Riparian restoration on Lyell Island, Haida Gwaii: understory vegetation and light

by

Rachel P. White Collings

B.Sc., (Honours), University of Victoria, 2008

Research Project Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF RESOURCE MANAGEMENT

In the
School of Resource and Environmental Management
Faculty of Environment

Report No. 561

SIMON FRASER UNIVERSITY
Fall 2012

Approval

Name:	**Rachel P. White Collings**
Degree:	**Master of Resource Management**
Project No.:	**561**
Title of Thesis:	***Riparian restoration on Lyell Island, Haida Gwaii: understory vegetation and light.***

Examining Committee:

Chair: Sandra Warren
MRM Candidate
Resource and Environmental Management

Kenneth P. Lertzman
Senior Supervisor
Professor of Resource and Environmental Management

Simon Fraser University

Andy MacKinnon
Research Ecologist, Coast

BC Ministry of Forests, Lands, and Natural Resource Operations

Sari Saunders
Research Ecologist, Coast

BC Ministry of Forests, Lands, and Natural Resource Operations

Date Defended/Approved: October 26, 2012

Abstract

Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site (Gwaii Haanas) has undertaken a riparian restoration project on Lyell Island that aims to restore salmon habitat and enhance biodiversity values. Past forestry practices in Sandy Creek, Lyell Island have left a dense forest canopy and introduced deer have left a depauperate understory. A range of openness treatments were used in the riparian forest of Lyell Island, Haida Gwaii, to create a more heterogeneous forest structure and light environment in the understory. This research examines the understory vegetation community of this ecosystem, as well as the change in light environment post-treatment due to the restoration, and one-year-post due to wind events throughout the winter. We found that tall stumps left over from logging provide important refugia from deer browsing. Mean height and percent cover of vegetation was significantly greater on stumps. However, species richness and diversity were greater in all ground plots. Mean height was significantly greater within exclosures, than in open ground plots. Maintaining exclosures and continuing deer control measures will be important if managers wish to restore understory biodiversity within Gwaii Haanas. Forest structure variables (basal area, and stand density), as well as light environment variables (percent full sun, canopy openness and effective leaf area) changed significantly post-restoration due to the treatments. Percent full sun increased in similarity to the percent full sun as measured in the old growth comparison in Windy Bay. One-year-post restoration showed similar mean values in most variables but higher standard deviations for percent full sun due to wind events throughout the winter: more similar to the spread of old growth light levels. This research will help inform management techniques for future restoration project success in Gwaii Haanas.

Keywords: Riparian restoration; understory; light; vegetation response; stump refugia; hemispherical canopy photography.

Acknowledgements

This study is a contribution to the Action On The Ground project managed by Gwaii Haanas, entitled “Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island).” I would like to thank the staff of Gwaii Haanas for their time and effort in helping with this project: Laurie Wein for managerial organization and support, Basia Wojtaszek for logistical organization with field equipment and crews, Peter Dyment for his incredible generosity of time, energy, and support, Clint Johnson and Jacques Morin for helping with the project and their superior boat driving skills. Thanks also to Stef Righi, Nik McEwan, and Laura White, field assistants, for their incredible energy, optimism, and keen spirits. This research project was the original idea of Basia Wojtaszek and Audrey Pearson; I thank them both for the time and energy they have put into the project. Special thanks to my Senior Supervisor, Dr. Ken Lertzman, and committee members Andy MacKinnon and Sari Saunders for their advice, feedback, guidance, patience, and encouragement. Finally, I have to thank my friends, family, and husband for their never ending and sometimes baffling support and belief in my ability to succeed. This project would not have been possible without them.

Table of Contents

List of Tables

List of Figures

Executive Summary

Ecological restoration is a method used to sustain biodiversity and re-establish functioning ecosystems and an ecologically healthy relationship between nature and culture. Situated in Gwaii Haanas National Park Reserve and Haida Heritage Site, Lyell Island was heavily logged throughout the last century and the effects of its history are still seen in the uniform structure and closed canopy of second growth forests. The Sitka black-tailed deer introduced in 1878 have posed an especially difficult challenge for the successful regeneration of understory vegetation in riparian forests.

Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site (herein *Gwaii Haanas*) have undertaken a riparian restoration project on Lyell Island entitled: “Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island).” The project aims to restore salmon habitat and enhance biodiversity values. Adequate habitat for salmon migration and spawning requires large woody debris (LWD) instream, as well as healthy understory growth to supply LWD in the future. Silviculture treatments in surrounding riparian forests such as canopy gap creation allow additional light into the understory and will enhance structural diversity, which is important for both the function and composition of a forest.

As part of this restoration project I describe the understory vegetation community and the response of understory light environment to restoration treatments. My research objectives are as follows:

- To describe the ecology of plant communities in Sandy Creek, including:
    - the difference between vegetation on stump refugia and ground plots open to deer browse;
    - the difference between vegetation within ground plots open to deer browse and those within deer exclosures and how vegetation responded due to exclosures.
- To describe the light environment in the understory including:
    - the difference in light before, immediately after, and one year after restoration treatments;
    - the difference in light between Sandy Creek and the old growth light environment in Windy Bay, Lyell Island;

- the difference in light from the restoration treatments as opposed to natural disturbance over the course of a year.

Results of the first research objective are that exclosures have thus far provided a faster recovery for understory species than the restoration treatments. Our hope is that multiple recovery strategies including: gap creation and thinning; exclosure maintenance; and deer control; will work in conjunction with each other to provide a successful regeneration of the understory.

Results from the second research objective are that our restoration treatments created a stand with a similar light environment as the old growth comparison. Furthermore, wind disturbance over the year helped to increase the variation of light closer to old growth variation.

This research will be of interest for the Ministry of Forests, Lands and Natural Resource Operations to add to a limited knowledge field of stumps within second growth forests on the west coast of BC. This research will be of interest as well for other coastal areas in British Columbia, such as Clayoquot Sound, that have been struggling with the uncertainty of natural disturbance in planning restoration treatments such as gap creation. Most importantly, this research will serve to inform future research, forest management and restoration initiatives happening on Haida Gwaii, specifically in Gwaii Haanas.

Chapter 1.
Introduction: Ecology and Management of Riparian Forests on Lyell Island, Haida Gwaii.

Coastal Temperate Rainforests

Coastal Temperate Rainforests

Coastal temperate rainforests are globally rare; they cover 0.1% of the globe (Kellogg 1995). British Columbia holds more than one-third of the global total of these forests and contains some of the only intact watersheds left in the world (DellaSala 2010). More than 40% of the rainforests throughout the Pacific Northwest have been fragmented by human induced land-use activities (DellaSala 2010). Coastal temperate rainforests are characterized by high levels of precipitation, mountainous terrain, and moderate temperatures (Green & Klinka 1994; Schoonmaker et al. 1997). The coastal temperate rainforest is classified under four climatic regions: subpolar; perhumid; seasonal; and warm (DellaSala, 2010).

In general, large, natural stand-replacing disturbances are rare in coastal temperate rainforests (Daniels and Gray 2006), with some stands passing many generations of trees between major disturbances such as fire (Lertzman et al. 2002). Rather, they are dominated by gap-phase dynamics. Gap-phase dynamics is the process of canopy gap creation by tree mortality and the ensuing filling of those gaps by young trees; over time this creates a heterogeneous forest structure and light environment (Bray 1956; Canham et al. 1990; Lertzman et al. 1996; Frazer et al. 2000a; Gavin et al. 2003; Griffiths 2010). Windthrow events are also an important developmental driver for forests in some areas of temperate rainforest (Kramer et al. 2001). Intensity of wind disturbance is often a function of exposure and topography; wind-protected forests are more likely to exhibit later stages of forest development (DeGayner et al. 2005).

These disturbance regimes result in old forests with complex forest structure and large trees (Arsenault & Bradfield 1995; Franklin et al. 2002; MacKinnon 2003). Large diameter trees are of significant ecological importance in coastal temperate rainforests; their loss equates to the loss of habitat for many animals and plants, as well as a substantial alteration of the dynamics of the entire stand (Lutz et al. 2012).

Old Growth Forests

Old growth forests have generally been defined using three different approaches: forest age class; structural or biological attributes; and stand dynamics theories (Holt et al. 2008). Ecosystem- based management (EBM) implementation on the BC coast has used forest age (250 years plus) to define old growth (CIT 2004). However, stand attributes (large, old trees; complex horizontal and vertical structure; coarse woody debris; etc.) and stand dynamics theory (keeping track of stand development) can be much more useful for classifying “old growthness” (Holt et al. 1999; Arsenault & Goward 2000).

Old growth coastal temperate rainforests are important economically, culturally, and ecologically. The large trees that these forests produce have contributed substantially to BC’s economic history. Furthermore, the most massive of these forests store among the highest amount of carbon of any forests in the world (Acker et al. 2000; Smithwick et al. 2002; Trofymow et al. 2008). Old growth coastal temperate rainforests are host to a vastly diverse array of flora and fauna (DellaSala 2010), and are important for meeting cultural and spiritual needs (Kanowski 2009). Coastal First Nations communities in British Columbia have used these forests for thousands of years for housing, clothing, transportation, medicine, spiritual guidance and sanctuary (Turner 2004).

Riparian Forests

Riparian forests are those occurring adjacent to streams, lakes and wetlands. Riparian forests yield some of the highest canopy volumes on earth (Van Pelt et al. 2006). These rich valley bottoms are diverse in both species composition and physical structure (Gregory et al. 1991; Pabst and Spies 1999; Smith 2005). Furthermore, riparian areas have distinctive microclimatic conditions such as air temperature, soil temperature, wind speed and solar radiation, and these conditions are significantly altered when forest harvesting near the stream occurs (Brosofske et al. 1997). Riparian forests link terrestrial and marine ecosystems to such an intricate degree, the name “hydroriparian ecosystem” describes this relationship more aptly (Clayoquot Sound Scientific Panel 1995). Streams benefit from riparian forests by receiving regulated inputs such as nutrients, solar radiation and large wood (Lienkaemper & Swanson 1987; Gregory et al. 1991; Naiman et al. 2000; Poulin et al. 2000a; Acker et al. 2003). Furthermore, salmon-derived nutrients are significant to plants and animals in areas with healthy salmon populations (Riemchen et al. 2003; Schindler et al. 2003; Field & Reynolds 2011).

Low elevation forests and riparian systems in BC’s Central Coast have been preferentially targeted for forest harvesting over the past century (Pearson 2010). Due to complex terrain and lower productivity on the rest of the land base, commercially viable logging is constrained to a small percentage of the land base, often the low elevation, easily accessible valley bottoms (Green 2007). Eighty-one percent of logging in the Central Coast of British Columbia occurred in valley bottoms (Pearson 2010). Furthermore, early forest harvesting activities left no riparian buffer (Poulin et al. 2000a). This has damaged stream morphology and salmon habitat along many streams on BC’s coast (Schoonmaker et al. 1997).

Second Growth Forests

Second-growth forests resulting from forest harvesting differ significantly from old-growth forests in composition, structure, and function (Alaback 1982; Banner & LePage 2008; Gerzon et al. 2011). Compositionally, species richness doubles for shrub and herb cover and is more diverse (0.81 to 0.91 Simpson’s index of diversity) in old-growth forests than second-growth forests (Banner & LePage 2008). In southeast Alaska, ferns and bryophytes dominate the understory for the first century after harvest with shrub species becoming more prevalent after the first century, when dense second growth canopies begin to open (Alaback 1982). Structurally, stem density decreases while average tree diameter at breast height (DBH) increases from second growth to old growth (Gerzon et al. 2011). Often, second growth stands have few snags >50cm DBH and no snags >100cm DBH and coarse woody debris biomass (CWD) may not reach the old growth average after over 220 years (Gerzon et al. 2011). It may take 200 years or more, without active intervention, to develop the diverse compositional and structural components of old growth that result in its functionality in providing quality wildlife habitat (Chan et al. 1996). For example, fish and wildlife habitat is dependent on the functions and characteristics of old forests that were discussed earlier (large conifer trees, a complex stand structure, and long-lived species that can provide stability to streambanks, channels and floodplains; Poulin et al. 2000a).

Ecological Restoration

In coastal BC, riparian forests have been logged extensively, and the first attempt at guidelines for restricting logging in riparian areas only came in 1986 with the *Coastal Fisheries/ Forestry Guidleines* (Poulin et al. 2000a). Even then, it was not until the Forestry Code in 1995 the riparian areas were legally protected within reserve zones. Since so much of BC's riparian areas had been logged prior to the Code, a substantial portion of those are in need of restoration.

Ecological restoration can be described as "the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems" (Jackson, L.L. et al. 2006). Structural diversity is important for both the function and composition of a forest (Franklin et al. 2002). The enhancement of structural diversity through restoration can speed recovery of both plant and wildlife communities. Some common riparian restoration treatments in coastal BC include: thinning, to increase conifer diameter growth; removing overstory to release understory conifers and vegetation; and manipulating stand structure for biodiversity and wildlife such as variable density thinning or creating gaps (Poulin et al. 2000a). These types of silvicutural treatments create a more heterogeneous forest structure and light environment in the understory, which enhances understory vegetation biodiversity (Newton et al. 1996; Baily et al. 1998; Poulin & Simmons 1999; Poulin et al., 2000a).

Information Gaps

Greater knowledge is still needed about both coastal temperate rainforests in general and riparian forests in particular (Hanely & Hoel 1996; Pabst & Spies 1998; Van Pelt et al. 2006; DellaSala 2010; Giesbrecht 2010; Lertzman & MacKinnon inpress). In-depth knowledge of coastal temperate old growth structural characteristics is still limited (Gerzon et al. 2011). More specifically, biological and physical research and monitoring of riparian restoration techniques and projects are limited (Poulin et al. 2000a; Roni et al. 2002). Furthermore, hemispherical canopy photography has not been used to describe the light environment in the forests of Haida Gwaii. As well, no peer-reviewed literature exists on the ecological phenomenon of stump refugia in Haida Gwaii and there is a very limited body of literature on the role of stumps in second growth forests, globally (Abrahamsson 2007; Arsenault 2002; Meggs et al. unpubl.).

In general, more information about an ecosystem will help guide better management of that ecosystem. For example, Naiman et al. (2000) show that greater understanding of the ecology of riparian zones in recent decades has led to better management of riparian ecosystems. Greater understanding of the natural disturbance history of a watershed and its structural and ecological characteristics can help to inform ecologically appropriate restoration techniques (Naiman et al. 2010). Furthermore, regionally specific knowledge is required to plan and implement effective restoration projects. Specifically, this research will provide quantitative data on the characteristics of understory vegetation and the response of canopy light to riparian restoration treatments in second growth floodplain spruce forests. The research is also applicable to current management issues in Haida Gwaii as they work to implement forest management policies within an Ecosystem Based Management framework. More broadly, the research is applicable to our understanding of riparian dynamics in coastal temperate rainforests and how the ecosystems of Haida Gwaii fit amongst other studies in the Pacific Northwest.

Chapter Organization

The research project will be presented in three chapters:

Chapter One provides a general introduction to the research by providing: an ecological overview of coastal temperate rainforests, old growth forests, riparian forests, and second growth forests; a background on ecological restoration; a description of the study area; a brief history of introduced deer on Haida Gwaii; a description of the Lyell Island restoration project; and the objectives and purpose of the research.

Chapter Two examines the concept of “stump refugia” and their potential role in allowing the understory to persist despite intense browse pressure from deer. In this chapter I describe the characteristics of stump refugia and their associated vegetation communities, how stump and ground vegetation communities differ, and how vegetation communities differ in ground plots with and without deer exclosures.

Chapter Three examines the understory light environment pre, post, and one-year post restoration. In this chapter I describe the riparian restoration treatments, the change in forest structure and the change in the light environment due to the restoration treatments, and one year after restoration treatments due to wind effects over the course of the year.

Study Area

The restoration project, and the study site for this research, is located on Lyell Island, in the southeast of Haida Gwaii, within Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site (herein “Gwaii Haanas;” 53deg 41’ 58” N, 131deg 35’ 14” W; Fig.1.1). Haida Gwaii is a remote archipelago off the northwest coast of BC.

