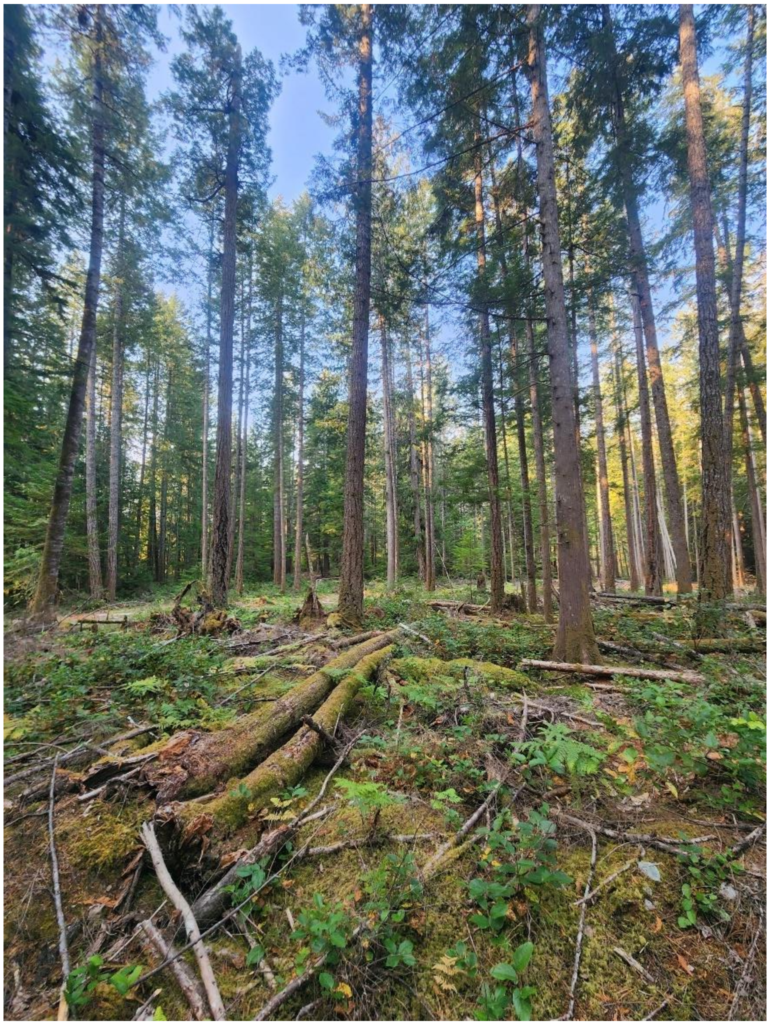
DRAFT REPORT

A retrospective study of forest practices on Cortes Island



By Alyssa Robinson, Joey Timmermans, Liam Jones, Jean Roach, and Suzanne Simard

June 2, 2023

Table of contents

List of Tables

List of Figures

Abstract

Diverse logging practices varying from high intensity harvesting such as clearcutting to moderate and low intensity harvests including seed tree cutting and thinning have been implemented at Cortes Island. This diversity of harvesting practices provided a unique opportunity to retrospectively study the outcomes of those practices. The study objective was to examine how recent harvesting systems as well as older clearcutting and planting have affected tree carbon stocks, forest structure, regeneration, understory plant communities, and the forest floor.

The practices that are "best" depend on the objectives of the treatment. Our study results indicate that:

- If the objective is to protect aboveground carbon pools, the order of best to worst treatment is: no logging > 60% retention or string of pearls > 10 x 10 m spaced seed trees > widely spaced seed trees > clearcut.
- The old plantations that we measured had regained 44 and 79% of the carbon stocks in the uncut forest by ages 30 and 40 years, respectively.
- The treatments that resulted in forest structure most similar to the uncut controls were the 60% retention and string of pearls treatments. The clearcut was least successful, followed by the 25 stems ha^{-1}seed tree treatment. Except for the string of pearls treatment, logging reduced structural complexity of the forests.
- If promotion of natural regeneration is the treatment objective, the two seed tree treatments were both successful, with at least 13,000 trees ha^{-1} <1.3 m tall 6-7 years after logging. The regeneration was dominated by western hemlock and western redcedar, which may compete with Douglas-fir, a species that may be more economically desirable and best adapted to a future drier climate.
- The string of pearls treatment promoted western hemlock and western redcedar natural regeneration in the openings, but four years after logging the density was only about half that of that seed tree blocks.
- The clearcut and 60% retention blocks were logged only one and two years prior to assessment so were to young assess natural regeneration.
- The old plantations and uncut forests had no regeneration <1.3 m tall.
- A diversity and abundance of herbaceous and shrub species was promoted by logging. However, the "weedy" bracken, which can outcompete other plant species and reduce growth of seedlings, was prevalent in the blocks logged at least four years prior to our assessment (seed tree blocks and string of pearls openings).
- The old plantations had sparse herbaceous and shrub cover, suggesting that these stands would benefit from restoration treatments to promote understory herbs and shrubs.
- The 10 x 10 m seed tree, 60% retention blocks, old plantations, and uncut forests had the most moss cover. The 25 stem ha^{-1} seed tree and string of pearls openings had less moss cover and the clearcut had none.
- Forest floor depth was similar in all logged blocks and the uncut controls, but its depth was reduced by more than half in the old plantations as the controls.

Introduction

Cortes is a 130 km^2 island located on the southern edge of the Discovery Island archipelago of British Columbia (Fig. 1). Its maximum elevation is 492 m. The island lies within the rain shadow of Vancouver Island in the Very Dry Maritime Coastal Western Hemlock biogeoclimatic subzone (CWHxm) (Green and Klinka, 1994), where high rainfall fuels productive and diverse forest ecosystems. The CWHxm subzone is characterized by warm, dry summers and moist, mild winters with little snowfall. The growing season is long and there are summer water deficits on zonal sites. Forests on zonal sites are dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), accompanied by western hemlock (*Tsuga heterophylla* Raf. Sarg.) and lesser amounts of western red cedar (*Thuja plicata* Donn. ex D. Don in Lamb.).

Figure 1. Map showing location of Cortes Island.

Cortes Island, like the rest of British Columbia's coast, has been subject to intense logging since European settlers arrived and the Klahoose First Nations (KFN) were displaced from their land in the early 1800's. The early days of logging on Cortes were gentle, where trees were hand felled with axes and moved by animals. When fuel-powered equipment including chainsaws, tractors, and trucks arrived in the 1950's and 60's, logging practices intensified and almost all of Cortes Island was harvested. Throughout the 1970's and 80's, second growth forests became the subject of intense logging, which the KFN and Cortes Island non-indigenous community were largely opposed to. This opposition led to the informal merging of these two communities in the 1990's, which became formalized in 1999 with the common goal of creating a community forest on Cortes and managing these forests sustainably. In 2013, the KFN and Cortes Community Forest co-operative (who represent the non-indigenous community of Cortes), known together as the Cortes Forestry General Partnership (CFGP), successfully gained tenure rights to 3,869 hectares of crown land (approximately 35% of the total land base of Cortes Island) to manage as a community forest.

Since it's establishment, the CFGP has been using innovative forest harvesting practices with the goal of promoting long-term sustainability of the ecosystems within the community forest. However, several challenges emerged such as meeting their mean annual increment requirements and performing economically viable cuts. To combat these challenges, diverse practices that vary from high intensity harvesting such as clearcutting to more moderate and low intensity harvests including seed tree cutting and thinning have been implemented. This diversity of harvesting practices provides a unique opportunity to retrospectively identify those practices that promote long-term forest resilience on Cortes Island.

The objective of this study was to examine how recent CFGP harvesting systems as well as older clearcutting and planting have affected tree carbon stocks, forest structure, regeneration, understory plant communities, and the forest floor.

Methods

Field measurements

Five previously logged sites within the CFGP operational forests were selected to compare the outcomes of their harvesting approaches (Table 1). At each site, between three and five plots were randomly located and measured in the harvested area to collect tree, plant community and ground substrate data. Between one and three plots were randomly located and measured in uncut forests (controls) and 30 to 50-year-old plantations adjacent to the harvested forests. At each plot, site information including slope, aspect, slope position, and soil moisture regime were recorded.

