of the habitat associated with individual stems often included observations on moistness of the soil and slope position. Analysis of those relationships revealed that stems were larger on sites that were slightly drier than those stems on very wet sites. Assuming that the very wet sites were sites that were not well drained, these observations are consistent with the perceived preference of devil's club for water-receiving but well drained sites (Beaudry *et al*. 1999, Klinka *et al*. 1989).

Devil's club stems were significantly larger when found growing in association with some species and significantly smaller when growing in association with other species or genera. Both *Rubus spectablis* and *Veratrum viride* are noted to be common associates of devil's club (Klinka *et al*. 1989) and can indicate sites suitable for devil's club even if it is not currently visible there. Smaller devil's club stems occurred when growing in the presence of *Sambucus racemosa*, *Veratrum viride*, *Epilobium angustifolium*, and *Gymnocarpium dryopteris* and may reflect more intense competition from those plants, several of which are known to be intense competitors on rich sites (Haeussler *et al*. 1990).

Conclusions

The need for this study was prompted by the fact that many First Nations in northwestern British Columbia consider devil's club to be one of the most important medicinal plants. Concern has been expressed that devil's club is no longer so abundant and that large stems believed to make the best medicine are not as easy to find now due to clearcut logging.

The results of this study reveal several important points related to the persistence and/or recovery of devil's club after logging:

- Devil's club can persist after logging, and there is a general tendency for stem numbers and size to increase as time passes;
- Unless they escape damage during logging, large devil's club stems can rarely be found in cutblocks less than 10 years old;
- Increase in size is only partially explained by time-since-logging, with stands as young as 11 years old producing stems equivalent in size to those in old-growth forests;
- Stems growing on sites that weren't burned after logging are significantly larger than stems growing on burned sites;
- "Dead shade" from slash and logs seems to be beneficial to the survival and growth of devil's club, as are somewhat well-drained (but still moist) soils;
- Devil's club can recover after logging provided that logging is carried out in a way that does not severely disturb existing devil's club populations.

Although devil's club can indeed persist and recover after clearcut logging, this does not mean that other components of old-growth ecology can recover as well. Some forest harvesting is a necessary part of our regional economy, but these results should not be considered an endorsement of old-growth logging or clearcutting. If we adopt a model of sustainable forest management that works toward the long-term conservation of all forest values (Adamowicz & Burton 2003), including the continued health of valuable medicinal plants such as devil's club, then the protection and facilitated recovery of non-timber forest products need to be considered before deciding where, when, and how to harvest trees.

In order to conserve devil's club populations, the following is recommended:

- Healthy populations of devil's club should be protected during clearcut logging, either in green tree retention patches or machine-free zones (Beese & Bryant 1999, Rosenvald & Lõhmus 2008);
- When clearcut logging, scattered slash should be left in devil's club patches to provide protective shade for recovering plants;
- Burn piles and slash-burning should not be located in devil's club patches;
- Large-scale harvesting of devil's club stems (if any) should be dispersed and monitored to determine sustainable rates of harvesting and recovery;
- A comprehensive ecosystem-based research trial should be undertaken to evaluate the demography, cover, biomass, and stem growth of devil's club over a period of several years (related to soil type, soil moisture, soil nutrients, plant community, slope position, aspect, and site history) after logging.

When considering the harvesting of devil's club amidst the inspiration of ancient trees, old-growth forests offer both practical and spiritual values that cannot be replaced in a short period of time. In an old-growth forest, there are large devil's club stems easily accessible on paths that have long been used for sustainable gathering. We cannot overlook the cultural and spiritual value of harvesting devil's club and other traditionally used plants at locations that are familiar and have long been used for such purposes.

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