Haida Gwaii

Haida Gwaii falls within the perhumid temperate rainforest, which extends from the northern tip of Vancouver Island to southeast Alaska (Schoonmaker et al. 1997). A history of intensive forestry activity on Haida Gwaii throughout the last century has led to a degraded stream morphology, and a dense, homogeneous forest canopy. Over the past century, 168,750 hectares of forest area (101,033,929 m^3 of wood) was harvested on Haida Gwaii (Gowgaia Institute 2007). This equates to the loss of 65% of good and medium forest sites in Haida Gwaii, and 74% on the Skidegate Plateau, where most logging has occurred (Gowgaia Institute 2007).

Climate, geology, and soils play a foundational role in vegetation assemblages in terms of moisture and nutrient availability (Meidinger & Pojar 1991). The average annual precipitation in Haida Gwaii is 1,359mm and falls mostly as rain (Golumbia 2007). The area has cool wet summers and very wet cold winters. The average annual temperature is approximately 8°C, and has an intra-annual fluctuation of about five degrees (MIEDS 2011). The area is mostly underlain by volcanic and intrusive granitic rocks, with the southeastern peninsula underlain by sedimentary rocks (Westland Resource Group 1994). Soils are highly influenced by precipitation levels, and experience weathering and leaching which result in Podzolic soils. They also experience a gradual build-up of organic matter due to slow decomposition rates and high moisture levels. Organic veneers and blankets are common, as are high water tables and poor drainage. Peat develops on some level terrain and is found on slopes up to 50% gradient. On water-shedding slopes, shallow Podzols and well-drained Folisols are present (Golumbia 2007).

The vegetation of Haida Gwaii has been described previously and has focused primarily on mature forest communities (Calder & Taylor 1968; Meidinger & Pojar 1991; Westland Resource Group 1994; Golumbia 2007). A large number of species are endemic to Haida Gwaii. These endemic species most likely survived through glacial refugia, and could also have arrived post-glacially (Golumbia 2007). In the later case, it is suggested that species benefitted from the advanced ecological succession of island communities (Reimchen 2005). Previous studies have helped to provide a baseline for both understory vegetation and forest structure in Gwaii Haanas. Exclosure studies (Golumbia 1999) and studies on the effect of deer browse on vegetation (Gaston et al. 2008) increasingly show the divergence between the natural vegetation assemblage and structure and its current depauperate state. The understory in some places is almost completely void of herb, fern, shrub, or young tree. In fact, there are only a few places where there is substrate high enough for understory vegetation to grow. Deer consume many culturally important plants such as Pacific crab apple (*Malus fusca*), huckleberry and blueberry (*Vaccinium sp.*), false azalea (*Menziesia ferruginea*), salmonberry (*Rubus spectabilis*), Nootka rose (*Rosa nutkana*), salal (*Gaultheria shallon*), devil's club (*Oplopanax horridus*), sword fern (*Polystichum munitum*), deer fern (*Blechnum spicant*), skunk cabbage (*Lysichiton americanum*), and foamflower (*Tiarella trifoliata*) (Gaston et al. 2008).

Lyell Island and the Creation of Gwaii Haanas

Lyell Island sits on the Skidegate Plateau physiographic region and is within the Coastal Western Hemlock Submontane Wet Hypermaritime variant (CWHwh1; Fig. 1.1; Green & Klinka 1994). On Lyell Island, thirty-three percent of its forests and forty-four percent of its riparian forest has been logged. Lyell Island is thus considered “high-risk” in its riparian forest watershed condition risk assessment (Gowgaia Institute 2007). The canopy of Lyell Island is dominated mainly by western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), with Sitka spruce (*Picea sitchensis* (Bong.)) and western redcedar (*Thuja plicata* Donn.) as co-dominant tree species.

The understory vegetation on Lyell Island is depleted due to forest harvesting and the introduction of Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Due to intense deer browse, the understory is characterized mainly by moss species such as lanky moss (*Rhytidiadelphus loreus*), and step moss (*Hylocomium splendens*). Herb and shrub species persisting on the ground include: single delight (*Moneses uniflora*); twayblade (*Listera sp.*); lady fern (*Athyrium filix-femina*); deer fern (*Blechnum spicant*); spiny wood fern (*Dryopteris expansa*); and red huckleberry (*Vaccinium parvifolium*). In general, individuals of these species exist in a constantly browsed state. In complex terrain, or on substrate higher than approximately 1.5m (deer browse-line), other understory species persist, and are able to grow large enough to reproduce. Large stumps left over from logging are generally tall enough to provide a substrate for understory vegetation to grow. These ecological structures are referred to as “stump refugia.”

Lyell Island, or Tllga Kun Gwaayaay in the Haida language, has an important role in the history of the Haida people and in their regaining governance of their lands. Forest harvesting on Lyell began in the early 1900s and reached its apex in the mid-1980s (Gowgaia Institute 2007). Around this time, the Haida people and many non-Haida became concerned about the intensity and manner of the logging. In 1985, Haida elders joined younger generations to protest the logging on Lyell Island. The Lyell Island protests served to bring significant national and international attention to the logging of old growth forests in Haida Gwaii, which eventually led to the signing of the Gwaii Haanas Agreement between the Government of Canada and the Council of the Haida Nation in 1993. The agreement designated the area as a National Park Reserve managed cooperatively by Government of Canada (Parks Canada) and the Council of the Haida Nation (Gwaii Haanas 2008). In 2010, the National Marine Conservation Area Reserve was added, which extended the protected area to the seafloor in the surrounding waters.

Sandy Creek

The study sites in Sandy Creek are located on medium to high bench riparian floodplain sites, dominated by Sitka spruce (Fig. 1.2). Its vegetation assemblage is the same as other areas on Lyell Island, and is described in the section above. See Table 1.1 for a list of tree, shrub, and herbaceous species in Sandy Creek. A complete species list including mosses can be found in Appendix 1.

The study area in Sandy Creek, Lyell Island, was harvested in the early 1940s (Gowgaia Institute 2007). Riparian logging regulations did not exist and many streams were cut to their banks, including Sandy Creek. Its stream morphology has been damaged by the harvesting practices (Ray 2010). The stream is straighter and faster than prior to logging and no longer provides adequate salmon habitat. The second growth forest has regenerated as a dense, homogenous Sitka spruce stand of approximately 30m in height, on average. The dense canopy and intensive deer browse has impacted the understory to the extent that, without active intervention, this forest will have difficulty providing the structural and compositional elements in the future to function as per pre-harvest.

Introduced Deer on Haida Gwaii

Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) were first introduced in 1878 at the north end of Haida Gwaii as additional food source. These deer have intensively browsed the understory herbs and shrubs in Haida Gwaii, leaving a carpet of moss as the dominant understory vegetation (Martin et al. 2010). With no predators, the deer population is unchecked and deer have spread throughout all but the most isolated islands.

It is uncertain exactly when deer where introduced to Lyell Island. Vila et al. (2004) reconstructed browsing history to determine when deer where introduced to a number of small islands just north of Lyell Island. They determined deer had been present since the 1950s or 1960s. The introduction of deer to Lyell Island could have occurred around the same time.

Understory vegetation has been severely reduced by the presence of these deer (Bartier et al. 2007; Gaston et al. 2006, 2008, 2010; Martin et al. 2010, 2011; Stroh et al. 2008). For example, Stroh et al. (2008) show that redcedar seedling survival and growth is lowered by deer populations. Gaston et al. (2006) illustrate a reversal of the normal species-area and species-isolation relationships such that larger, less isolated islands support fewer plant species as a result of deer browsing. Furthermore, reduction of understory vegetation through deer browse has also had substantial impacts on other taxa, such as understory invertebrates and shrub dependant songbird communities (Gaston et al. 2006; Martin et al. 2010).

Stump Refugia

In the early 1900's in BC, the biggest and most accessible trees were harvested, which meant riparian areas were the main focus for logging. During this time, springboard logging was used to fall the old growth trees to get above the wide bases that were harder to cut through (A. Pearson 2010). Those old growth trees now exist as large stumps surrounded by second growth forests, and are referred to as "stump refugia." These stumps can provide refuge for understory plant species by serving as substrate tall enough to protect plants from deer browse, and thus serve as islands of habitat. There is limited documentation of the vegetation communities stump refugia maintain, or of the extent to which these refugia can be relied on to maintain a viable understory assemblage.

Some research on stump refugia on Haida Gwaii has been conducted or is underway. Holmes (2010) found that percent cover of understory vegetation was only significantly greater on stumps in forests more than 60 years old. Percent cover was greater on the forest floor in forests 10 and 30 years old. Additionally, the Research Group for Introduced Species (RGIS) is currently investigating how the understory community changes with proximity to stumps (Chollet pers. com 2010). However, results are not available at this time. Lastly, students of the Haida Gwaii Higher Education Society have conducted some exploratory studies on understory vegetation and stump refugia. The summary of these results showed support for the concept of stump refugia: culturally significant plants showed a significantly higher presence on stumps (Sherlock unpubl.); and a negative relationship was found between log height and evidence of deer browse (Marshall-Hill unpubl.)

Lyell Island Restoration Project

A mandate of Gwaii Haanas is to preserve biological diversity (Gwaii Haanas, 2008). Understory plants are essential to the traditional Haida way of life. Gwaii Haanas has undertaken a riparian restoration project on Lyell Island, Haida Gwaii. The restoration project is entitled "Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island)." The restoration project has a number of components including restoration treatments for both in-stream locations and the surrounding riparian forest, research and monitoring, and community engagement.

Research Objectives:

This research focuses on vegetation and light response to the riparian restoration treatments. Although the one-year timeline of this study is not long enough to analyze vegetation response due to restoration treatments, the research describes baseline conditions in depth for future monitoring, as well as the vegetation response due to built deer exclosures. I used hemispherical canopy photography (HCP) to assess the utility of structural manipulations to restore old growth light conditions.

The goals of this research are:

- to explore the influence of "stump refugia" and the impact of deer browsing on understory vegetation in Sandy Creek, Lyell Island; and
- to explore the effects of restoration treatments, such as canopy gap creation, on forest structure and understory light in Sandy Creek, Lyell Island.

This research will serve to inform future research and is intended to provide insight to the restoration initiatives occurring on BC's coastal areas, in Haida Gwaii and specifically in Gwaii Haanas National Park Reserve and Haida Heritage Site.

Tables and Figures

Tables

Table 1.1 Species list: all species present in vegetation plots, listed by code, scientific name, common name and whether the species was found only on stumps, ground, or both.

Latin Name	Common Name	S/ G	Code (Fig. 2.3)
Species Present on Stumps Only			
Gaultheria shallon	Salal	S	GAULSHA
Maianthemum dilatatum	False lily-of-the-valley	S	MAIADIL
Polypodium glycyrrhiza	Licorice fern	S	POLYGLY
Sambucus racemosa	Red elderberry	S	SAMBRAC
Vaccinium alaskaense	Alaskan blueberry	S	VACCALA
Vaccinium ovalifolium	Oval-leaved blueberry	S	VACCOVA
Species Present on Ground Only			
Athyrium filix-femina	Lady fern	G	ATHYFIL
Blechnum spicant	Deer fern	G	BLECSPI
Claytonia siberica	Siberian miner's lettuce	G	CLAYSIB
Clintonia uniflora	Queen's cup	G	CLINUNI
Galium triflorum	Sweet-scented bedstraw	G	GALITRI
Linnaea borealis	Twinflower	G	LINNBOR
Polystichum munitum	Sword fern	G	POLYMUN
Stachys cooleyae	Cooley's hedge-nettle	G	STACCOO
Tiarella trifoliata	Foamflower	G	TIARTRI
Viola biflora ssp. carlottae	Queen Charlotte twinflower violet	G	VIOLBC
Species Present on both Stump and Ground			
Dryopteris expansa	Spiny wood fern	G/S	DRYOEXP
Listera sp.	Twayblade	G/S	LIST
Menziesia ferruginea	False azalea	G/S	MENZFER
Moneses uniflora	Single delight	G/S	MONEUNI
Rubus spectabilis	Salmonberry	G/S	RUBU SPE
Picea sitchensis	Sitka spruce	G/S	SITKSPR
Vaccinium parvifolium	Red huckleberry	G/S	VACCPAR
Tsuga heterophylla	Western hemlock	G/S	WESTHEM

Figures

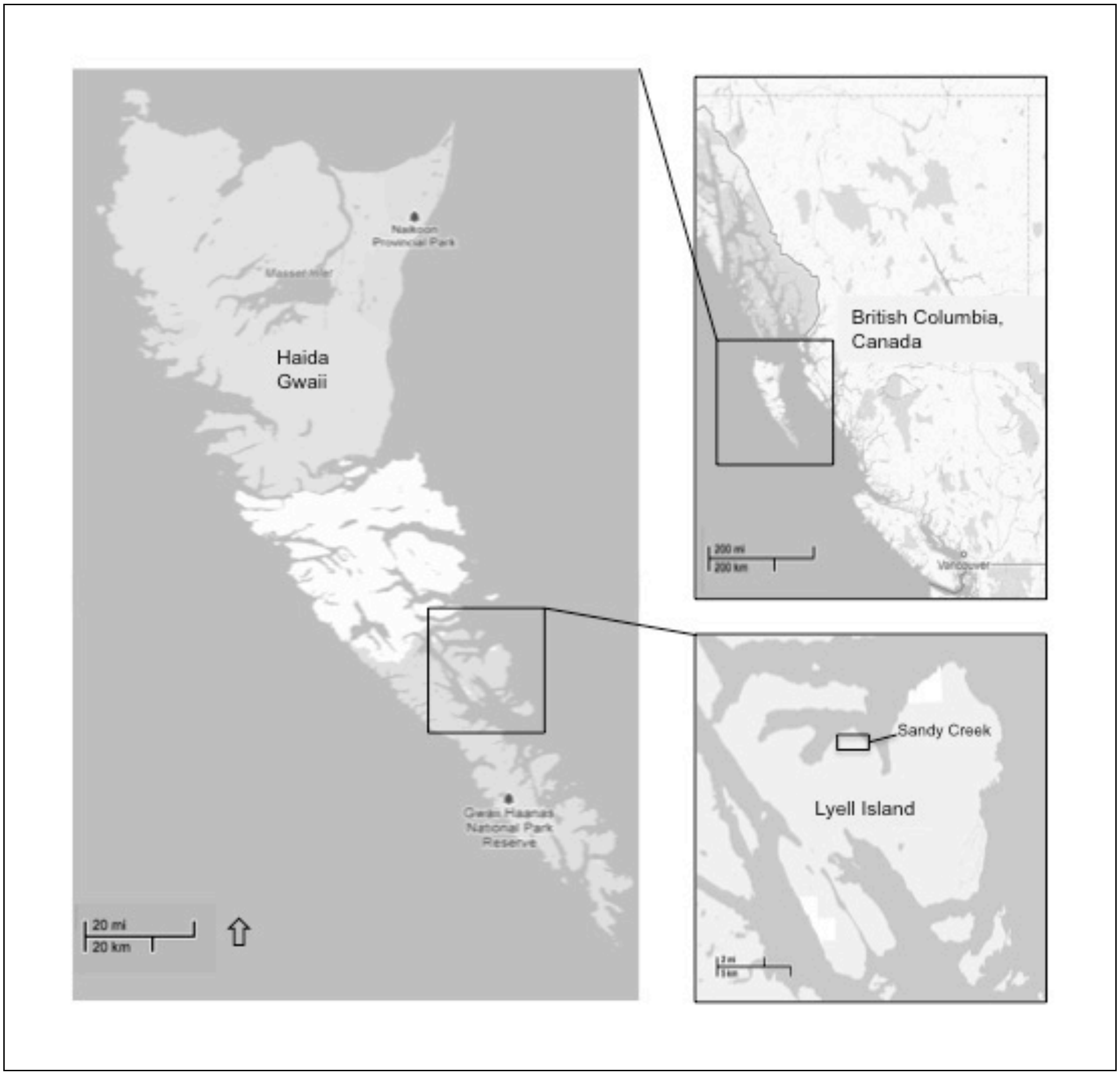


Figure 1.1 Map of Haida Gwaii, British Columbia.