Table 1. Overview of the assessed sites.

	Old Von Donup Road	Squirrel Cove	Larson's Meadow	Green Mountain	Carrington Bay
# of plots in harvested area	3	5	5	3	4
# of plots in uncut control	1	6	2	2	2
# of plots in old plantation		3			1
Site series	01	01(06/03)	01(03/05/06)	01(03)	01(06)
Year logged	2021	2016	2015	2018	2020
Harvesting treatment	Clearcut	Seed tree	Seed tree	String of pearls	60% retention
Treatment description	Everything cut except Pw and Fd vets	10% of stems (25 trees/ha) and 20% of volume retained	10 x10 m spacing of seed trees	Small openings connected by a network of skid trails	A combination of thinning from below and thinning from above
Planting Details	Fd, Pw throughout, Cw in wet areas	1:1 Fd and Cw	Fd and Cw	Fd and Pw	Not planted

Goals	Reduce root rot	Create structural diversity; retain old trees	Retain old trees; create large enough gaps so that Fd regenerates		Retain trees for future harvest; create structural diversity

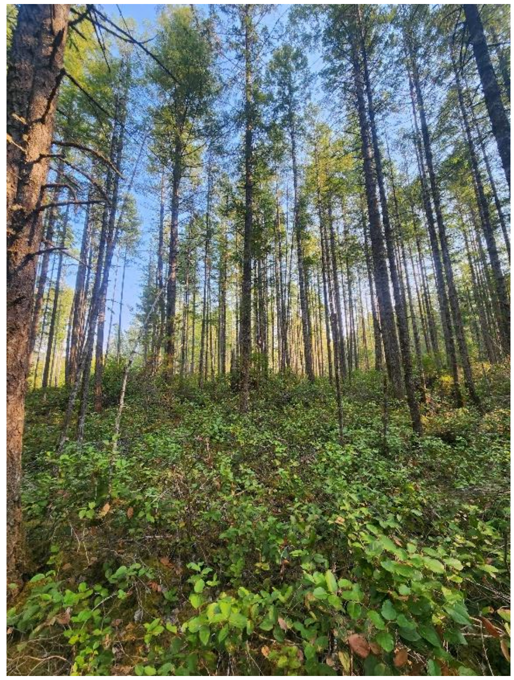
Fd: Douglas Fir, Cw: Western Red Cedar, Pw: White Pine

Plantation (Carrington Bay).

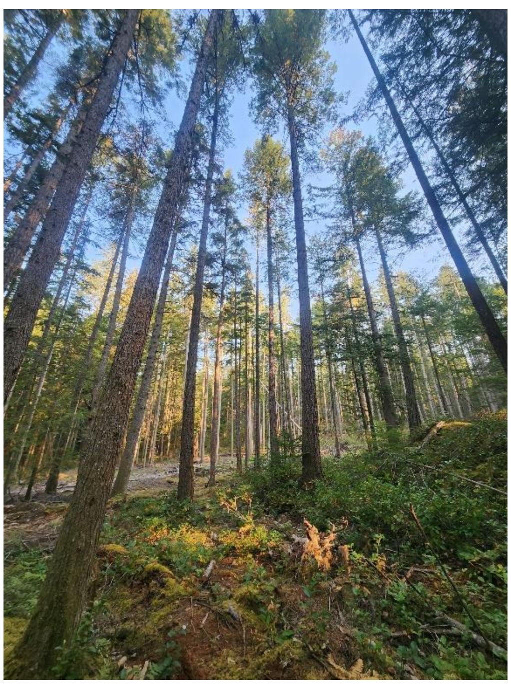
Plantation (Squirrel Cove).

Clearcut (Von Donup).

25 SPH seed tree (Squirrel Cove).

10 x 10 m seed tree (Larsen's Meadow). String of pearls (Green Mountain)



60% retention (Carrington Bay).

Figure 2. Photographs of the treated stands in 2022.

All live and dead trees taller than 1.3 m within circular 0.02 ha plots (r=8.00 m) were assessed for species, diameter at breast height (DBH), height, vigor, and origin (planted or natural regeneration). Species, height class (0-10 cm; 10-50 cm, 50-130 cm), vigour, and origin were recorded for trees shorter than 1.3 m within a circular 0.005 ha plot (r = 3.99 m). Overstory percent cover and species composition were recorded.

Substrate type and depth to mineral soil were recorded every 4 m along two 16 m transects, one running North to South, and the other running East to West, and centered on the moss0.02 ha plot centre.

To assess plant abundance and community composition, herb and shrub percent cover were estimated for the 10 most abundant species, and total moss cover was recorded within the 0.002 ha plot.

Data analyses

Descriptive statistics were calculated in Microsoft Excel and statistical analyses were done using RStudio and Microsoft Excel.

Plant Community: Plant percent covers were averaged by treatment type (logged, control, old plantation) for each site. Those plants which averaged 0.5% cover or less were set to 0.5%. Because only the 10 most abundant species were recorded for each plot, the lists of plants could not be used to calculate biodiversity.

Moss: Moss percent covers were averaged by treatment for each site.

Natural regeneration (<1.3 m tall): Natural regeneration density and species composition in the same treatment type were averaged for each site. Observed species included western hemlock, western redcedar, Douglas-fir, western white pine, shore pine, Sitka spruce, grand fir, and arbutus, but analyses were limited to the first four of these species due to small sample sizes for the others. Density of each regenerating species was calculated by overstory cover class, and the presence or absence of the species in the overstory.

Stand structure: Trees greater than 1.3 m tall were grouped into five height classes, then average density, height, diameter at 1.3 m (DBH), species composition, and vigour were calculated for each class for each treatment at each site.

Tree carbon: The biomass of each measured tree >1.3 m tall was determined using allometric equations (Ung et. al., 2008) that incorporate DBH, height, and species. Individual tree biomass was summed to obtain total tree biomass by plot. The biomass was scaled up to a hectare then converted to Mg ha^{-1} of carbon by multiplying biomass by 0.50 (Harmon et al., 2013).

Ground substrate: Average substrate depth and the percentage of stations having organic, rotten wood, and mineral soil substrate were calculated for each plot at each site. Plots with the same treatment were averaged.

Results

Natural regeneration (< 1.3 m tall)

The two seed tree blocks averaged >13,000 stems ha^{-1} of natural regeneration <1.3 m tall, which was more than the other treatments (Fig. 3). These were the oldest blocks that were assessed. The openings in the string of pearls blocks averaged about 7,000 stems ha^{-1} <1.3 m tall. The clearcut and 60% retention blocks had sparse regeneration, likely because they were logged just one and two years, respectively, before assessment. Western redcedar and western hemlock dominated the natural regeneration in all treatments. The Larsen's Meadow seed tree treatment was designed to create openings large enough for Douglas-fir regeneration, and while Douglas-fir density was much lower than western redcedar and western hemlock here, it was greater than in the other blocks.

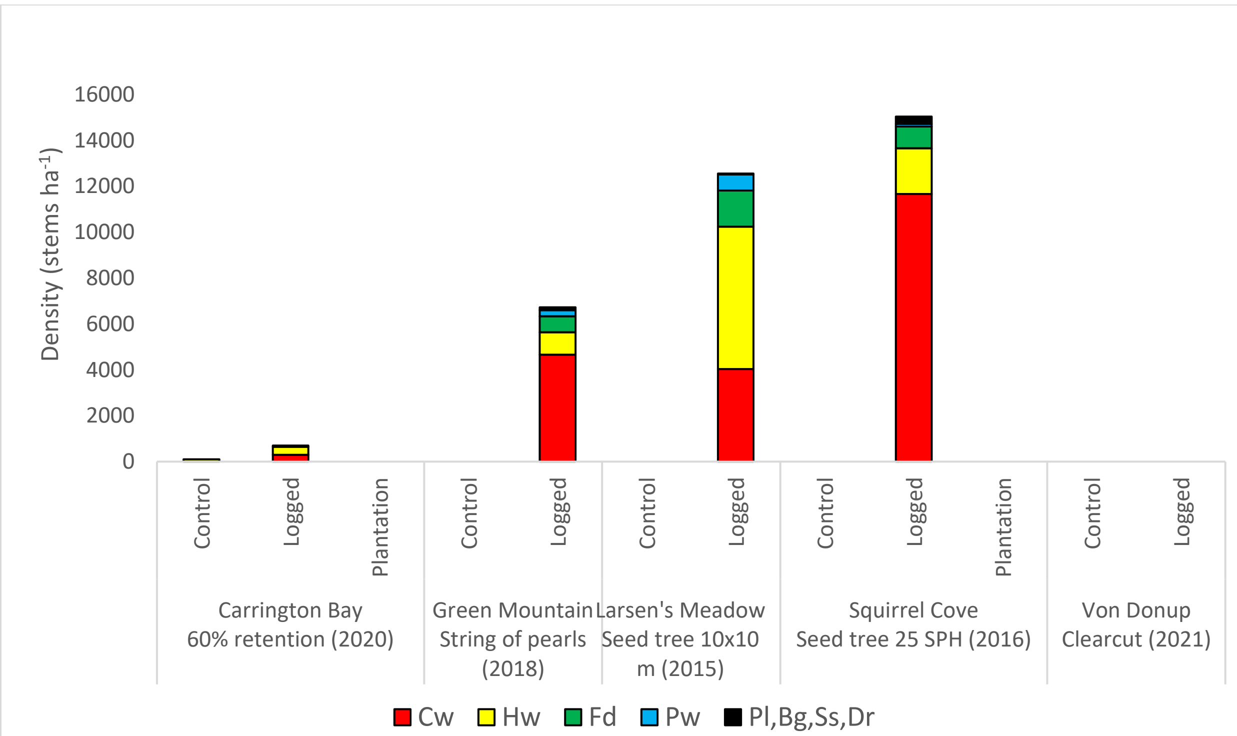


Figure 3. Average density of natural regeneration (trees < 1.3 m tall) by species.

Western hemlock, Douglas-fir, and western white pine regenerated best when overstory cover was between 15 and 40%, and western redcedar regenerated best when overstory cover was <15% (Fig. 4). No natural regeneration of any species occurred in the logged areas where overstory cover remained greater than 40%, or in the controls or old plantations (where cover was consistently >40%). There was an average of 5,180 more seedlings per hectare of western redcedar when overstory cover was less than 15% than when it was 15-40%. Conversely, there were 6,840 more western hemlock seedlings per hectare when overstory cover was between 15 and 40% than when it was less than 15%. Douglas-fir density was slightly higher under 15-40% canopy cover than <15% cover. Western white pine natural regeneration was sparse due to few overstory trees of this species, but regeneration was more abundant under 15-40% canopy cover than <15% cover. Scattered naturally regenerated grand fir, Sitka spruce, and arbutus seedlings were also present.

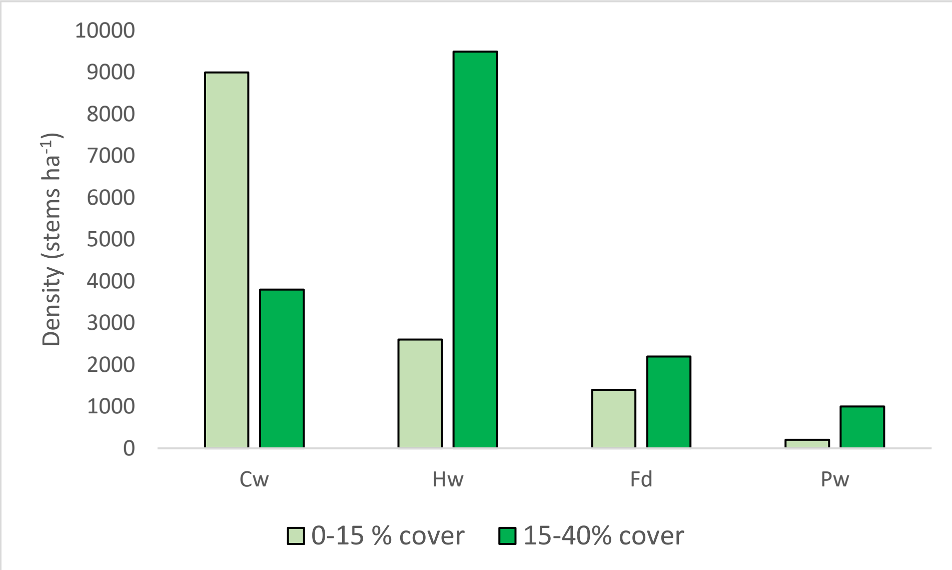


Figure 4. Average density of natural regeneration <1.3 m tall by overstory cover class.

The density of all species of natural regeneration was greater when the species was present in the overstory. There were, 3, 2.5, and 2 times as much western redcedar, Douglas-fir, and western hemlock regeneration, respectively, when the species was in the overstory compared to being absent (Fig. 5). Because western hemlock is rarely retained as an overstory species on Cortes Island, there were few plots where western hemlock was present in the overstory. Data could not be summarized for the other naturally regenerating species (grand fir, Sitka spruce, western white pine, and Arbutus) because sample sizes were too small. Field observations indicate that Sitka spruce and western white pine regenerate only in small pockets across the island, particularly on wet and dry sites, respectively.

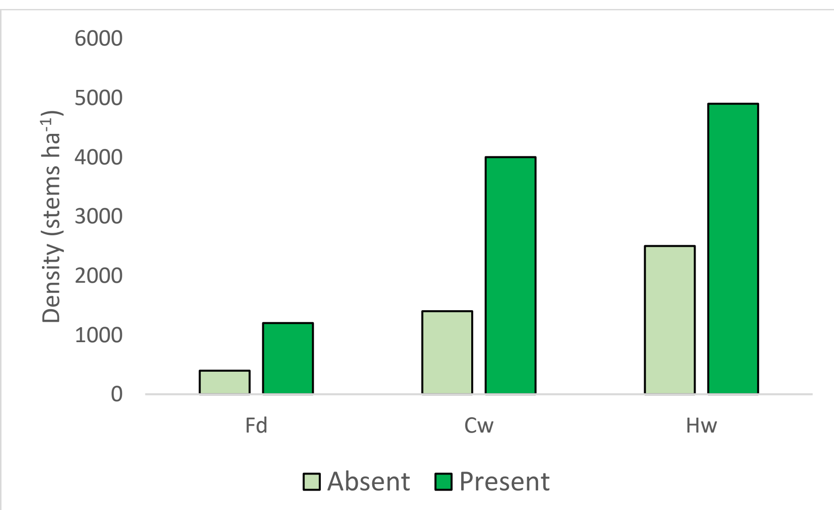


Figure 5. Average density of natural regeneration when the species was absent or present in the overstory.

Residual trees (>1.3 m tall)

Clearcut

The clearcut had few residual trees and no new regeneration greater than 1.3 m tall.

Seed tree, 25 stems ha^{-1}

These seed tree blocks had live trees in the <5 and >30 m height classes only (Table 2; Fig.6). The prescription called for retention of 25 seed trees ha^{-1} but we measured a density of only 10 seed trees ha^{-1}. However, there was a high density of dead trees, which varied from 5 to 20 m in height. Seed trees were shorter but with a larger diameter than dominant trees in the controls (Table 3). Seed trees were western redcedar and understory trees were primarily western hemlock (Tables 4, 5). In the adjacent control, understory trees were mainly western red cedar and western hemlock, with Douglas-fir more prevalent in the higher height classes. Seed and understory trees in the seed tree blocks were of good vigour (Table 6). In the adjacent controls, most trees <5 and >30 m tall were of good vigour, but trees 5-30 m tall were variable.