Lyell Island is situated in the south-east of Haida Gwaii, in Gwaii Haanas National Park Reserve, Haida Heritage Site and National Marine Conservation Area Reserve (Gwaii Haanas). Our study site is Sandy Creek, Lyell Island, located inside the black box in the picture on the bottom right.

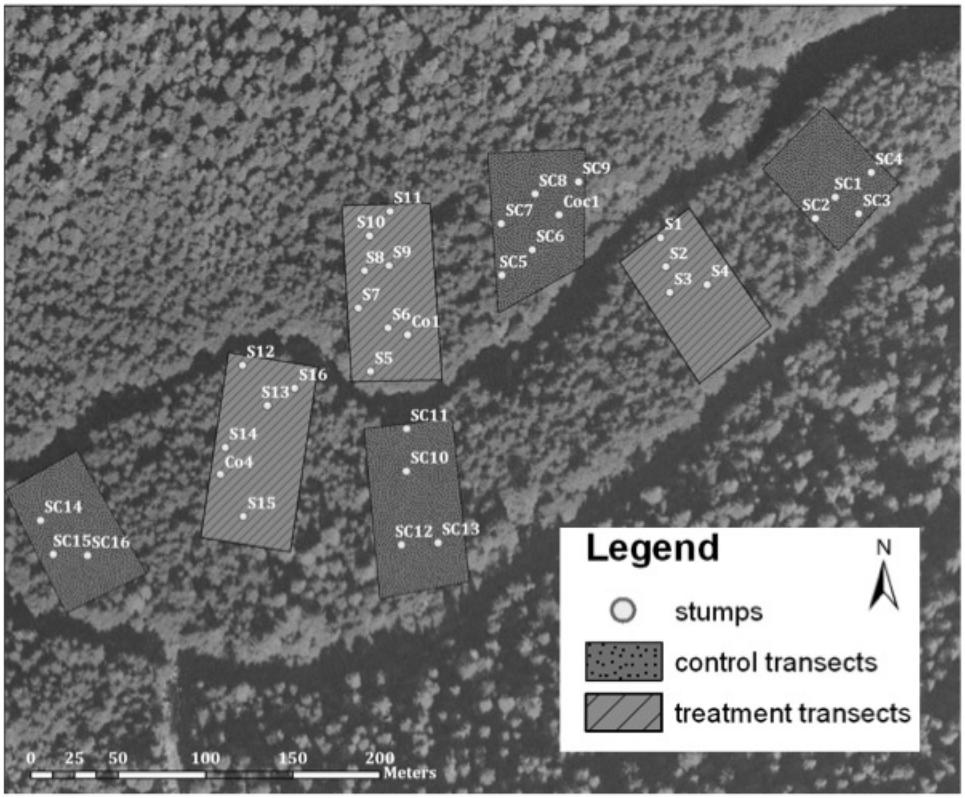


Figure 1.2 Transect Locations in Sandy Creek.

Figure shows locations of each stump within treatment and control transects.

Chapter 2.
Stumps on Lyell Island, Haida Gwaii: refugia for understory vegetation from deer browsing

Introduction

Introduced species and habitat loss are the two largest threats to native species worldwide (Wilson 1992). The introduction of large mammalian herbivores to any ecosystem is especially damaging and can have far-reaching direct and indirect impacts, (Hobbs 1996; Vàsquez 2002). Intensive browsing can reduce plant cover and density, alter the cycling of carbon and nutrients, and even change the forest canopy over time (Rooney & Waller 2003; Côté et al. 2004). Other impacts of browsing include local extinction of seed sources, and difficulty re-establishing species (Coombs et al. 2003). Furthermore, browsing pressure from herbivores has cascading effects on other species, including invertebrate and songbird communities, by direct competition for resources and by indirectly changing the structure and composition of habitat (Côté et al. 2004; Gaston et al. 2006; Martin et al. 2010).

Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) were introduced to Haida Gwaii, British Columbia, at least five times between 1880 and 1925 by the BC Game Commission. The population has thrived with no major competition or predation threat and deer have spread to virtually every island in the archipelago, except for a few small, remote islands (Golumbia 1999). It has been estimated that deer extended their range south to our study site, Lyell Island, sometime after 1925 (Vila et al. 2004; Gaston et al. 2008). Research has shown that the deer on Haida Gwaii have a significant effect on the understory vegetation. Western redcedar (*Thuja plicata* Donn.) seedling survival and growth are negligible and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.)) are often severely stunted in growth (Stroh et al. 2008; Vila et al. 2002, 2003; Gaston et al. 2008). Shrub and herb communities are also severely impacted, leaving the forest understory a groomed carpet of moss (Daufresne & Martin 1997; Gaston et al. 2008).

Decomposing woody debris enhances soil nutrient levels and contributes to the structure and function of an ecosystem as habitat, refugia, and as a source of nutrient input (Harmon et al. 1986; Stevens 1997; Bunnel et al. 2002; Sucre & Fox 2009; Hannam 2012). Although much research has focused on the importance of coarse woody debris, very few studies have examined, specifically, the role that stumps created from logging play in forest ecosystems (Meggs et al., in progress). There has been increasing interest in harvesting residues from logging (i.e. stumps and logs) in Europe for some time, and recently in BC (Rudolphi et al. 2011).

Stumps created from logging in the early 1900s are generally tall (2-6m), and therefore provide a substrate tall enough for vegetation to grow above the height that deer can browse (the 'browse line', approximately 1.5m). The term "stumps" is used herein to describe these remaining 'high stumps' of large trees cut from logging in the 20th century. Understory vegetation can escape browse pressure on root masses, stumps, and areas of high blow-down or where movement would be difficult for deer. In Sandy Creek, the forest is relatively protected from the wind and there are no areas of large blow-down. Furthermore, root masses are rare. Some remnant root masses are present from pre-logging, as are a few recent small blowdowns (1-5 trees) along the streambank, but these are not common. The large diameter stumps left over from logging are the most frequent structure in this system that is available for vegetative growth out of deer's reach. In effect the stumps are acting as habitat islands for understory species in a sea of constant deer browse, and are thus referred to as "stump refugia" (A. Pearson pers com. 2010). Plant communities differ on stumps and on the ground (Kennedy & Quinn 2001). However, there has been limited research focused specifically on describing plant communities existing on stump refugia in Haida Gwaii, BC (Holmes 2010; Chollet pers com. 2010). Gwaii Haanas National Park Reserve and Haida Heritage Site (herein referred to as "Gwaii Haanas") is interested in the natural history of these stumps since they are a key aspect of the forest ecosystem. Further, Gwaii Haanas is interested in the role these stumps may play in restoration of the riparian forest and its understory.

Two important limiting factors for understory growth in this system are deer browse and understory light. Forest restoration efforts such as gap creation can aid understory growth by creating a more favourable light environment (Franklin et al. 2002; Drever 2005). Measures such as deer exclosure and deer population control can help understory vegetation become re-established. Stump refugia may also provide an important role for re-establishing understory vegetation by providing a seed source for the regeneration of understory plants. Gwaii Haanas National Park Reserve and Haida Heritage Site (Gwaii Haanas) is interested in the natural history of these stumps since they are a key aspect of the forest ecosystem. Further, Gwaii Haanas is interested in the role these stumps may play in restoration of the riparian forest and its understory, and whether gap creation should be focused around stump refugia.

On Lyell Island, Haida Gwaii, the impacts of introduced deer are compounded by the effects of forest harvesting activities over the last century. The dense canopy that has regenerated after riparian harvesting creates low levels of light in the understory, which is an additional limitation for the growth of understory vegetation growth. Forest restoration techniques such as gap creation have been found to aid understory growth in other systems by creating a more favourable light environment (Franklin et al. 2002; Drever 2005). Gap creation treatments specifically centered on stump refugia on Lyell Island may add additional benefits by providing a more favourable light environment to the understory vegetation already established on stumps. These habitat islands, equipped with more favourable light conditions, could perhaps act as prolific seed sources and speed the recovery of surrounding ground vegetation communities.

This research is part of a restoration project on Lyell Island, entitled "Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island)," which aims to restore the health of riparian forests and salmon-bearing streams on Lyell Island (Gwaii Haanas 2008). Deer pose a challenge to the successful regeneration of riparian forests in Haida Gwaii (Gaston et al. 2006; Martin et al. 2010). In this chapter I explore the extent to which stumps provide understory refuge and the characteristics enabling them to do so. To address these overarching themes, this chapter asks:

1. What are the biophysical characteristics of stumps in Sandy Creek, Haida Gwaii, and is percent cover of vegetation correlated with any of these characteristics?

2. How does the vegetation community on stumps differ from the vegetation community on the ground which is open to deer browse, both compositionally and structurally?

3. How does the ground community differ in vegetation growth between plots open to deer browse and plots protected from browsing through built deer exclosures?

We expected that stump characteristics would have an effect on the percent of shrubs growing on stumps. We also expected a greater mean height, percent cover and number of individuals on stumps. We did not expect to see any response in ground vegetation over one year in open ground plots, nor in exclosures.

Study Site and Methods

Study Area

Haida Gwaii is a remote archipelago off the north west coast of BC (Fig. 1.1). Lyell Island is situated off Haida Gwaii's south east coast, within Gwaii Haanas' protected area boundaries. Average annual precipitation of 1,359mm falls mostly as rain (Golumbia 2007). The area has cool, wet summers and cold, very wet winters. The average annual temperature is approximately 8°C, and has an intra-annual fluctuation of about five degrees (MIEDS 2011). Lyell Island sits on the Skidegate Plateau physiographic region and is within the Submontane Wet Hypermaritime Coastal Western Hemlock variant (CWHwh1) (Green & Klinka 1994).

The study sites in Sandy Creek are located on mid bench riparian floodplain dominated by Sitka spruce (*Picea sitchensis* (Bong.); Fig. 1.2). Due to intense deer browse, the understory is characterized mainly by moss species such as lanky moss (*Rhytidiadelphus loreus*), and step moss (*Hylocomium splendens*). Herb and shrub species persisting on the ground include: single delight (*Moneses uniflora*); twayblade (*Listera sp.*); lady fern (*Athyrium filix-femina*); deer fern (*Blechnum spicant*); spiny wood fern (*Dryopteris expansa*); and red huckleberry (*Vaccinium parvifolium*). In general, individuals of these species exist in a constantly browsed state. In complex terrain, or on substrate higher than approximately 1.5m (deer browse-line), other understory species persist, and are able to grow large enough to reproduce. These species that have been mostly confined to stump substrates include: false lily-of-the-valley (*Maianthemum dilatatum*); salal (*Gaultheria shallon*); red elderberry (*Sambucus racemosa*); Alaskan blueberry (*Vaccinium alaskaense*); and oval-leaved blueberry (*Vaccinium ovalifolium*). Table 1.1 lists species found only on stumps, only on the ground, and those that were found on both substrates. See Appendix 1 for a complete species list including mosses.

Restoration Treatments

Riparian forest restoration treatments (overstory tree removals) were located adjacent to areas requiring in-stream restoration, as assessed by Northwest Hydraulic Consultants (Ray 2010). The objectives for restoration treatments were to create gaps in the canopy to encourage faster growth of larger diameter trees and understory regeneration (Bancroft & Zielke 2002). Riparian forest restoration treatments were centered around "stump refugia" to encourage the potential of greater understory propagation from seed sources on stumps. To mimic old growth gap sizes, we planned our treatment to remove 1- 10 trees around each stump (Lertzman et al. 1996). Although the restoration treatments (canopy openings) do not affect the research described in this chapter, they impacted how our research was designed. Trees were felled in July 2010.

Research Design

The research design was guided by the goal for the riparian forest treatments to provide large woody debris for the creation of in-stream structures. In this way, no additional material needed to be brought in for in-stream structures, and wood did not need to be moved a large distance. Therefore, each riparian forest treatment transect was located perpendicular to a planned in-stream treatment location (as prescribed by Ray 2010). At three in-stream restoration locations (100m, 300m, and 380m from tidal influence), 30m wide by 100m long treatment transects (.30ha) were set-up perpendicular to the stream (Fig. 2.1A). Within this area, only stumps 20m apart, starting from the first encountered, were included for sampling. Preliminary research suggests that 20m maintains statistical independence for canopy light (Roburn 2003). Control transects were located in between treatment transects, with a minimum of 100m distance between any two transects (Fig. 2.1A).

A total of 16 stumps within three treatment transects (T) and 16 stumps within four control transects (C) were selected for sampling. Stumps were chosen that had a flat top, indicating that they had been logged, were tall enough that deer could not reach them (approximately 1.5m), and were less than or equal to 5m in height (stumps taller than 5m could not safely be sampled).

At each stump, in both the treatment areas and control areas, data were gathered from three plots, the stump (Stump; S), and two associated ground plots: one open to deer browse (Open Ground; G); and one within a built deer exclosure (Exclosed Ground; E; Fig. 2.1B). I collected data on the characteristics of the stump itself, the vegetation community on top of the Stump, and the vegetation community within the Open Ground plot and the Exclosed Ground plot.

Stump plot

Stump characteristics were described by species, diameter at breast height (DBH), height, top diameter, decay class and volume. These characteristics were chosen to be described due to their possibility of affecting percent cover of vegetation. For example, difference in stump heights (taller than the deer browse line) could affect light or moisture availability. Similarly, top diameter reflects the total surface area available for growth.

We identified the species of stumps from the shape of the bole, bark remnants where available, and the shape and colour of decaying wood. DBH was measured using a standard DBH tape and was measured at 1.3m from point of growth. Height was measured from the point of highest ground to the top of the stump. Top diameter was measured twice, once north-south and once east-west. These two measurements were averaged. Decay class was measured using the decay classes for coarse woody debris in Table 7.1 of *Field Manual for Describing Terrestrial Ecosystems* and ranged from 1 (intact, hard), to 5 (many small pieces, soft portions) (BC Ministry of Forests and Range, 2010). Volume was calculated in the lab and is explained below in Data Analysis.

On the top of stumps we gathered vegetation data (see details in Vegetation Data below) and took canopy light data using hemispherical canopy photography. Canopy photo data was not used in the analysis for this chapter. Analysis of canopy photo data is described in Chapter 3. These data were collected by climbing a 6m extendable ladder leaning against the stump.

Ground plots

The two ground plots (2x2m) at each stump were established at a random bearing and random distance 2-5m away from each stump. This distance was decided in order to avoid sampling plants associated with the base of the stump (Kennedy & Quinn, 2001), and to stay within similar light conditions (Lertzman pers com. 2010). In all ground plots vegetation data and canopy light data was collected. Canopy photo data was not used in the analysis for this chapter. Analysis of canopy photo data is described in Chapter 3.

To create the exclosures, we built a deer fence around the second randomly chosen plot at each stump, unless topography or surrounding trees made building the exclosure impossible, then the exclosure was built around the first plot. Out of a total of 40 exclosures built (20 in treatment areas and 20 in control areas), 15 were built of strong plastic material with wooden stakes and 25 were built of garden netting material. The latter material was used due to funding constraints, and was not as sturdy. During the winter of 2011, multiple severe wind storms occurred. I conducted an exclosure survey in May 2011 to inventory the damage to exclosures, and to repair as many exclosures as possible prior to the start of the growing season. Due to the repairs during this survey, twenty of the exclosures were in good condition at the beginning of the growing season (11 in control transects and 9 in treatment transects).

Vegetation data

Vegetation data were collected at all plots and included: a species list; percent cover (tree seedlings under 5m tall, shrubs, ferns, herbs and mosses); number of stems (tree seedlings under 5m tall, shrubs, and ferns) and heights of stems (tree seedlings under 5m tall, shrubs, and ferns). Number of stems is simply the number of individual stems growing within each plot of each species. Only one stem per cluster was counted for species that grow in clusters (deer fern, spiny wood fern). Height was measured for each stem noted above. The tallest stem was measured for species that grow in clusters. Number of fronds for deer fern were also counted, but not used in the analysis.