Seed tree, 10 x 10 m

Like the 25 stem ha^{-1} seed tree block, trees in these blocks were either <5 or >30 m tall (Fig. 6). The number of seed trees was close to the prescribed density of 100 trees ha^{-1} and they were similar in size to the dominant trees in the control. Seed trees were predominantly Douglas-fir, with some western redcedar and western hemlock (Fig. 6). The <5 m height class was 40% Douglas-fir, with western redcedar, western hemlock, and lesser amounts of western white pine. In the adjacent control, western redcedar, western hemlock, and Douglas-fir were all present in the understory and trees >30 m tall were all Douglas-fir. Seed and understory trees were of good vigour. In the adjacent controls, most trees <5 and >30 m tall were of good vigour, but those 5-30 m tall were variable. There were no standing dead trees in the seed tree blocks.

String of pearls

Live trees >1.3 m tall were absent in the openings created by the string of pearls treatment. There were 68 dead trees ha^{-1} in the openings, and their sizes were variable. The retention patches of the string of pearls blocks were not sampled. Here skid roads were the only disturbance, and it is expected that stand structure was similar to the control.

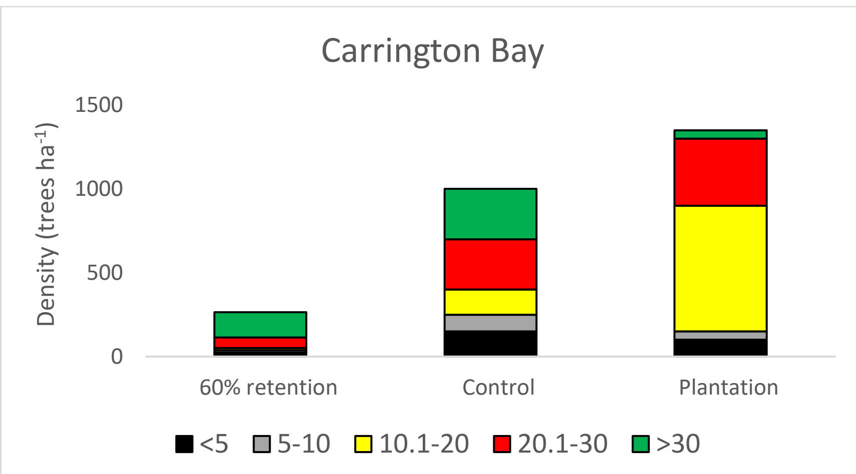
60% retention

The 60% retention treatment had a higher density of live trees than the other treatments, but at 264 stems ha^{-1} density was only about one-fifth that in the adjacent uncut control. Live trees were present in all height classes but as in the control, trees >20 m tall had the highest density (Fig. 6). In the 60% retention treatment, trees <5 m tall were predominantly hemlock, and western redcedar was the main species of the 5-20 m height class (Fig. 6). Taller trees were a mix of western redcedar, western hemlock, and Douglas-fir. In the adjacent control, trees <20 m tall were mainly western hemlock but Douglas-fir was a dominant species of the taller trees. In the

60% retention blocks, 25% of trees >20 m tall were of poor vigour, but trees ≤20 m tall were all good or moderate. All size classes averaged better vigour in the 60% retention blocks than the adjacent controls. Dead trees were absent in the 60% retention blocks, compared to an average of 625 dead trees ha^{-1} in the adjacent controls.

Old plantations

The 30 to 40-year-old Douglas-fir plantations were dominated by trees 10-30 m tall, and there were more naturally regenerated trees than planted trees (Fig. 6). Dominant planted trees were taller than dominant naturals, but they were not as tall as in the controls. In the plantation at Carrington Bay, natural regeneration <10 m tall was western redcedar while taller trees were western hemlock with lesser amounts of western white pine. Natural regeneration in the plantation at Squirrel cove was dominated by grand fir in all size classes, with lesser amounts of western redcedar and western hemlock and occasional Douglas-fir. Vigour of planted and natural trees >20 m tall was generally good. For trees 10.1-20 m tall, there were more healthy naturals than healthy planted trees. Vigour of naturals 5-10 m tall was generally poor. Naturals <5 m tall were of good vigour at Squirrel Cove but moderate at Carrington Bay. Dead planted trees were common at both sites (about 500 stems ha^{-1}). The density of dead natural regeneration was 550 stems ha^{-1} at Carrington Bay, and about half that at Squirrel Cove. More dead trees were broken in the controls than the plantations.



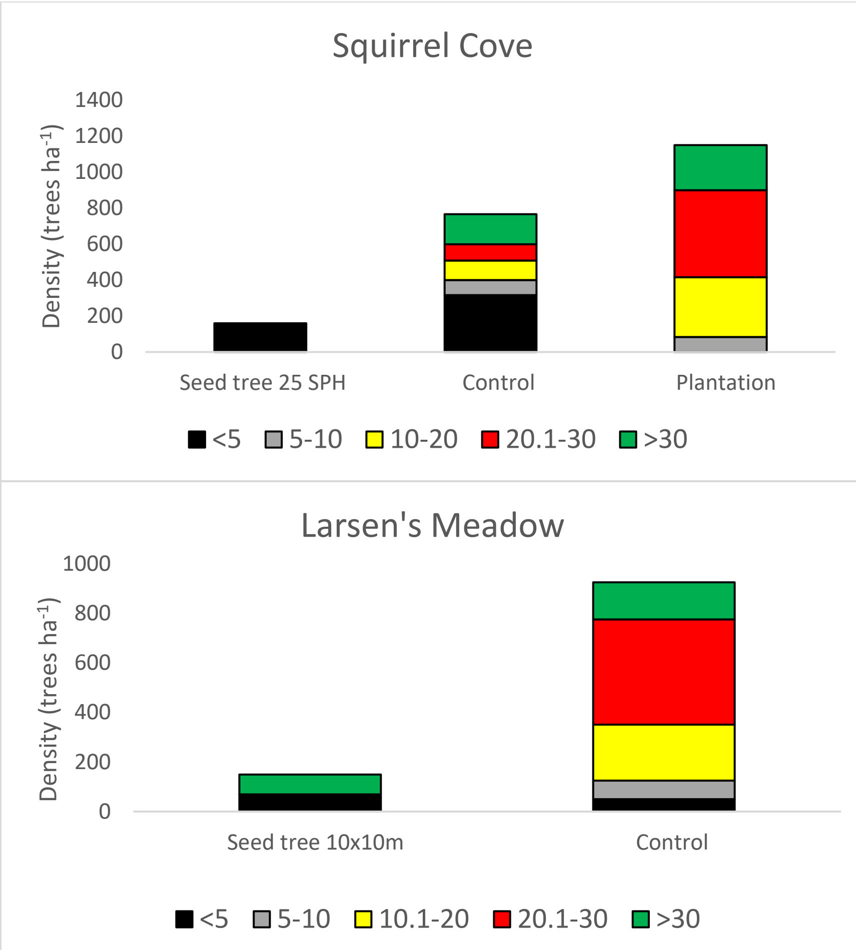


Figure 6. Density of live trees by height class (m) in the 60% retention and seed tree blocks, and adjacent controls and old plantations.

.

Table 2. Density of live and dead trees greater than 1.3 m tall.

Site and Treatment	Density of live trees by height class (stems ha^{-1})												Density of dead trees by height class (stems ha^{-1})											
	Natural						Planted						Natural						Planted					
	<5	5-10	11-20	21-30	>30	Total	<5	5-10	11-20	20-30	>30	Total	<5	5-10	11-20	20-30	>30	Total	<5	5-10	11-20	21-30	>30	Total
Carrington Bay																								
60% retention	25	13	13	63	150	264																		
Control	150	100	150	300	300	1000							275	200	150			625						
Plantation	100	50	450	200		800			300	200	50	550	100	250	200			550	50	350	150			550
Green Mountain																								
String of Pearls**													17	17	17		17	68						
Control	25	75	225	450	75	850							100	100	150			350						
Larsen’s Meadow																								
Seed tree 10x10m	70				80	150																		
Control	50	75	225	425	150	925							50	125		25		200						
Squirrel Cove																								
Seed tree 25 SPH ***	150				10	160							1150	100	750			2000						
Control	317	83	108	92	167	767							108	83	42	17		250						
Plantation ***		83	317	367	50	817			17	117	200	334	67	133	50	17		267	200		50	200	50	500
Von Donup																								
Clearcut		8	8		17	33							25					25						
Control	150	150	125	150	50	625									100			100						

** Plots were all situated in openings

*** Dead “natural” = unknown if natural or planted

Table 3. Height and diameter at 1.3 m (DBH) of live trees greater than 1.3 m tall.

Site and Treatment	Height of live trees by height class (m)										DBH of live trees by height class (cm)									
	Natural regeneration					Planted trees					Natural regeneration					Planted trees				
	<5	5-10	11-20	21-30	>30	<5	5-10	11-20	20-30	>30	<5	5-10	11-20	21-30	>30	<5	5-10	11-20	21-30	>30
Carrington Bay																				
60% retention	2.3	8.5	12.9	26.5	40.2						1.7	19.2	25.6	37.5	54.8					
Control	3.2	6.3	13.8	23.7	37.6						2.5	8.9	12.9	26.7	54.4					
Plantation	2.3	5.1	17.0	24.0				16.7	24.9	32.6	1.5	3.9	12.5	24.4				10.9	29.7	47.1
Green Mountain																				
String of Pearls**						1.9										0.7				
Control	4.3	7.3	14.6	24.8	32.9						4.3	15.1	17.6	29.0	48.4					
Larsen’s Meadow																				
Seed tree 10x10m	2.3				41.4	1.8					2.8				65.2	0.8				
Control	2.6	7.0	15.5	23.5	39.9						3.2	20.5	23.2	29.3	63.1					
Squirrel Cove																				
Seed tree 25 SPH	2.2				32.3						1.2				97.1					
Control	2.8	8.1	15.2	25.4	42.1						2.6	11.4	18.2	34.9	65.9					
Plantation		8.0	15.9	25.9	33.4	2.2		13.5	26.7	49.2		6.9	11.5	23.1	35.6	1.4		7.8	24.9	37.6

Von Donup																				
Clearcut		7.4	12.1		32.1							8.0	20.2		64.5					
Control	3.0	6.9	13.3	24.6	31.6						9.5	8.5	15.0	39.4	70.8					

** Plots were all situated in openings

Table 4. Species composition of live natural trees 1.3-5, 5-10, and 10.1–20 m tall, based on density.

Site and Treatment	1.3-5 m						5-10 m							10.1-20 m					
	Cw	Hw	Fd	Bg	Pw	Total	Cw	Hw	Fd	Bg	Pw	Dr	Total	Cw	Hw	Fd	Bg	Dr	Total
Carrington Bay																			
60% retention	0	100	0	0	0	100	100	0	0	0	0	0	100	100	0	0	0	0	100
Control	0	100	0	0	0	100	0	75	25	0	0	0	100	25	75	0	0	0	100
Plantation	100	0	0	0	0	100	100	0	0	0	0	0	100	11	67	0	0	22	100
Green Mountain																			
String of Pearls**																			
Control	0	0	100	0	0	100	25	0	50	0	25	0	100	30	0	70	0	0	100
Larsen's Meadow																			
Seed tree 10x10	25	25	40	0	10	100													
Control	50	50	0	0	0	100	50	0	50	0	0	0	100	47	30	23	0	0	100
Squirrel Cove																			
Seed tree 25 SPH	0	85	0	9	3	100													
Control	9	91	0	0	0	100	40	50	0	0	0	10	100	40	40	20	0	0	100
Plantation							20	0	0	80	0	0	100	11	5	5	79	0	100
Von Donup																			
Clearcut							0	100	0	0	0	0	100	100	0	0	0	0	100
Control														0	100	0	0	0	100

** Plots were all situated in openings

Table 5. Species composition of live natural trees 20.1-30 and >30 m tall, based on density.

Site and Treatment	20.1-30 m								>30 m							
	Cw	Hw	Fd	Bg	Pw	Ss	Dr	Total	Cw	Hw	Fd	Bg	Pw	Ss	Dr	Total
Carrington Bay																
60% retention	38	24	38	0	0	0	0	100	13	24	63	0	0	0	0	100
Control	0	65	35	0	0	0	0	100	0	11	89	0	0	0	0	100
Plantation	0	75	0	0	25	0	0	100								
Green Mountain																
String of Pearls**																
Control	20	0	80	0	0	0	0	100	0	0	100	0	0	0	0	100
Larsen's Meadow																
Seed tree 10x10									10	10	80	0	0	0	0	100
Control	36	22	42	0	0	0	0	100	0	0	100	0	0	0	0	100
Squirrel Cove																
Seed tree 25 SPH									100	0	0	0	0	0	0	100

Control	31	8	44	0	0	17	0	100	28	5	27	10	0	10	20	100
Plantation	17	40	0	43	0	0	0	100	0	0	0	100	0	0	0	100
Von Donup																
Clearcut									50	0	0	0	50	0	0	100
Control	66	0	17	0	0	0	17	100	100	0	0	0	0	0	0	100

** Plots were all situated in openings

Table 6. Vigour of natural and planted live trees greater than 1.3 m tall.

Site and Treatment	Vigour by height class (% of trees)																													
	Natural															Planted														
	<5 m			5-10 m			10.1-20 m			20.1-30 m			>30 m			<5 m			5-10 m			10.1-20 m			20.1-30 m			>30 m		
	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P	G	M	P
Carrington Bay																														
60% retention	50	50	0	0	100	0	100	0	0	50	25	25	75	0	25															
Control	0	88	12	50	50	0	50	25	25	35	20	45	65	29	6															
Plantation	0	100	0	0	0	100	78	22	0	75	25	0										67	17	17	100	0	0	100	0	0
Green Mountain																														
String of Pearls**																														
Control				50	50	0	50	38	12	88	0	12	100	0	00															
Larsen's Meadow																														
Seed tree 10x10	100	0	0										100	0	0															
Control	100	0	0	100	0	0	60	40	0	63	37	0	100	0	0															
Squirrel Cove																														
Seed tree 25 SPH													100	0	0															
Control	87	3	10	33	50	17	65	15	20	67	33	0	93	7	0															
Plantation	100	0	0	20	20	60	53	26	21	90	10	0	100	0	0							0	100	0	90	10	0	100	0	0
Von Donup																														
Clearcut				100	0	0	0	0	100				100	0	0															
Control							75	25	0	83	0	17	100	0	0															

** Plots were all situated in openings

Tree carbon

As expected, the higher retention treatments had a larger aboveground tree carbon pool than the lower retention treatments (Table 7; Fig. 7). Tree carbon stocks in the controls varied by site, but the pool was consistently higher in the controls than in the adjacent logged blocks or old plantations. The string of pearls treatment had no tree carbon stocks because only the removal patches were sampled.

Table 7. Average carbon stocks in aboveground trees.