We tagged individuals that had a basal diameter greater than one centimetre with a metal tag strung on a small zip tie. We recorded the dimensions of the individual including: basal diameter; height to crown; crown height; width; and length. Basal diameter and volume measurements are not used in the following analyses due to the limited scope of the project, but can be used as a baseline for future monitoring.

Data Analysis

Stump characteristics

Most stump characteristics (species, DBH, height, top diameter, decay class) were measured in the field. Stump volume, however, was calculated in the lab using the equation for the frustum of a cone. Volume was calculated for the area of stump above diameter at breast height (DBH), since we did not have a basal diameter measurement, and is calculated as:

$$V = \frac{\pi h}{3} (R^2 + Rr + r^2)$$

Where:

V = stump volume;
h = height of the stump (from DBH to top);
R = radius of the base (at DBH); and
r = radius of the top (top diameter (averaged), divided by 2).

The mean and standard deviation were calculated for all stump characteristics using JMP Version 9.0.

Relationship of stump characteristics and vegetation

I used linear regression (JMP Version 9.0) to test if percent cover of vegetation was influenced by any of the stump characteristics listed above. I used the percent cover of all shrub species combined to represent abundance of vegetation on top of the stump.

I used linear regression to test the relationship between the percent cover of shrubs on top of the stump and each of DBH, height, top diameter, and volume of stumps. I did not examine if vegetation was affected by decay class since all most all stumps were the same decay class. All comparisons used an alpha of 0.05.

Vegetation communities on stumps and ground open to browse

Since the main objective is to explore the baseline vegetation community, I used only 2010 data (pre- restoration treatments) from both control and treatment transects to explore the differences between stump plots and ground plots open to deer browse. Sample sizes are therefore small and affected the significance of the findings in some cases.

I compared compositional differences among stump and ground plots open to deer browse using: species richness, evenness, Shannon's Diversity Index, Simpson's Diversity Index, and dominance diversity curves. I calculated species richness (S), evenness (E) and Shannon's Diversity Index (H) and Simpson's Diversity Index (D) for each plot using PC- ORD 6 (McCune & Mefford 2010). Species richness (S) is defined as the number of species present. Evenness (E) is a measure of the equality, or distribution of individuals among species and is calculated by dividing Shannon's Diversity Index (H) by richness (ln(S)). Simpson's Diversity Index shows "the likelihood that two randomly chosen individuals will be different species" and is calculated as:

$$D = 1 - \sum(p_i^2)$$

Where:
D = Simpson's Diversity Index
p_i = proportion of individuals belonging to species *i* (McCune & Grace 2002, p.26).

Shannon's Diversity Index tends to emphasize richness, whereas Simpson's Diversity Index tends to emphasize evenness. I used PC-ORD6 to analyze dominance-diversity curves. Dominance diversity curves show the relative abundance of each species. For PC- ORD analyses, species were removed from the dataset that had fewer than five occurrences overall. Diagnostic statistics showed this to lower the level of skewness, kurtosis, and coefficient of variation (CV). A relativization by species maximum was applied to diminish the dominance of a few abundant species, in effect, equalizing common and uncommon species (McCune & Grace 2002). An arcsine square-root transformation was performed as well, which spreads out the tails of proportion data, improving normality (McCune & Grace 2002).

I compared structural differences among stumps and ground plots open to deer browse using mean number of stems, mean height, and sum of plant heights. The number of stems of each species was averaged over plots. The heights of each stem of each species was averaged over plots as well. Sum of plant heights was calculated by summing the heights of all stems of each species in each plot and then finding the average over plots. A two-tailed t-test assuming unequal variances was performed for all comparisons of means between two variables. Normality of each variable was tested using the Shapiro- Wilk test, and some variables were found to be non-normal, however the t-test has been shown to be robust with the violation of normality, as long as samples are independent. Deviations from a normal distribution do not have a large impact on Type I Error rates (Zar 1996).

Vegetation communities on ground plots open to browse and in exclosures

For exclosure analysis, the main objective is to measure any difference in growth over the year, due to exclosure effect alone. Therefore, 2010 and 2011 data were used to test for growth over the year, and these data were pulled only from controls to avoid complications with treatment effect (creation of canopy openings). The same structural comparisons were made between open ground and exclosure plots that were described above for stump and open ground comparisons. A two-tailed t-test assuming unequal variances was performed for all comparisons of means. See above section for further details.

Results

Physical characteristics of stumps

Stumps averaged 3.5m tall (N=32; SD = 0.98), 2.2m in diameter at breast height (DBH; N= 32; SD = 0.81), 1.4m in top diameter (N= 32; SD = 0.50), and had an average volume of 11.3m^3 (N= 32; SD = 9.4; Fig. 2.2). Most (N=29; 90.6%) stumps were identified as Sitka spruce. Stumps that were not spruce were western hemlock (N=3; 9.4%). A few individual trees may have been misidentified due to the lack of bark and level of decay but these were unlikely to impact the results. Most (N=29; 90.6%) stumps were classified as decay stage four, with the rest (N=3, 9.4%) classified as decay class three (BC Ministry of Forests and Range, 2010).

Relationship between stump characteristics and vegetation

Percent cover of shrubs on stumps was not correlated with stump volume (r^2= 0.001, p-value= 0.82), top diameter (r^2= 0.18, p-value= 0.47), DBH (r^2= 0.007, p-value= 0.64), or height (r^2= 0.003, p-value= 0.76).

Vegetation communities on stumps and ground plots open to browse

Compositional differences

Ground plots (G) outside of exclosures (herein "ground plots") are characterized by various species of moss, single delight, sparse and intensively browsed shrub species, and tree seedlings (mostly western hemlock). Stump plots (S) are either predominantly moss with little herb and shrub growth, or, more often, are characterized by shrubs such as huckleberry and blueberry (*Vaccinium* sp.), salal, and false azalea (*Menziesia ferruginea*). Red huckleberry was the most common shrub species and was present on 23 of the 32 stumps sampled. False azalea and salal, the second and third most common shrubs, were present on 8 and 6 stumps respectively.

Dominance-diversity curves based on percent cover clearly showed mosses to be the most common taxa in both ground and stump plots, with step moss most common in ground plots and lanky moss most common in stump plots. Other than moss, ferns such as spiny wood fern and deer fern are more common in ground plots and shrub species such as red huckleberry and false azalea are more common in stump plots (Fig. 2.3).

Species richness (S) was greater in ground plots than on stumps (S_G: $\bar{x}$ = 9.41, N = 73, SE= 0.32; S_S: $\bar{x}$ = 5.38, N = 32, SE= 0.48; t-test, p-value= <0.0001; Fig. 2.4). There were species that grew only on the ground, only on stumps, and on both. Species found growing only on the ground include: sword fern (*Polystichum munitum*); deer fern; and lady fern; as well as numerous herbaceous species (Table 1.1). Species growing only on stumps include: salal; oval-leaved blueberry; Alaskan blueberry; and red elderberry. See Table 1.1 for a full list of species by habitat association.

Ground plots were also more diverse than stumps. Species evenness (E) was higher on the ground (E_G: $\bar{x}$ = 0.51, N = 73, SE = 0.02; E_S: $\bar{x}$ = 0.39, N = 32, SE = 0.04; t-test, p-value= 0.0091, Figure 6). Shannon's diversity index (H) was higher on the ground as well (H_G: $\bar{x}$ = 1.14, N = 73, SE = 0.04; H_S: $\bar{x}$ = 0.71, N = 32, SE = 0.09; t-test, p-value= <0.0001; Fig. 2.4). Lastly, Simpson's diversity index (D), also scored higher on the ground (D_G: $\bar{x}$ = 0.55, N = 73, SE = 0.02; D_S: $\bar{x}$ = 0.35, N = 32, SE = 0.04; t-test, p-value= <0.0001, Fig. 2.4).

Structural differences

The mean number of stems (I) present in each plot, including ferns, shrubs and seedlings combined, was not significantly different on average between ground and stump plots (t-test, p = 0.15). When comparing the mean number of stems for each habitat type by species, only red huckleberry showed significantly greater abundance on stump plots (I_S: $\bar{x}$ = 5.65, N = 20, SE = 0.85; I_G: $\bar{x}$ = 2.79, N = 24, SE= 0.47; t-test, p = 0.0064; Fig. 2.5, Table 2.1). There was no significant difference in the abundance of western hemlock seedlings, false azalea and salmonberry present on ground and stump plots (t-tests, p-values = 0.55, 0.47, 0.30; see Table 2.1).

As expected, due to deer browse, the mean height of stems (H) was greater on stumps than on the ground, for seedling, shrub, and fern species combined (H_S: $\bar{x}$ = 49.14cm, N = 65, SE = 6.58; H_G: $\bar{x}$ = 9.36 cm, N = 179, SE = 0.54; t-test, p-value = <0.0001; Fig. 2.6). Species that appeared on both ground and stump plots were selected for further testing. Western hemlock, red huckleberry and false azalea were significantly taller on stumps (t-tests, p-values = 0.0141, <0.0001, and 0.0114; Fig. 2.7; Table 2.2). Western hemlock seedlings were 6.81cm (SE = 0.69) on the ground and 29.45 cm (SE = 8.36) on stumps. Red huckleberry was 10.94cm (SE = 2.03) on the ground and 49.99cm (SE = 6.82) on stumps. False azalea was 8.28cm (SE = 2.83) on the ground and 134.99cm (SE= 35.32) on stumps. Salmonberry, however, was taller on average in ground plots, but no significant difference was found (H_G: $\bar{x}$ = 3.61cm, SE= 0.38, H_S: $\bar{x}$ =

1.88cm, SE = 0.65; t-test, p-value = 0.0682). Red elderberry did not have large enough sample size for testing. However, one noteworthy individual was 53cm on a 2.4m stump in 2010. Even on a stump this high, a deer ate all foliage and most stems of this individual by the beginning of the 2011 field season.

The mean percent cover (%) of seedling, shrub, and fern species combined was also greater on stumps than on the ground ($\%_S$: $\bar{x}$ = 5.63%, N = 68, SE = 0.86%; $\%_G$: $\bar{x}$ = 0.78%, N = 199, SE = 0.08%; t-test, p-value = <0.0001; Fig. 2.8). Select species that appeared on both ground and stump plots were also tested. Western hemlock, red huckleberry, false azalea, and salmonberry had significantly greater percent cover on stumps (t-tests, p-values = 0.007, 0.002, 0.032, 0.021; Table 2.3). Western hemlock seedlings had 0.72% cover (SE = 0.13) on the ground and 4.55% cover (SE= 1.28) on stumps. Red huckleberry had 0.82% cover (SE=0.29) on the ground and 7.41% cover (SE = 1.88) on stumps. Salmonberry was the only shrub with a slightly higher percent cover on the ground, with 0.63% cover (SE=0.05) on the ground and 0.5% cover (SE = 0.0) on stumps. Sample size was too small for adequate confidence.

Comparison of vegetation communities on ground inside and outside exclosures

I compared ground plots within exclosures (referred to as "exclosures," "exclosure plots" or "E") and ground plots outside exclosures ("ground plots" or "G") for difference in the change in number of stems between 2010 and 2011, and mean plant heights in 2010 and 2011. There were statistically significant differences between exclosures and ground plots for the mean heights of plants.

All species combined, there was no significant difference in the change of mean number of stems (ΔI) from 2010 to 2011 between ground and exclosure plots (t-test, p-value = 1.000; Table 2.4). Nor was there a significant difference found when examining species separately. However, two species showed more of an effect than the others: lady fern and spiny wood fern. Lady fern has a very small sample size and therefore no significance can be drawn, however the change in the mean number of stems was substantially more in exclosure plots than in ground plots (ΔI_E: $\bar{x}$ = 2.67, N = 3, SE = 2.03; ΔI_G: $\bar{x}$ = 22.5, N= 2, SE = 8.5; t-test, p-value= 0.2431; Fig. 2.9). Spiny wood fern did not show a significant difference, however there was a greater increase of stems in exclosure plots than in ground plots (ΔI_E: $\bar{x}$ = 3.86, N= 14, SE = 1.32; ΔI_G: $\bar{x}$ = 9.1, N= 10, SE = 3.57; t-test, p-value= 0.1943; Fig. 2.9).

The mean height of stems (H) in exclosures was significantly different than ground plots in 2011 (H_G: $\bar{x}$ = 7.08cm, N = 42, SE = 0.61; H_E: $\bar{x}$ = 11.83cm, N = 41, SE = 1.28; t-test, p-value = 0.0015; Table 2.5, Fig. 2.10). Examining species separately, deer fern was taller in exclosure plots in 2011 (H_G: $\bar{x}$ = 8.11cm, N = 9, SE = 0.85; H_E: $\bar{x}$ = 15.73cm, N = 6, SE = 2.35; t-test, p-value = 0.0209, Table 2.5). Although insignificant, the following species showed a trend of decreasing height in ground plots and increasing height in exclosures in 2011: lady fern, deer fern, spiny wood fern and salmonberry (Table 2.5).

Similar to the results for mean heights, the sum of plant heights also increased more in the exclosure plots than in ground plots from 2010 to 2011. However, results were not statistically significant (Table 2.6).

Discussion

Stump characteristics and vegetation

The percent cover of shrubs growing on stumps was not related to the characteristics of stumps, including DBH, height, top diameter, and volume. Kennedy and Quinn (2001) also did not find a relationship between vegetation and stump area, height or decay, however they called on the need for further study. The difference in percent cover of shrubs could be related to a number of factors such as past environmental conditions in which shrub growth was initiated, stochasticity, or current light or canopy conditions. Preliminary analysis shows percent canopy openness and percent full sun to be significantly related to percent shrub cover (see Chapter 3).

Differences of vegetation communities on stumps and on the ground

In Sandy Creek, stumps are providing refuge for a number of species. This is consistent with other studies that found stumps acting as refugia in Haida Gwaii (Holmes

2010; Sherlock unpubl.). Red huckleberry, false azalea, and salal are the most common shrubs found on stumps and grow much taller on stumps than on the ground. Furthermore, six species grew only on stumps, indicating that stumps are serve a critical role for these species (salal, false lily-of-the-valley, licorice fern, red elderberry, Alaskan blueberry, oval-leaved blueberry). This is consistent with our understanding of habitat preferences for these species. For instance, in Olympia, WA plant communities differed significantly between stump and ground substrates; red huckleberry and salal were more common on stumps and trailing blackberry (*Rubus ursinus*) and sword fern were more common on the ground (Kennedy & Quinn, 2001).

Interestingly, plant communities on stump refugia in Haida Gwaii lack the abundance and diversity of ground communities, even though stumps are protected from the intense browse pressure occurring on the ground. Although vegetation on the ground appears exceptionally sparse at first glance, ground plots actually averaged significantly higher species richness, evenness and diversity scores. Plants on the ground are in fact more numerous and diverse than those on stumps, however they are simply unable to grow past one to five centimetres tall, in most cases. Contrary to my findings in Haida Gwaii, Kennedy & Quinn (2001) found no difference in richness, evenness and diversity measures across ground and stump substrates in Washington state. The difference was due to the fact that intense shrub competition on the ground was limiting richness and diversity measures on the ground in their case. Therefore, a stump in their ecosystem was acting as a different kind of refugium, providing a substrate free from shrub competition occurring on the ground. Perhaps in Haida Gwaii, shrub competition is occurring on stumps, rather than on the ground, limiting species diversity on stumps.

Although stump refugia are not providing a refuge for the full suite of understory species in Haida Gwaii, they are still serving an essential role in maintaining the persistence of certain shrub species, such as red huckleberry. Each stem found on the ground is browsed constantly so that it is often only one centimetre tall, or less. Although not tested formally, sexually reproducing individuals (shrubs with berries) observed throughout the study area were never seen on the ground. Rather, they were always observed on top of stumps, root mounds, and elevated nurse logs. Stumps may, in fact, be the only substrate where shrub species can grow tall enough to reproduce. Further research should explore this hypothesis further.