Site	Treatment	Tree carbon (Mg ha^{-1})
Carrington Bay	Control	303.1
	60% retention	170.8
	Plantation	133.2
Green Mountain	Control	170.6
	String of pearls	0.0
Larsen's Meadow	Control	337.1
	Seed tree, 10 x 10 m	116.5
Squirrel Cove	Control	342.8
	Seed tree, 25 SPH	66.2
	Plantation	271.0
Von Donup	Control	201.1
	Clearcut	32.0

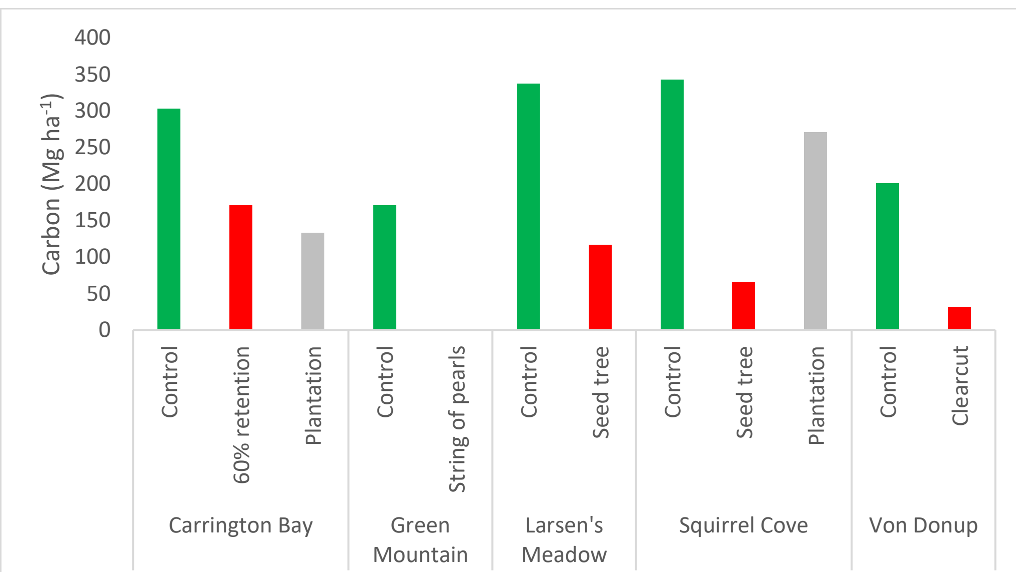
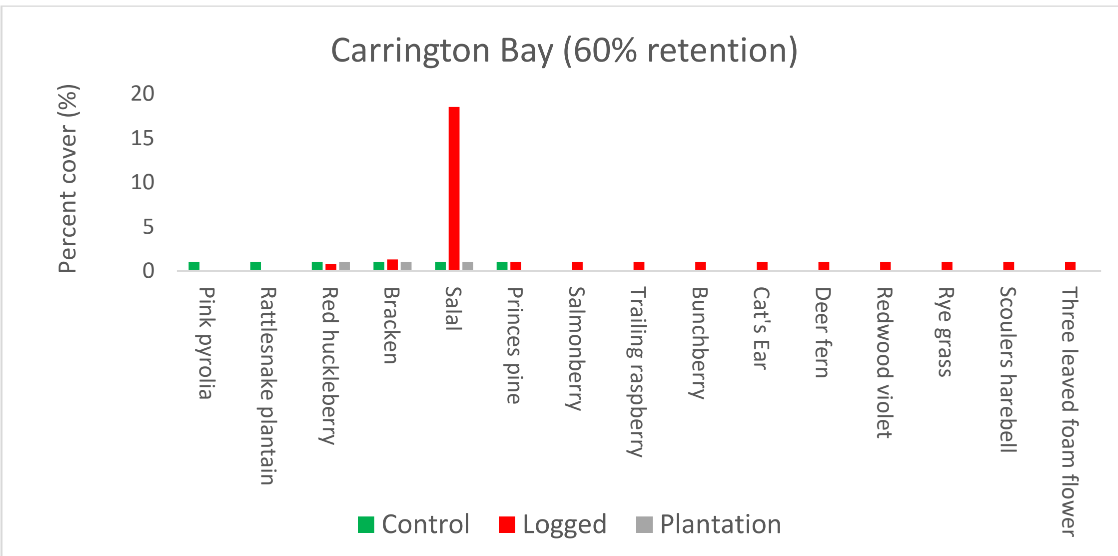


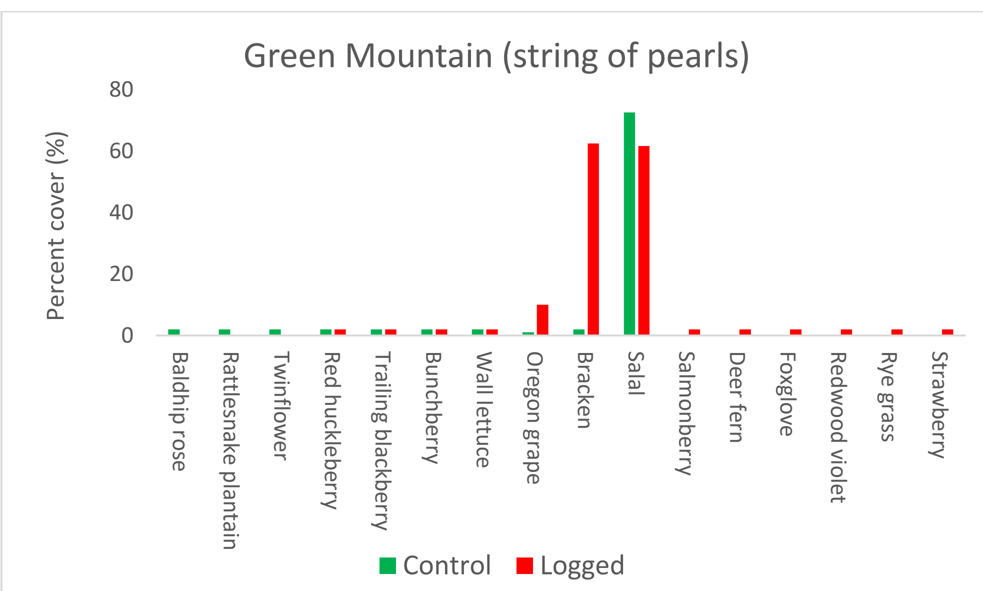
Figure 7. Aboveground tree carbon stocks at each site.

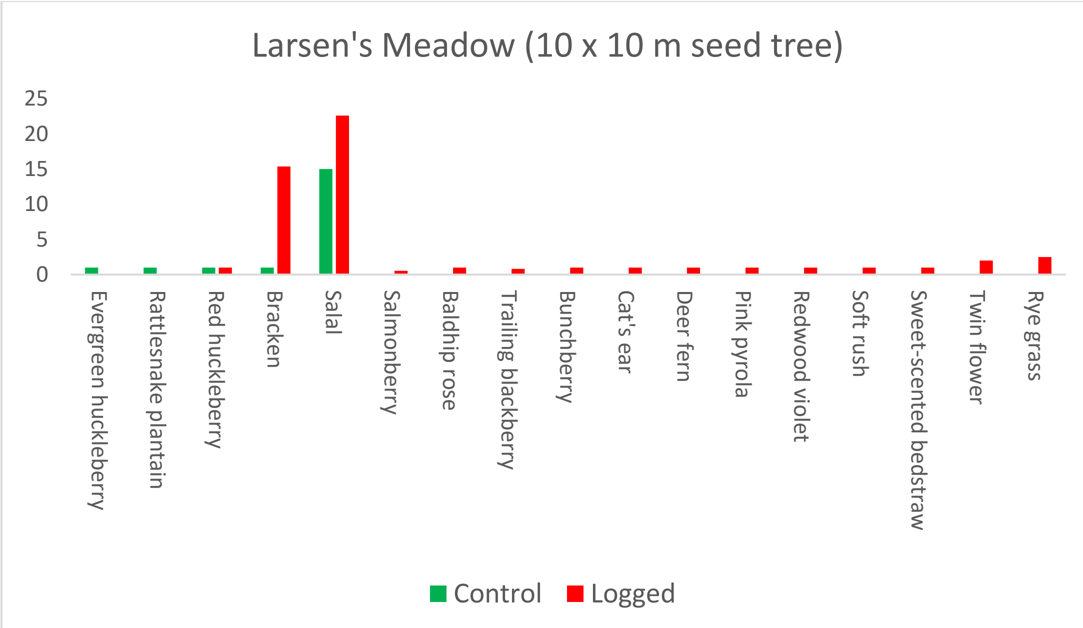
Shrub and herb community composition

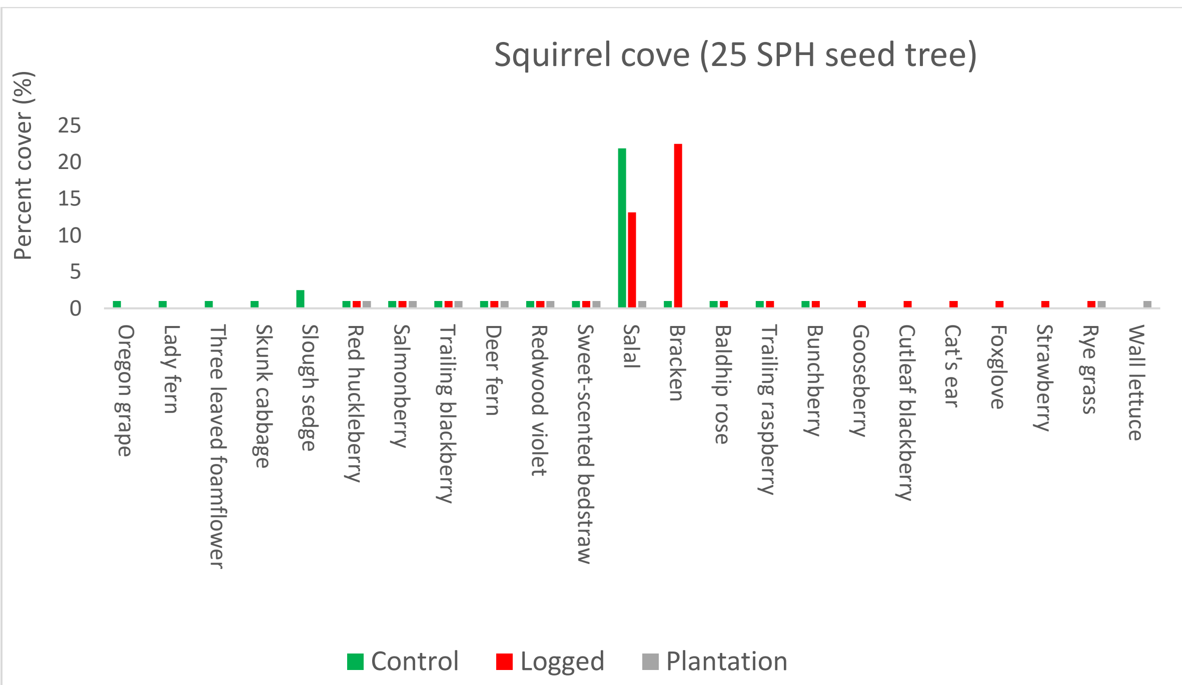
At all sites, there were more plant species in the harvested area than in the adjacent uncut control or old plantation (Fig. 8). Some species were only found in the controls (e.g., rattlesnake plantain), and others only in the logged areas.

Salal was the dominant species in the control at all sites except Carrington Bay where there was no dominant species. Salal was also a major species in the logged areas at all sites except in the Von Donup clearcuts, which were logged just one year prior to assessment. Bracken was present at all logged and unlogged sites but was a minor species in the controls. Bracken was the dominant herbaceous species in the two seed tree areas (Squirrel Cove and Larsen's Meadow) and the openings in the string of pearls treatment (Green Mountain). Other than bracken, "weedy" species were not common in the logged or unlogged areas.






Larsen's Meadow (10 x 10 m seed tree)
25
20
15
10
5
0
Evergreen huckleberry
Rattlesnake plantain
Red huckleberry
Bracken
Salal
Salmonberry
Baldhip rose
Trailing blackberry
Bunchberry
Cat's ear
Deer fern
Pink pyrola
Redwood violet
Soft rush
Sweet-scented bedstraw
Twin flower
Rye grass
Control
Logged


Squirrel cove (25 SPH seed tree)
Percent cover (%)
25
20
15
10
5
0
Oregon grape
Lady fern
Three leaved foamflower
Skunk cabbage
Slough sedge
Red huckleberry
Salmonberry
Trailing blackberry
Deer fern
Redwood violet
Sweet-scented bedstraw
Salal
Bracken
Baldhip rose
Trailing raspberry
Bunchberry
Gooseberry
Cutleaf blackberry
Cat's ear
Foxglove
Strawberry
Rye grass
Wall lettuce
Control
Logged
Plantation

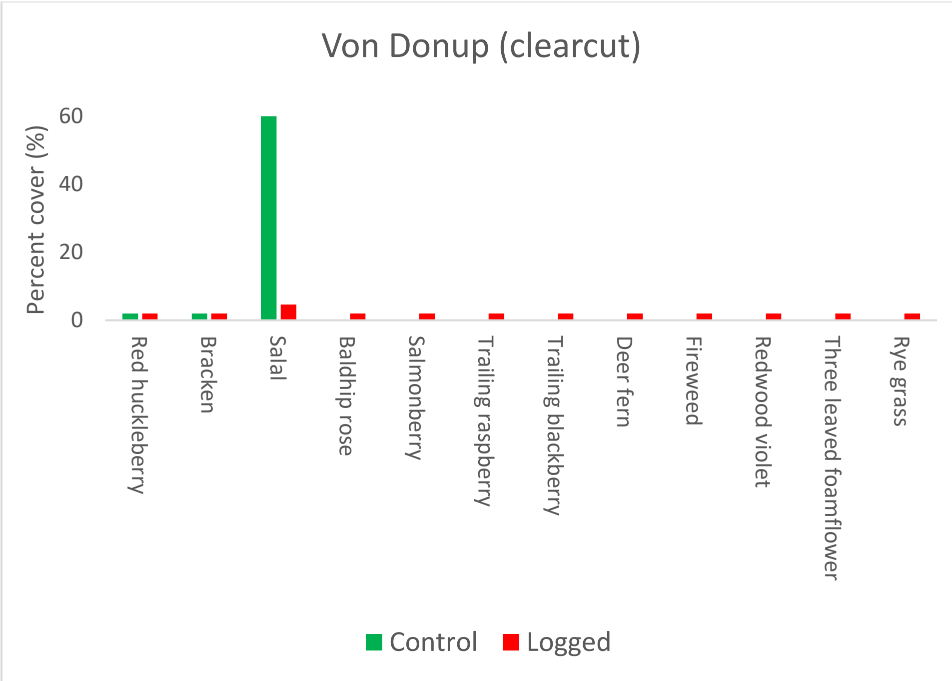


Figure 8. Percent cover of herb and shrub species at each site.

Moss abundance

Average moss percent cover was higher in the uncut control than the harvested plots at each site (Fig. 9). The least difference from the control occurred in the 10 x 10 m seed tree block logged in 2015 at Larson's Meadow, and the greatest difference occurred in the Von Donup block, which was clearcut in 2021.

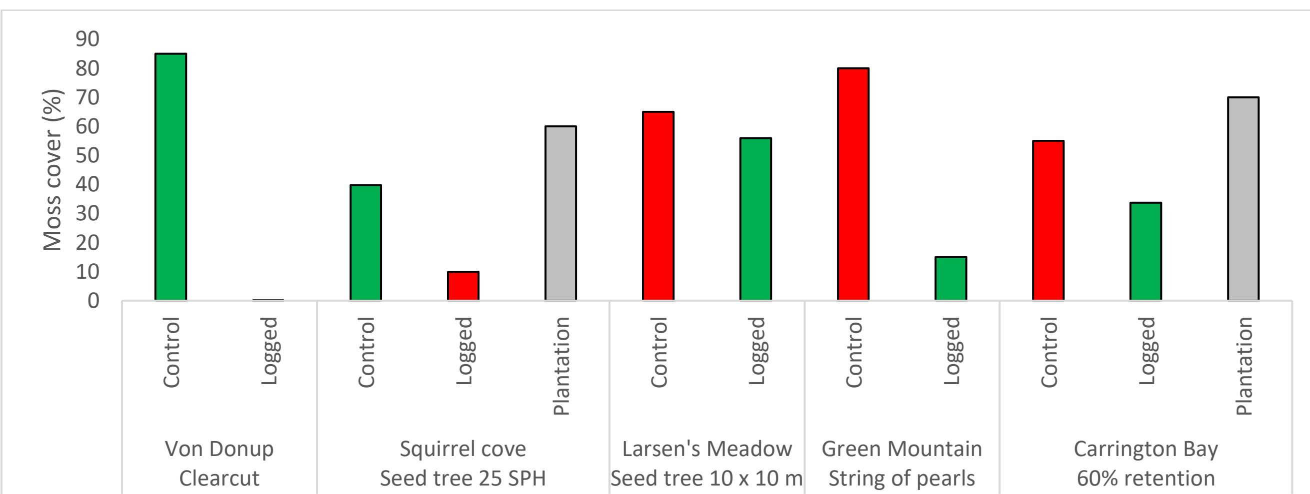


Figure 9. Average moss percent cover at each site.