Differences in vegetation in open ground plots and in exclosures

Herbivory by the introduced deer clearly plays an important role in shaping plant communities. Although we did not expect to see a visible change in vegetation one year after the construction of deer exclosures, certain species benefitted from the exclosures over only one year. Specifically, spiny wood fern, deer fern, and lady fern showed evident growth within exclosures after only one year. The fact that our results showed any change at all is surprising, given the short one year time frame. Compensatory growth after browsing changes with the level of stress the plants experience and the amount of time for recovery (Oesterheld & McNaughton, 1991). Therefore, it is likely that in Sandy Creek the main stressor to plant vitality is the intensity of herbivory (specifically deer browse). In this study area environmental variables, such as water and nutrient availability, seem relatively abundant and plants have a lower level of stress and grow at a higher relative growth rate than other coastal forests (Oesterheld & McNaughton, 1991). Once the traumatic effect of herbivory is removed, certain species may rebound quickly.

Our results are consistent with previous exclosure studies in Haida Gwaii, showing remarkable differences in exclosed areas and their surroundings (Golumbia 1999; Martin et al. 2010). The impact of deer browse on the understory vegetation on Haida Gwaii is well documented (Golumbia 1999; Stockton et al. 2005; Gaston et al. 2008; Stroh et al. 2008; Martin et al. 2009). Although much literature exists globally on deer overabundance (Coombs et al. 2003; Rooney & Waller 2003; Cote et al. 2004), introductions (Vasquez 2002) and herbivory (Hobbs 1996; Hobbs et al. 2009), there is limited information on the impacts to forest understory by introduced deer herbivory in an ecosystem with virtually no natural predators. Some black bears will prey on a sick or dying deer, however the occurrence is not common enough to control the population. Haida Gwaii has no other natural predator to control the deer population. The situation has therefore become ecologically devastating for the forest understory.

Over time, these exclosures could provide a dramatic impact on the entire understory ecosystem. Even maintaining these exclosures for just a few years could allow the individual species within to establish themselves enough to begin to reproduce. Furthermore, if exclosures can help reduce browsing extent, this could have far-reaching impacts for the health of the riparian area. Literature suggests that understory functions such as hydrologic functions (ie. water storage and release), shade and sediment storage can return with as little as 5-10 years of browsing reductions (Roni et al. 2002). In this ecosystem, due to fast growth rates and availability of seed sources from stumps, we may even be able to anticipate a shorter time span than this.

Roni et al. (2002) suggest that riparian restoration efforts should focus first on landscape-scale habitat connectivity, then on restoring hydrologic, geologic, and riparian processes through road decommissioning and elimination of grazing (in Haida Gwaii this means elimination of deer browsing) before in-stream habitat enhancement is employed. This framework would suggest removal of herbivory is the highest priority.

Limitations

Analysis for the effect of restoration on vegetation growth was outside of the time limitations of this study. A more in-depth analysis of how vegetation is affected by restoration treatment vs exclosures should be pursued. Furthermore, other than the difference of substrate type and exclosure, comparative analysis of other potential contributing factors to vegetation growth, such as light environment or forest structure, was outside the scope of this study. Chapter 3 explores the relationship of shrub vegetation on stumps to light and forest structure before restoration. However, the ability for conclusive analysis with these variables is very difficult, due to the limited extent of vegetation on the ground. Further analysis with these variables in the future, once vegetation has had adequate time to respond, should be explored.

Management Implications

Stumps are an important component of this ecosystem and provide refuge for certain shrub species, yet they will not be the ultimate solution for the restoration of understory vegetation in Haida Gwaii. Since stumps do not provide a refuge for the full suite of understory species, riparian restoration treatments should not focus on gap creation centered specifically around stumps. It would, however, be beneficial for some gaps to include stumps within the treated areas to provide a greater spectrum of light environment for species taking advantage of stump substrates. Stumps are clearly facilitating the persistence and productivity of shrubs in this ecosystem. Only on stumps and other substrate protected from deer are shrubs able to grow large enough to reproduce. Stumps are thus an important component of the overall recovery of the forest understory in this ecosystem. Restoration practices such as gap creation will increase the heterogeneity of stand structure and of understory light, encouraging growth across all substrates.

In the context of forest management, this study determined that riparian restoration does not need to focus on gap creation centered specifically around stumps. It would, however, be beneficial for some gaps to include stumps. This study affirms that stumps are clearly assisting the persistence of shrubs in this ecosystem. Only on stumps and other substrate protected from deer are shrubs able to grow large enough to reproduce. They will therefore likely be an important element to the overall recovery of the understory in this ecosystem. Restoration practices such as gap creation may be adequate to increase stand structure heterogeneity and increased understory light throughout the stand, encouraging growth across a broad range of substrates.

Elsewhere in the province, stumps are being increasingly removed from second growth forests and used as biofuel (Hannam, 2012). The justification for the removal of stumps include clean energy, site preparation, and root disease control (Hannam, 2012). Although the literature provides limited evidence for the role stumps play in second growth forests, the literature does show the importance of coarse woody debris (Harmon et al., 1986; Franklin et al. 2000). Stumps and stump roots are sometimes the major form of decaying wood in second growth forests and can be expected to perform a vital role in second growth forest structure and function. This study illustrates another unexpected role of stumps in second growth forests.

Other measures should be employed to enhance vegetation growth, such as deer control and maintenance of current deer exclosures and/ or construction of new exclosures, if restoration of understory plant community and productivity is to be pursued. An objective of this restoration project includes establishing a healthy forest understory in Sandy Creek. To achieve this, its main stressor, the deer population on Lyell Island, must be substantially reduced or removed. Efforts have been made in the past to control and manage introduced species in Gwaii Haanas (Golumbia 1999), and ongoing efforts are currently being made to control deer population on Lyell Island. However, due to resource limitations, and the prohibitive scale of deer management on an island as large as Lyell Island, these efforts have not yet heralded noteworthy impacts.

Conclusions

The stumps in Sandy Creek are providing a refuge from herbivory for some understory species such as red huckleberry. Stump plant communities lack, however, the richness and diversity of the ground communities, even when those communities are exposed to heavy browsing pressure. This is consistent with our understanding of these species' habitat associations; many species prefer to grow on ground rather than the wood of stumps (Kennedy & Quinn 2001; Harmon et al. 1986).

Herbivory by the introduced deer clearly plays an important role in shaping plant communities. Considerably more growth was observed in ferns, herbs, and some shrubs within the exclosures over only one year. This is consistent with previous exclosure studies in Haida Gwaii, showing remarkable differences in exclosed areas and their surroundings (Golumbia 1999; Martin et al. 2010). Deer control is an obvious management action for Gwaii Haanas policy makers to consider if restoration of understory plant community and productivity is to be pursued.

Tables and Figures

Tables

Table 2.1. Number of stems found in ground and stump plots for selected species: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)).

Species	Substrate	Mean # Stems	N	SE	p-value
All species combined	Ground	5.07	179	0.60	0.1556
	Stump	6.77	66	1.03	
Red huckleberry	Ground	2.79	24	0.47	**0.0064**
	Stump	5.65	20	0.85	
Western hemlock	Ground	9.98	45	2.06	0.5524
	Stump	12.10	20	2.88	
False azalea	Ground	1.75	4	0.48	0.4695
	Stump	2.57	7	0.97	
Salmonberry	Ground	3.67	18	1.18	0.3011
	Stump	2.00	4	1.00	

*Note – p-values in bold are significant

Table 2.2. Mean height of stems found in ground and stump plots for selected species: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)).

Species	Substrate	Mean Height (cm)	N	SE	p-value
All species combined	Ground	9.36	179	0.54	**<0.0001**
	Stump	49.14	65	6.58	
Red huckleberry	Ground	10.94	24	2.03	**<0.0001**
	Stump	49.99	20	6.82	
Western hemlock	Ground	6.81	45	0.69	**0.0141**
	Stump	29.45	20	8.36	
False azalea	Ground	8.28	4	2.83	**0.0114**
	Stump	134.99	7	35.32	
Salmonberry	Ground	3.61	18	0.38	0.0682
	Stump	1.88	4	0.65	

*Note – p-values in bold are significant

Table 2.3. ***Mean percent cover found in ground and stump plots for selected species: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)) .***

Species	Substrate	Mean % Cover	N	SE	p-value
All species combined	Ground	0.78	199	0.08	**<0.0001**
	Stump	5.63	68	0.86	
Red huckleberry	Ground	0.82	33	0.29	**0.002**
	Stump	7.41	21	1.88	
Western hemlock	Ground	0.72	48	0.13	**0.007**
	Stump	4.55	22	1.28	
False azalea	Ground	0.5	4	0.0	**0.032**
	Stump	7.25	8	2.53	
Salmonberry	Ground	0.63	20	0.05	**0.021**
	Stump	0.5	4	0.0	

*Note – p-values in bold are significant

Table 2.4. Mean change in the mean number of stems found in ground and exclosure plots between 2010 and 2011: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)).

Species	**Substrate**	**Mean Change in Mean # Stems from 2010 to 2011**	**N**	**SE**	**p-value**
All species combined	Ground	1.67	57	0.71	1.000
	Exclosure	1.67	51	1.34	
Lady fern	Ground	2.67	3	2.03	0.2431
	Exclosure	22.5	2	8.50	
Spiny wood fern	Ground	3.86	14	1.32	0.1943
	Exclosure	9.10	10	3.57	

*Note – p-values in bold are significant

Table 2.5. ***Mean height of stems in ground and exclosure plots in 2010 and 2011: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)).***

Species	Substrate	Mean Height (cm)	N	SE	p-value
All species combined 2010	Ground	7.85	43	0.76	0.2006
	Exclosure	9.87	40	1.37	
All species combined 2011	Ground	7.08	42	0.61	**0.0015**
	Exclosure	11.83	41	1.28	
Lady fern 2010	Ground	14.68	2	4.68	0.6620
	Exclosure	10.82	2	5.92	
Lady fern 2011	Ground	6.78	2	1.11	0.2746
	Exclosure	15.21	2	4.14	
Deer fern 2010	Ground	10.59	10	1.36	0.5974
	Exclosure	11.58	10	1.23	
Deer fern 2011	Ground	8.11	9	0.85	**0.0209**
	Exclosure	15.73	6	2.35	
Spiny wood fern 2010	Ground	8.70	10	0.72	0.6261
	Exclosure	9.69	8	1.83	
Spiny wood fern 2011	Ground	7.50	12	0.74	0.1597
	Exclosure	9.88	9	1.41	

*Note – p-values in bold are significant

Table 2.6. ***Sum height of stems in ground and exclosure plots in 2010 and 2011: descriptive statistics (mean, sample size (N), standard error (SE) and test statistic for a two-tailed t-test (p-value)).***

Species	Substrate	Sum Height (cm)	N	SE	p-value
Lady fern 2010	Ground	24.35	2	14.35	0.5628
	Exclosure	111.20	2	106.30	
Lady fern 2011	Ground	40.05	2	23.05	0.4012
	Exclosure	508.75	2	342.75	
Deer fern 2010	Ground	50.25	10	17.20	0.2713
	Exclosure	28.86	10	6.91	
Deer fern 2011	Ground	57.30	9	29.81	0.9101
	Exclosure	15.73	6	22.43	
Spiny wood fern 2010	Ground	38.92	10	17.20	0.6024
	Exclosure	52.24	8	21.52	
Spiny wood fern 2011	Ground	60.03	12	17.36	0.1820
	Exclosure	161.16	9	67.76	

*Note – p-values in bold are significant

Figures

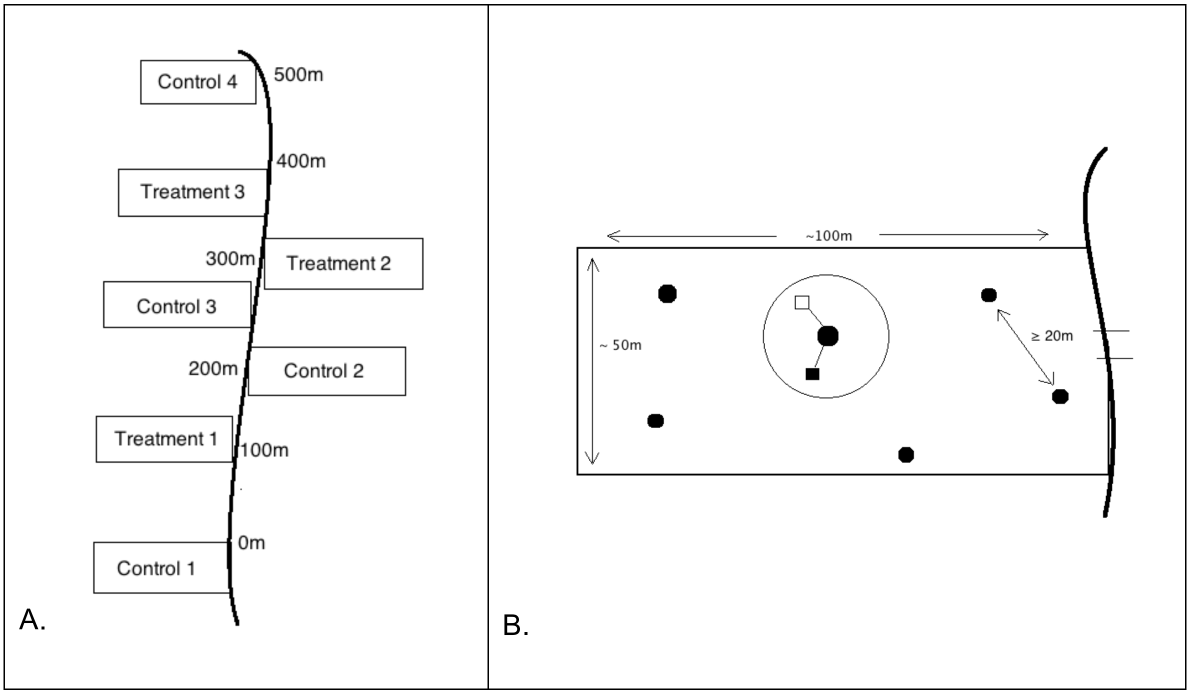


Figure 2.1. Research design.

A. Layout of treatment and control transects along Sandy Creek (0m is where tidal influence is no longer present). Treatment transects were located at 100m, 300m and 380m. Control transects were located in sites with similar characteristics and at least 100m away from treatments. Four control transects were necessary in order to get the same number of plots as treatment transects.
B. Layout of plots within treatment and control transects. Within this area, only stumps 20m apart, starting from the first encountered, were included for sampling. Each stump had 2 paired ground plots, one fenced (black square) and one open (white square), located at a random distance (2-5m) and bearing from the stump.