Forest floor

Average forest floor depth in the plantations was about half that of the adjacent controls (Table 8). In contrast, depth was similar in the logged areas and adjacent controls. In the controls and Squirrel Cove plantation, the substrate was 90-100% organic material, and the remainder was rotten wood. The logged areas and Carrington Bay plantation had more rotten wood and exposed mineral soil than the other areas. The 10 x 10 m seed tree and clearcut had the least rotten wood on the forest floor.

Table 8. Average forest floor depth and percentage of stations having each type of substrate.

Site	Treatment	Average forest floor depth (cm)	Percent of ground (%)		
			Mineral soil	Organic	Rotten wood
Carrington Bay	Control	9.9	0	90	10
	60% retention	8.1	10	65	25
	Plantation	4.4	10	60	30
Green Mountain	Control	4.1	0	90	10
	String of pearls	6.7	0	77	23
Larsen's Meadow	Control	5.6	0	100	0
	Seed tree, 10 x 10 m	7.6	4	84	12
Squirrel Cove	Control	10.6	0	96	4
	Seed tree, 25 SPH	12.3	2	68	30
	Plantation	4.3	0	97	3
Von Donup	Control	9.2	0	100	0
	Clearcut	9.3	7	87	7

Summary

This study examined how tree carbon pools, stand structure, tree regeneration, plant communities, and forest floor characteristics following recent harvesting treatments compare with unlogged forests and old plantations on Cortes Island. Table 9 summarizes the outcomes of each treatment. The "best" treatment depends on the objectives, as described below.

If the objective is to protect aboveground carbon pools, the best option is to not log. Of the logging treatments that we investigated; 60% retention conserved the most tree carbon (56% of the stocks in the uncut controls). Considering both openings and retention areas (disturbed only by skid trails), the string of pools treatment conserved considerable carbon, but because we established plots in the openings only, carbon stocks in the retention area were not quantified. The 10 x 10 m seed tree treatment conserved 35% of the carbon stocks of the uncut forest and the 25 stems ha^{-1} treatment conserved about half of this. Conventional clearcutting removes all tree carbon, but because residual trees were retained in the clearcut we measured, carbon stocks were similar in the clearcut and 25 stems ha^{-1} seed tree treatment. Regeneration that establishes after logging can take more than a decade to contribute measurably to aboveground carbon stocks (J. Roach, pers. comm). The plantations that we measured had regained 44 and 79% of the carbon in the uncut forest by age 30 and 40, respectively.

The treatment that resulted in forest structure most similar to the uncut controls was the 60% retention and string of pearls treatments. The clearcut was least successful, followed by the 25 stems ha^{-1}seed tree treatment. The plantations were structurally simpler than the uncut forest.

If promotion of natural regeneration is the treatment objective, the two seed tree treatments were both successful, with at least 13,000 trees ha^{-1} <1.3 m tall 6-7 years after logging. The regeneration was dominated by western hemlock and western redcedar which may compete with Douglas-fir, a species that may be more economically desirable and better suited to a more arid future climate. The string of pearls treatment promoted natural regeneration in the openings, but four years after logging the density was only about half that of that seed tree blocks. Again, regeneration was dominated by western hemlock and western redcedar. The clearcut and 60% retention blocks were logged only one and two years prior to assessment so were to young assess natural regeneration. The old plantations and uncut forests had no regeneration <1.3 m tall.

A diversity and abundance of herbaceous and shrub species is desirable for many reasons, including providing food resources and hiding, shelter, and reproductive cover for wildlife, as well as contributing to forest floor development. All logging treatments promoted these values, although the “weedy” bracken that was prevalent in the seed tree blocks and string of pearls openings can outcompete other plant species and was competing with tree seedlings. Although the 60% retention block had low cover of bracken, the assessment was done only two years after logging which may be too soon for full development of the species. However, given its preference for full sun, bracken in the 60% retention blocks is not expected to reach the cover values seen in the seed tree and string of pearls openings. The old plantations had sparse herbaceous and shrub vegetation, suggesting that these stands would benefit from restoration treatments to promote understory herbs and shrubs.

Mosses are ecologically valuable for their roles in reducing soil erosion, maintaining soil moisture, reducing soil temperature fluctuations, providing shelter for microfauna and nurseries for regenerating seedlings, providing food for moose, deer, snails, slugs, moth caterpillars, mites and termites, and in northern forests for nitrogen fixation. The 10 x 10 m seed tree treatment resulted in 86% moss cover seven years after logging; the 60% retention treatment had 61% of the control moss cover two years after logging. The 25 stems ha^{-1} seed tree and string of pearls openings had 25% and 19% of the control moss values, respectively. The clearcut treatment was worst at retaining moss: that which wasn’t torn and displaced was dried up and dead one year after logging.

The forest floor is important for carbon storage, nutrient cycling and effects on soil moisture and temperature. It contains vast numbers of organisms, including invertebrates, fungi, algae, and bacteria. Forest floor depth was similar in all logged blocks and the uncut controls but was less than 50% the depth of the control in the old plantations, possibly due to high disturbance levels during logging coupled with low inputs from understory plants.

Table 9. A summary of outcomes of each treatment.

Treatment	Clearcut	Seed tree 25 SPH	Seed tree 10 x 10 m spacing	String of pearls -- openings	60% retention	Old plantation	Control
Location	Von Donup	Squirrel Cove	Larsen's Meadow	Green Mountain	Carrington Bay	Carrington Bay and Squirrel Cove	
No. of years since logging	1	6	7	4	2	30+	
Tree carbon	16% of control	19% of control	35% of control	None in openings	56% of control	44 - 79% of control	More than any logged area
Stand structure	Most different from controls	Second most different from controls	Third most different from controls	Retention areas similar to controls; small openings add structural diversity	More similar to control than seed tree or clearcut	Structure less complex than controls	More complex than logged areas
Regeneration (<1.3 m tall)	None (too soon to tell)	15,000 per hectare; dominated by Cw	13,000 per hectare; dominated by Hw and Cw; more Fd than other treatments	7,000 per hectare, dominated by Cw	500 per hectare (too soon to tell)	None	None
Herb and Shrub plant community	No dominant species; more species than control	Dominant species bracken and salal; many species in logged area and control	Dominant species bracken and salal; more species than control	Dominant species bracken and salal; many species in logged area and control	Dominant species salal; more species than control	Sparse	Dominant species salal except at Carrington Bay
Moss cover	None	25% of control	86% of control	19% of control	61% of control	1.3 to 1.5 times control cover	40 – 85% cover
Forest floor depth	Similar to control	Similar to control	Similar to control	Similar to control	Similar to control	<50% of control	Thinnest on dry sites

References

Green, R.N., Klinka, K. (1994). A field guide to site identification and interpretation for the Vancouver Forest Region. Land Manag. Handb. 28. B.C. Ministry of Forests, Research Branch, Victoria B.C.

Harmon, M.E., Fasth, B., Woodall, C.W., Sexton, J. (2013). Carbon concentration of standing and downed woody detritus: effects of tree taxa, decay class, position, and tissue type. For. Ecol. Manag. 291, 259-267. https://doi.org/10.1016/j.foreco.2012.11.046

Ung, C.-H., Bernier, P., Guo, X.-J. (2008). Canadian national biomass equations: new parameter estimates that include British Columbia data. Can. J. For. Res. 38(5), 1123–1132. https://doi.org/10.1139/x07-224