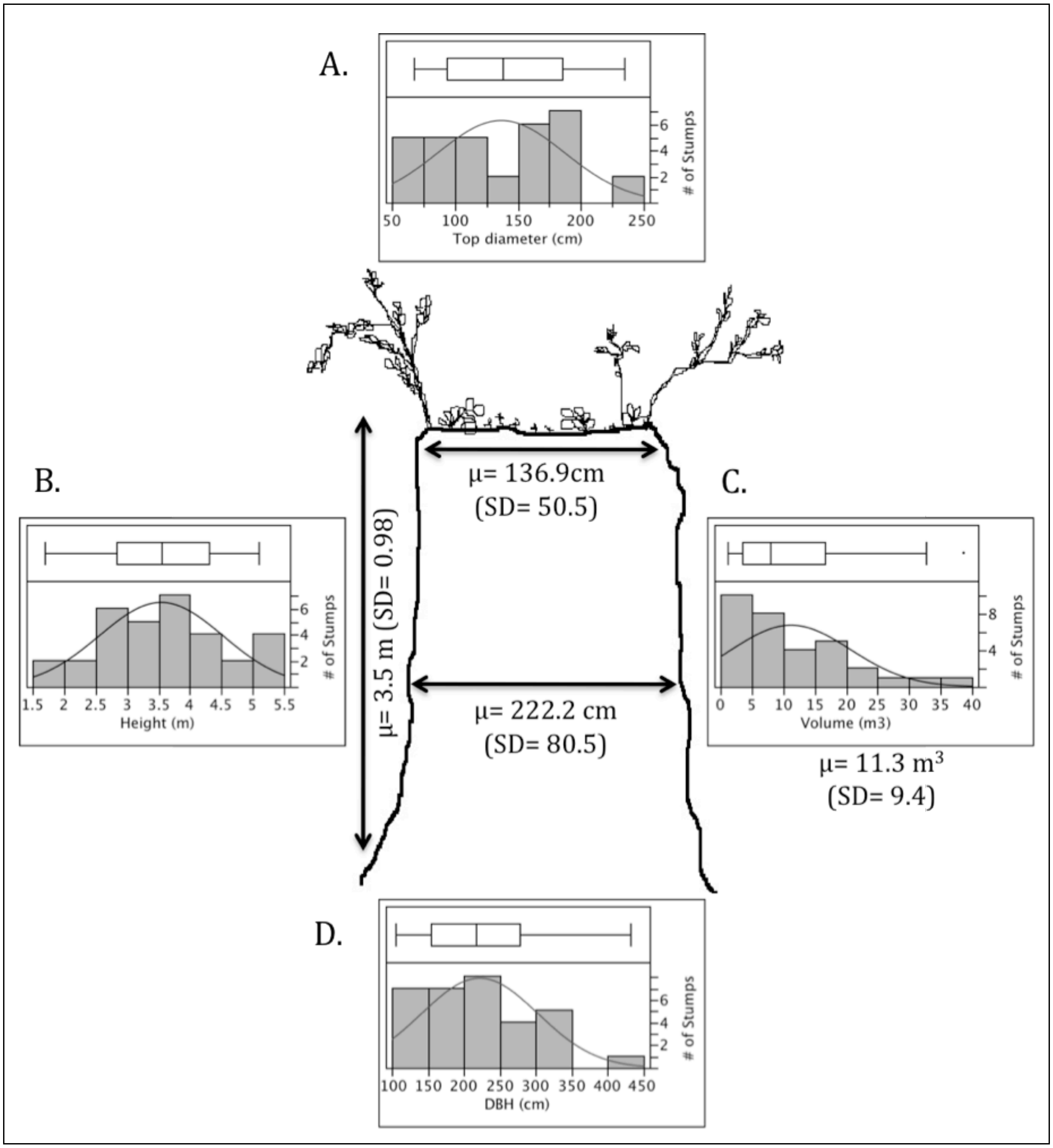


Figure 2.2. Diagram of a "stump refugium" with distributions of A. top diameter, B. height, C. volume, and D. diameter at breast height (DBH)

Figure includes means (μ) and standard deviations (SD) of these stump characteristics. The middle line of the box plot represents the median, the upper and lower boundaries of the box represent each quantile (75 and 25%, respectively), and the upper and lower tail limits represent the maximum and minimum values. Dots outside the upper and lower tail limits indicate outliers.

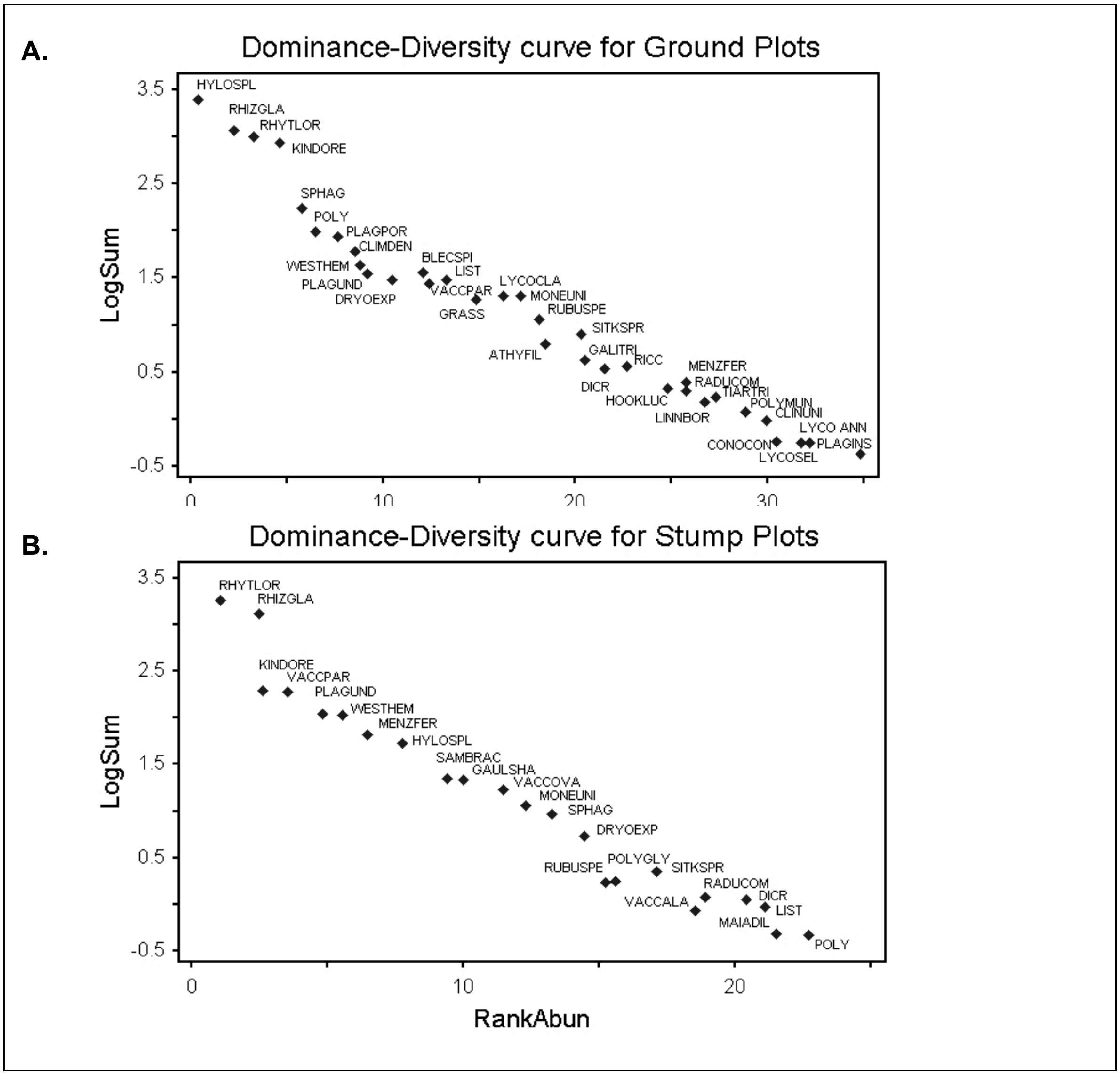


Figure 2.3. Dominance Curves for A. Ground Plots and B. Stump Plots.

Each point on the curve is a species. Those top left are most common, those bottom right are least common. See Table 1 for latin, common, substrate for each code name used above for tree, shrub and herbaceous species. Moss species are listed in the full species list in Appendix 1.

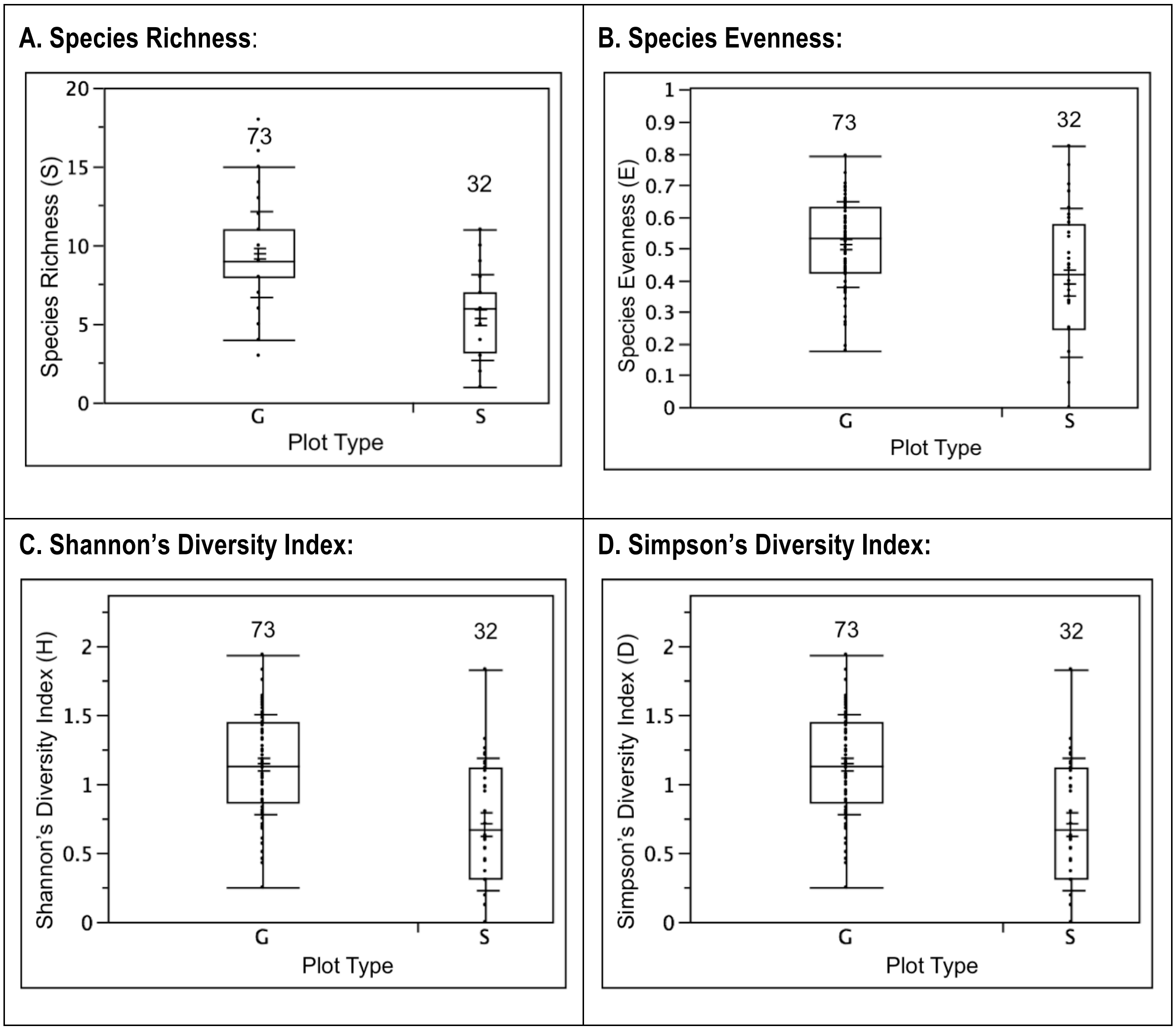


Figure 2.4. Boxplots for A. species richness, B. evenness, C. Shannon's Diversity Index, and D. Simpson's Diversity Index for ground (G) and stump (S) plots.

The middle line of the box plot represents the median, the upper and lower boundaries of the box represent each quantile (75 and 25%, respectively), and the upper and lower tail limits represent the maximum and minimum values. The shorter lines from the middle outward represent the mean, standard error, and deviation lines. The number above each box represents its sample size (N). The width of the X-axis is proportional to each N. A two-tailed t-test assuming unequal variances was used to test significance.

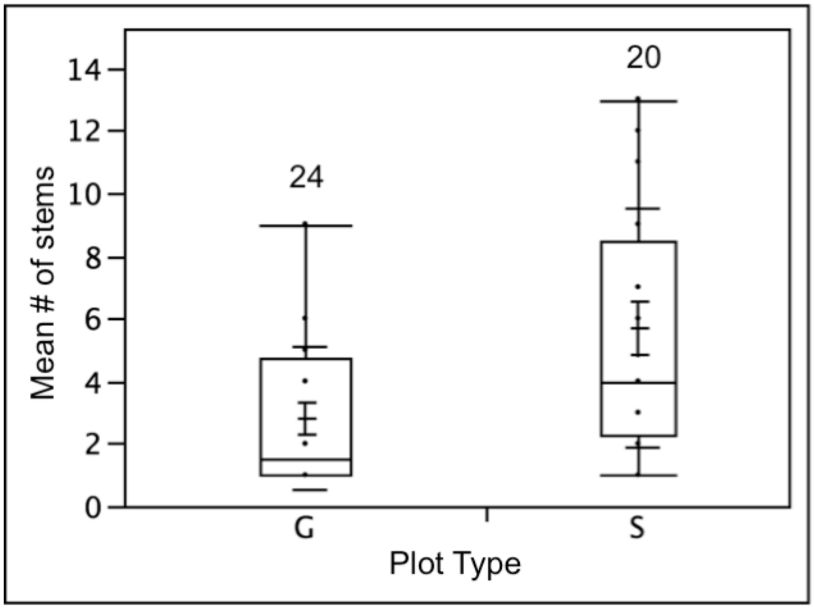


Figure 2.5. Boxplot of the number of red huckleberry stems in ground (G) and stump (S) plots.

I used a two-tailed t-test assuming unequal variances to test the difference in number of individual red huckleberry plants on the ground and on stumps (p-value= 0.0006). Please refer to Figure 2.4 for further explanation of test and boxplot details.

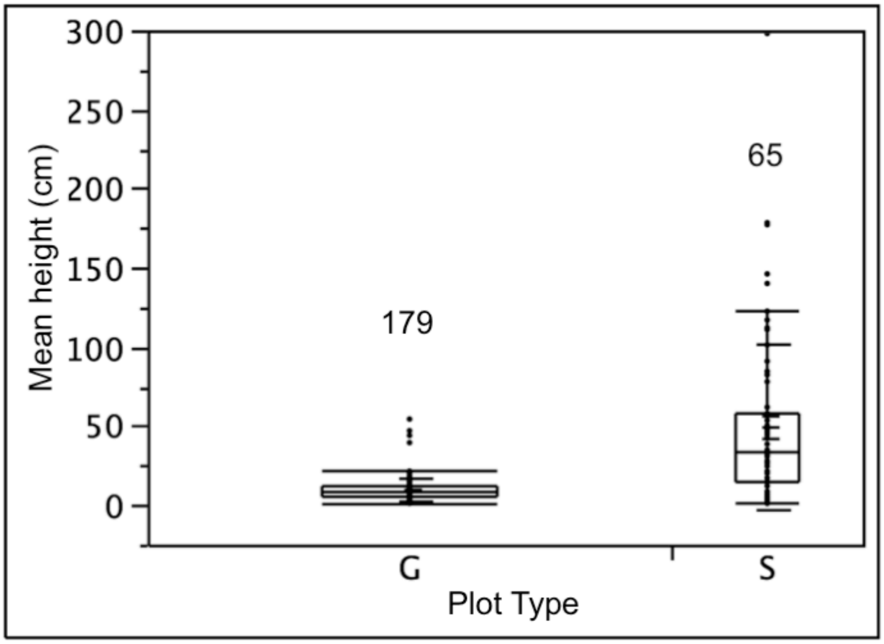


Figure 2.6. Boxplot of mean stem heights for ground (G) and stump (S) plots.

A two-tailed t-test assuming unequal variances was used to test the difference in mean height over all species (p-value= <0.0001). Please refer to Figure 2.4 for further explanation of test and boxplot details.

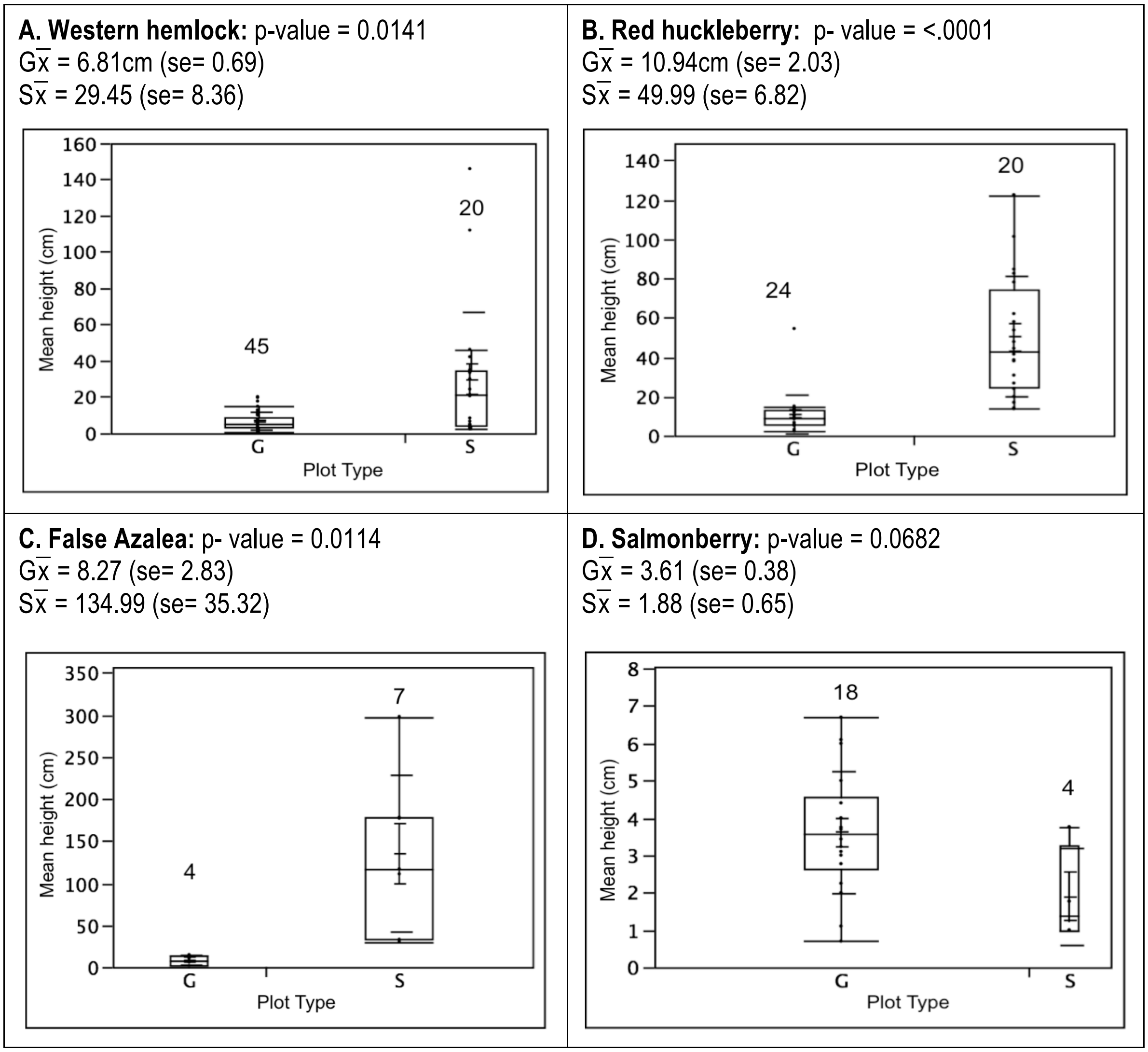


Figure 2.7. Boxplots of mean stem heights for select species in ground (G) and stump (S) plots.

A two-tailed t-test assuming unequal variances was used to test the difference in mean heights between ground and stump plots for each species. Please refer to Figure 2.4 for test and boxplot details.

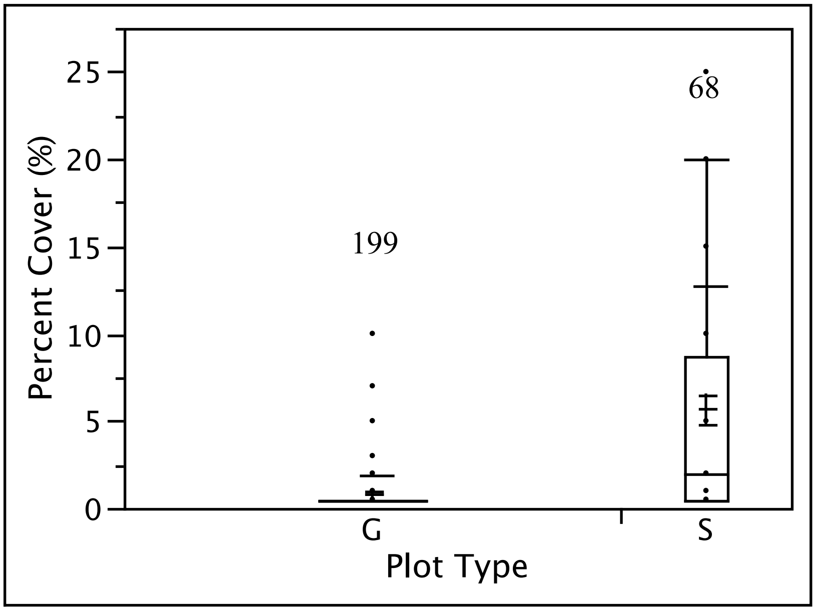


Figure 2.8. Boxplot of percent covers of all species combined for ground (G) and stump (S) plots.

A two-tailed t-test assuming unequal variances was used to test the difference in percent cover between ground and stump plots for all species combined (p-value= <0.0001). Please refer to Figure 2.4 for test and boxplot details.

A. Lady fern: p-value = 0.2431
$G\bar{x}$ = 2.67 (se= 2.03)
$S\bar{x}$ = 22.5 (se= 8.5)

B. Spiny wood fern: p-value = 0.1943
$G\bar{x}$ = 3.85 (se= 1.32)
$S\bar{x}$ = 9.1 (se= 3.57)

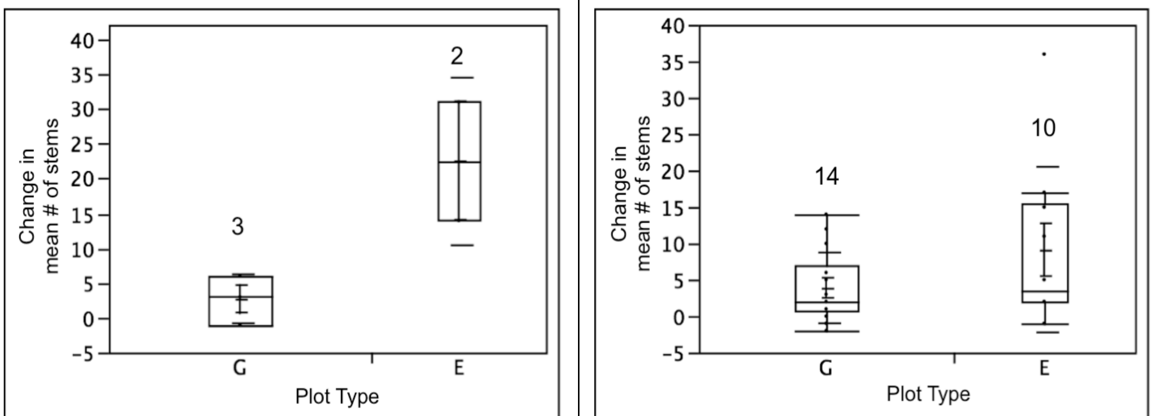


Figure 2.9. Change in mean number of stems between 2010 and 2011 for select species in ground (G) and exclosure (E) plots.

A two-tailed t-test assuming unequal variances was used to test the difference in the change in number of stems from 2010 to 2011 between ground and exclosure plots for each species. Please refer to Figure 2.4 for test and boxplot details.

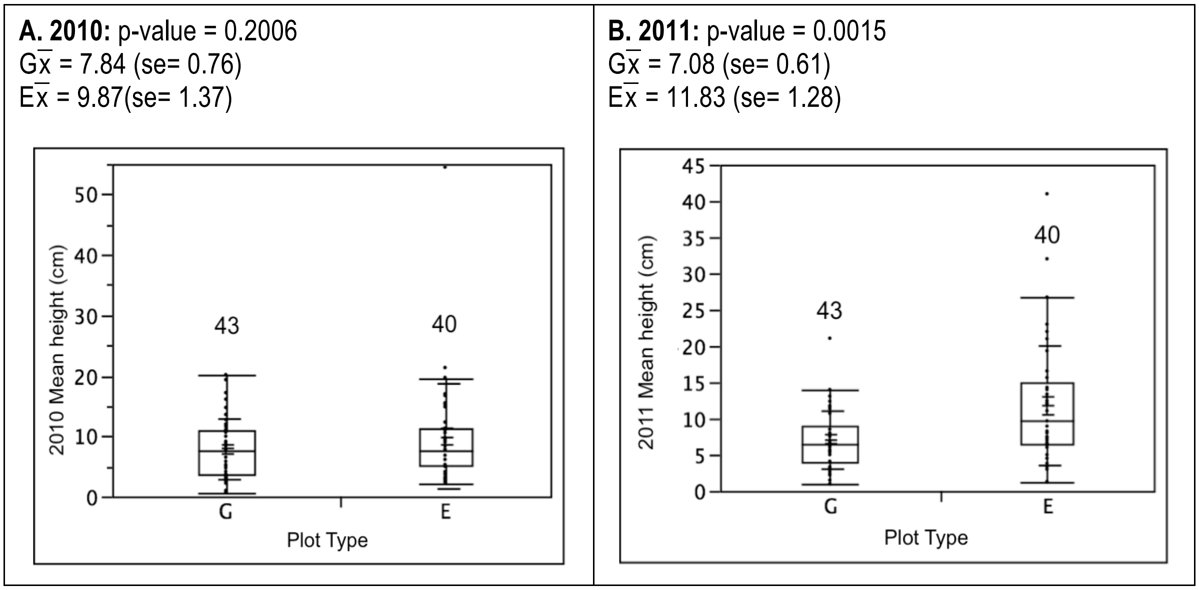


Figure 2.10. Mean stem height in 2010 and 2011 for ground (G) and exclosure (E) plots with all seedling, shrub and fern species combined.

A two-tailed t-test assuming unequal variances was used to test the difference in mean heights between ground and exclosure plots in 2010 and 2011. Please refer to Figure 2.4 for test and boxplot details.

Chapter 3. Understory light response to riparian restoration on Lyell Island, Haida Gwaii

Introduction

Riparian forests grow adjacent to streams, lakes and wetlands. Riparian areas in old growth coastal forests of British Columbia are the most productive forests in North America and yield some of the highest canopy volumes on earth: greater than 200,000m3/ha (Van Pelt et al. 2006). Riparian forests are diverse in both species composition and physical structure, which encompasses vertical elements such as canopy layers and horizontal elements such as canopy gaps and variation of stem size (Gregory et al. 1991; Pabst & Spies 1999; Franklin et al. 2002; Van Pelt 2004; Smith 2005). Furthermore, riparian areas have distinctive microclimatic conditions such as air temperature, soil temperature, wind speed and solar radiation, and these conditions are significantly altered when forest harvesting near the stream occurs (Brosofske et al. 1997).

Interactions between disturbance regimes, geomorphology and hydrology determine the attributes of floodplain forests that make them so productive and diverse (Van Pelt 2006). In general, large, natural stand-replacing disturbances such as fire are rare in coastal temperate rainforests (Lertzman et al. 2002; Daniels & Gray 2006). Rather, these forests are dominated by gap-phase dynamics. Gap-phase dynamics is the process of canopy gap creation (1- 10 trees) by tree mortality or small wind events and the ensuing filling of those gaps by young trees; over time this creates a heterogeneous forest structure and light environment (Bray 1956; Canham et al. 1990; Lertzman et al. 1996; Frazer et al. 2000a; Gavin et al. 2003; Griffiths 2010). Larger windthrow events are also an important developmental driver for forests in southeast Alaska (Kramer et al. 2001).

Gap phase dynamics in old growth temperate riparian forests are important in promoting the structure and function of riparian areas and vegetation dynamics characteristic to this ecosystem type (Alaback 1982; Lertzman et al. 1996; Curzon & Keeton 2010) It is generally accepted that an increase of full sun reaching the understory will increase total understory vegetation cover (Turner & Franz 1986). Spatially distributed gaps in the canopy increase the heterogeneity of light reaching the forest floor (Lertzman et al. 1996; Frazer et al. 2000a; Franklin & Van Pelt 2004; Griffiths et al. 2010). This type of spatial complexity affects the spatial composition of the understory, and generally increases species diversity. For example, in gaps, shrub competition can limit conifer regeneration (Pabst & Spies 1999; Giesbrecht 2010), and in darker areas herb diversity is sometimes higher due to less shrub competition (Giesbrecht 2010).

In British Columbia, logging had major impacts on rivers and low-elevation old-growth forests (DellaSala 2010). Clearcut forest harvesting practices do not mimic the small scale natural disturbances in coastal temperate forests (Pearson, 2010; Bergeron & Fenton 2012; Lertzman, Spies & Swanson 1997). Furthermore, second growth forests do not have the same structural complexity as old growth forests (Alaback 1982; Banner & LePage 2008; Gerzon et al. 2011; Frazer et al. 2000a). Second growth stands are generally homogenous in age and height, with dense canopies and dark understory light conditions (Chan et al. 1996; Banner & LePage 2008). As well, the amount and size of coarse woody debris on the forest floor and in streams in second growth is reduced (Bilby & Ward 1991). Due to these factors, habitat availability for wildlife is limited, understory vegetation in second growth is often severely limited, and salmon habitat in streams is degraded.

Forest managers are increasingly interested in understanding how to restore second growth forests to a state more similar to old growth in structure and function (Franklin et al. 2002). Ecological restoration is a tool used by forest managers to physically change stands to mimic old growth stand characteristics; a difficult task when so little is known about these complex riparian forests (Van Pelt et al. 2006). Further, it is challenging to understand patterns in areas which are subject to complex, multi-scale processes (Pabst & Spies 1999). Ecological riparian restoration attempts to mimic natural disturbances through gap creation and promotes an increase in canopy light and natural forest characteristics (Franklin et al. 2002). Restoration efforts can be focused at manipulating and retaining structure to create the functional light environment that will support vegetation communities and release conifer growth. However, to conduct effective restoration, benchmark information is needed regarding the structure and function being restored, as well as information on how well various manipulations work in achieving these values.

Many studies have used hemispherical canopy photography (HCP) to examine the forest understory light environment and the utility of structural manipulations to restore old growth light conditions (Stewart 1988; Beaudet & Messier 2002; Clarke & Murphy 2011) as HCP is the most precise method for estimating canopy openness (Brown et al. 2000; Keane et al. 2005; Leblanc et al. 2005). A few studies have focused on old growth in coastal BC, including canopy openness and leaf area on Vancouver Island, canopy openness and light in the Seymour Valley in the Vancouver region, and percent full sun in Stika spruce floodplain sites, (Frazer et al. 2000a; Roburn 2003; Giesbrecht 2010). Other studies focus on deciduous or mixed hardwood forests (Beaudet & Messier 2002; Beaudet et al. 2004), tropical forests (Brown et al. 2000), or temperate conifer forests dominated by Douglas-fir (Clark & Murphy 2011; Drever & Lertzman 2001, 2003; Drever 2005). HCP techniques are also effective at describing canopy light changes from various silvicultural or restoration treatments (Lhotka & Loewenstein 2006; Drever & Lertzman 2003; Hutchison 2011). Quantitative documentation of the light environment before and after restoration is a quick and accurate method of documenting canopy change and will enhance the current monitoring program created by Ryland & Thomas (2012).

My research is part of a restoration project on Lyell Island, entitled “Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island),” which aims to restore the health of riparian forests and salmon-bearing streams on Lyell Island (Gwaii Haanas 2008). The riparian forest treatments in Sandy Creek consist of the creation of a range of sizes of gap openings. There is a need for documentation of riparian restoration projects, to understand how future projects can be planned and implemented to restore old growth characteristics most effectively (Roni et al. 2002; Deal 2007).

In this paper I quantify the consequences of manipulations in forest structure associated with riparian restoration efforts for understory light environments. I used hemispherical canopy photography (HCP) to assess the utility of structural manipulations to restore old growth light conditions. Specifically, this chapter asks:

1. How was the forest structure affected by the restoration treatments within the treated areas of the riparian forest in Sandy Creek? How was the forest structure affected by wind events one year after the restoration treatments?

2. How was the understory light environment affected by the restoration treatments within the treated areas of the riparian forest in Sandy Creek? How was the understory light environment affected by wind events one year after the restoration treatments?

3. Is there a relationship between forest structure and understory light with which forest managers could use in restoration planning?

4. Is there a relationship between understory vegetation on stumps and the understory light environment?

We expected a decrease in forest volume and density and an increase in understory light post treatment due to the removal of trees. We expected a further change again one-year post treatment due to windthrow effects. Other studies have found a significant, negative relationship between forest structure variables and light, as well as correlations between percent cover and light. We expected that changes in the light environment associated with structural manipulations would increase vegetation growth.

We had hoped initially to be able to distinguish the vegetation response effects of the canopy removal treatment from the effects of deer browse via deer exclosures. However the one-year time duration of the study was too short for the experiment to develop mature results. We hope that future efforts will examine the results of the experiment as they develop.

Study Site and Methods

Study Area

Haida Gwaii is a remote archipelago off the northwest coast of British Columbia (BC). Lyell Island is situated off Haida Gwaii's southeast coast, in Gwaii Haanas National Park Reserve and Haida Heritage Site (Gwaii Haanas; Fig. 1.1). Average annual precipitation of 1,359mm falls mostly as rain (Golumbia 2007). The area has cool, wet summers and cold, very wet winters. The average annual temperature is approximately 8°C, and has an intra-annual fluctuation of about five degrees (MIEDS 2011). Lyell Island sits on the Skidegate Plateau physiographic region and is within the Submontane Wet Hypermaritime Coastal Western Hemlock variant (CWHwh1; Green & Klinka 1994).

The study sites in Sandy Creek are located on mid bench riparian floodplain dominated by Sitka spruce (*Picea sitchensis* (Bong.); Fig. 1.2). Due to intense deer browse, the understory is characterized mainly by moss species such as lanky moss (*Rhytidiadelphus loreus*), and step moss (*Hylocomium splendens*). Herb and shrub species persisting on the ground include: single delight (*Moneses uniflora*); twayblade (*Listera sp.*); lady fern (*Athyrium filix-femina*); deer fern (*Blechnum spicant*); spiny wood fern (*Dryopteris expansa*); and red huckleberry (*Vaccinium parvifolium*). In general, individuals of these species exist in a constantly browsed state. In complex terrain, or on substrate higher than approximately 1.5m (deer browse-line), other understory species persist, and are able to grow large enough to reproduce. These species that have been mostly confined to stump substrates include: false lily-of-the-valley (*Maianthemum dilatatum*); salal (*Gaultheria shallon*); red elderberry (*Sambucus racemosa*); Alaskan blueberry (*Vaccinium alaskaense*); and oval-leaved blueberry (*Vaccinium ovalifolium*). Table 1.1 lists species that are found only on stumps, only on the ground, and those that are found on both substrates. See Appendix 1 for a complete species list including mosses.

Restoration Treatments

Riparian forest restoration treatments (overstory tree removals) were located adjacent to areas requiring in-stream restoration, as assessed by Northwest Hydraulic Consultants (Ray, 2010). The objectives for restoration treatments were to encourage faster growth of larger diameter trees, and create gaps in the canopy to encourage faster growth of larger diameter trees and understory regeneration (Bancroft & Zielke 2002). Riparian forest restoration treatments were centered around "stump refugia" to encourage the potential of greater understory propagation from seed sources on stumps. To mimic old growth gap sizes, we planned our treatment to remove 1- 10 trees around each stump (Lertzman et al., 1996). Trees were selected to be cut based on species (hemlock over spruce), size (co-dominant and suppressed over dominant), extent of crown cover directly over the stump (higher cover over lower), feasibility (whether the tree could be felled without damaging important features such as snags, stumps and non-target trees), and safety during falling.

The goal of the treatment was to create a range of canopy openness over each stump by removing up to 100% of the trees surrounding that stump, which was usually between 1-10 of the trees included in the prism sweeps around each stump. This was planned by felling a number of trees appropriate to four categories at each stump: Category 1 removed 1 to 24% of trees, Category 2 removed 25 to 49% of trees, Category 3 removed 50 to 74% of trees, and Category 4 removed 75 to 100%. We managed to include a consistent number of plots within each category, with the exception of Category 1. The number of plots in each category are as follows: Category 1, N= 2; Category 2, N= 6; Category 3, N= 7; Category 4, N= 5. See Figure 3.1. A few of the treatments that were planned for Category 1 ended up in Category 2, 25-49%, since additional trees were taken in the falling process. From a total of 218 trees within the treated areas, 112 were cut. The mean DBH of cut trees was 47.7cm (SD= 16.5), whereas the mean DBH of trees left standing was 54.4cm (SD= 21.2).

Research Design

The research design was guided by the goal for the riparian forest treatments to provide large woody debris for the creation of in-stream structures. In this way, no additional material needed to be brought in for in-stream structures, and wood did not need to be moved a large distance. Therefore, each riparian forest treatment transect was located perpendicular to a planned in-stream treatment location (as prescribed by Ray 2010). At three in-stream restoration locations (100m, 300m, and 380m from tidal influence), 30m wide by 100m long treatment transects (.30ha) were set-up perpendicular to the stream (Fig. 2.1). Within this area, only stumps 20m apart, starting from the first encountered, were included for sampling. Preliminary research suggests that 20m maintains statistical independence for canopy light (Roburn 2003). Control transects were located in between treatment transects, with a minimum of 100m distance between any two transects (Fig. 2.1).

A total of 16 stumps within three treatment transects (T) and 16 stumps within four control transects (C) were selected for sampling. Stumps were chosen that had a flat top, indicating that they had been logged, were tall enough that deer could not reach them (approximately 1.5m), and were less than or equal to 5m in height (stumps taller than 5m could not safely be sampled).

At each stump, in both the treatment areas and control areas, I gathered data on forest structure and light environment for the stump and two associated ground plots (see Chapter 2 for details on stump characteristics, vegetation and exclosure data, methodology, analysis and results). Sampling was conducted at three time periods: before the restoration treatments in June of 2010 (pre-treatment), immediately after restoration treatments in August 2010 (post-treatment) and then one-year after restoration treatments in June 2011 (one-year-post). The post-treatment measurements in 2010 describe the affect of structural manipulations on forest structure and light, whereas the one-year-post treatment measurements in 2011 describe the affect of wind on forest structure and light.

Fieldwork and data collection

Forest structure data

Forest structure was quantified by measuring the stand volume (basal area (BA); m3/ha) and stand density (stems per hectare (SPH); stems/ha). BA was measured using prism-based variable radius plots (BC Ministry of Forests 2010) 2m away from both the north and south side of the stump, which were averaged for one stump plot measurement, as well as in the center of each ground plot. A sample sweep of the area indicated that a Basal Area Factor (BAF) of 10m^2/ha would include between 6-10 trees. Therefore I used a *BAF* of 10m^2/ha across all plots to avoid the bias that occurs when a *BAF* is selected at the sampling point (Watts & Tolland 2005). We measured diameter at breast height (DBH) for all trees in the stump plots, however did not take DBH measurements in ground plots due to lack of sampling time. Therefore, SPH could only be calculated for the stump plots, not the ground plots. SPH was calculated in the lab (see below in Data Analysis for calculation).

Light environment data

I measured light environment using hemispherical canopy photography (HCP). I used a Sigma 8mm F3.5 fisheye lens and a Canon 5D digital SLR to take canopy photographs. Hemispherical canopy photography (HCP) is an effective method for estimating canopy openness and understory light variables due to its usefulness and accuracy in estimating canopy light in the understory (Lieffers et al. 1999; Machado & Reich, 1999; Brown 2000; Breda 2003; Clark and Murphy 2011). It is the most precise at estimating canopy openness (Brown et al. 2000; Keane et al. 2005; Leblanc et al. 2005).

I took canopy photos in the center of each stump and ground plot. Where vegetation was sparse, I took photos at one height (stump at 30cm above stump edge, ground at 150cm (+/-2cm)). Where the vegetation was profuse (only on stumps), I took photos under the shrub layer (30cm), and above (70cm, +/-2cm). All analysis herein used photos taken above shrub cover.

Vegetation Data

I collected vegetation data at each plot (both ground plots and the top substrate of the stump) including: a species list; percent cover (tree seedlings under 5m tall, shrubs, ferns, herbs and mosses); and heights for individual plants (tree seedlings under 5m tall, shrubs, and ferns, and herbs). We tagged individuals with a basal diameter greater than one centimetre and recorded the dimensions of the individual including: basal diameter; height to crown; crown height; width; and length.

Data Analysis

Forest structure

I described forest structure using basal area and stand density (stems/ha). Basal area in m^2/ha is calculated as the basal area factor (BAF) multiplied by the number of trees counted within the variable radius plot:

BA= *BAF**(# of trees "in")* (Watts & Tolland 2005)

The average number of trees "in" per plot across all plots was 7.46 (SD= 2.54, N= 107) pre-treatment (range: 2 trees (N=2) to 16 trees (N= 1)).

Stems per hectare (SPH) requires a DBH measurement for calculation. Therefore SPH was only calculated for Stump plots. Each tree in a stump plot represents a number of trees per hectare. The number of trees per hectare represented by each tree was calculated as:

$$TF_t = \frac{BAF}{ba_t} = \frac{BAF * 40{,}000}{\pi * dbh_t^2}$$ (Watts & Tolland 2005)

Where:

TF_t = the stems per hectare represented by tree *t* (each "in" tree in *BAF* sweep);
ba_t = the basal area of tree *t* in m^2;
dbh_t = is the diameter at breast height for tree *t* in cm.

This is then summed over all "in" trees to find the plot SPH.

I tested for differences in mean BA and mean SPH among different plot types using the Tukey-Kramer HSD (honestly significant difference) test with JMP Version 9.0 (Tukey 1953; Kramer 1956). Comparisons were tested among every combination of the following plot types:

- control transects pre-treatment (C-pre)
- control treatments post treatment (C-post),
- control treatments one-year post treatment (C-yrpost),
- treatment transects pre-treatment (T-pre),
- treatment transects post treatment (T-post),
- treatment transects one-year post treatment (T-yrpost),

Light environment

I used Gap Light Analyzer Version 2 (GLA 2.0) (Frazer et al. 1999; Frazer et al. 2000b) to estimate light transmission for each plot before and after treatment. Total transmitted photosynthetic active radiation is calculated by GLA as the sum of direct radiation (neither scattered nor absorbed by atmosphere), and diffuse radiation (scattered by the atmosphere; Frazer et al. 1999).

GLA allows the researcher to enter site specific configurations for more accurate analysis. Site specific data was generated for elevation, latitude, longitude, spectral fraction, beam fraction, growing season, and cloudiness index. These last two variables were developed jointly using expert advice (Dr. K. Lertzman, A. MacKinnon, J. Pojar, G. Frazer, I. Giesbrecht) and local climate normals for degree days above 5°C and frost free period (MIEDS 2011; Wang et al. 2006). When provided with monthly estimates of these variables, GLA provides accurate light transmission estimates in areas with seasonally variable climate (Frazer et al. 2000a). The cloudiness index was created by I. Giesbrecht (2010). Calibration of the lens is necessary for accurate GLA analysis (Frazer et al. 1999). I used a calibration which was previously defined and successfully employed for this lens (Giesbrecht 2010).

GLA uses manual thresholding to delineate sky and non-sky. While processing the photos, I followed methodology from Roburn (2003) and Giesbrecht (2010) to maintain consistency and reduce human error or bias. I used regional thresholding, a tool of GLA, to make sure that foliage against bright sky was not washed out, and small gaps near the horizon were not filled in.

Following the initial analysis, I re-processed a number of photos taken in 2011 to assess my variability and accuracy in processing. The photos I chose to re-process were outliers that did not seem consistent with the dataset. The sky conditions were not ideal (very sunny) in outlier photos and had sun spots obscuring some vegetation. For re-processing, I used the 2010 photos as a baseline for exposure and consistent vegetation, such as tree trunks and branches that had not changed.

I tested for differences in mean percent Full Sun (FS), mean percent canopy openness (CO), and Leaf Area Index (LAI) among different plot types using the Tukey-Kramer HSD (honestly significant difference) test with JMP Version 9.0 (Tukey 1953; Kramer 1956). Comparisons were tested among every combination of the following plot types:

- control transects pre-treatment (C-pre)

- control treatments post treatment (C-post),
- control treatments one-year post treatment (C-yrpost),
- treatment transects pre-treatment (T-pre),
- treatment transects post treatment (T-post),
- treatment transects one-year post treatment (T-yrpost),
- small mammal grids (SM) as a pre-treatment control comparison,
- Windy Bay old growth (OG) as an old growth comparison,

The small mammal grids are a second research project happening as part of the restoration project. I took canopy photos in these grids as a secondary comparison for pre-treatment controls, to ensure accuracy of pre-treatment baseline conditions. Also, the Windy Bay old growth photo points were laid out with the same design as the small mammal grids in Sandy Creek, so comparability between designs had to be examined. If there had been a different trend in small mammal grids, Windy Bay old growth photos would have been compared to only small mammal grid photos. There was no difference between small mammal grids and C-pre, therefore Windy Bay old growth was compared to all data. Standard deviations for percent full sun were also compared among pre-treatment, post-treatment, one-year-post treatments and old growth.

Forest structure and light

I created a lattice plot in R to visually examine any trends in the data. From this I deciphered a negative trend in the relationship of structure to light in the treatment transects due to the structural manipulations. This verified that effect was due to treatment and not transect or time effects. Therefore, I examined the relationships of forest structure variables (BS and SPH) and light (FS and CO) with all plots combined (treatment and control transects with pre, post and yrpost measurements) in order to evaluate the effect of structure on light along the continuum of light environment provided by these plot types. Further, since BA and light data were collected for ground plots and stumps, I averaged these values for each plot to avoid pseudoreplication in the regression analysis.

I tested the relationship between forest structure variables and light environment using non-linear regression in JMP Version 9.0. Multiple sources in the literature cite a significant, negative, non-linear relationship between forest structure variables and light

(Poulin et al. 2000a; Drever & Letzman 2003; Clark & Murphy 2011). The analysis was performed using a simple negative non-linear model of exponential decay:

$$Y = a * e^{(-b*x)} + \varepsilon$$

where *a* and *b* are the model parameters, and ε is an error term.

We verified assumptions of this model by looking at residuals plotted against predicted values to determine it was normal relationship, had constant variance and was curvilinear.

Vegetation and light

I used pre-treatment data to explore if there was a relationship between percent cover of shrubs on stumps and light. I summed percent cover of all shrub species on stumps. I used a square-root transformation to normalize percent shrub cover data. I examined the relationship between percent cover of both FS and CO using both a linear and non-linear regression in JMP Version 9.0. The non-linear model used was quadratic polynomial.

Results

Forest Structure

In total, we created 16 gaps of various sizes across 0.9ha. Each of the three treatment transects was 0.3ha in size and 4-7 gap openings of 1-10 trees were made in each transect.

Forest structure pre-treatment

Before treatment, the overall average Basal Area (BA) throughout Sandy Creek in control transects (C) and treatment transects (T) was 76.12m^2/ha (SD= 21.04). There was no significant difference in BA between control (C-pre) and treatment (T-pre) transects ($BA_{C\text{-}pre}$: $\bar{x}$ = 71.77m^2/ha, SE= 3.49, N= 16; $BA_{T\text{-}pre}$: $\bar{x}$ = 79.96m^2/ha, SE= 6.03, N= 18; Tukey Kramer HSD, p-value= 0.7726, Table 3.1, Fig. 3.2).

The overall average stand density (SPH) throughout Sandy Creek in control transects and treatment transects was 488stems/ha (SD= 174.56). There was no significant difference in SPH between control (C-pre) and treatment (T-pre) transects ($SPH_{C\text{-}pre}$: $\bar{x}$ = 494stems/ha, SE= 46.52, N= 16; $SPH_{T\text{-}pre}$: $\bar{x}$ = 483stems/ha, SE= 39.82, N= 18; Tukey Kramer HSD, p-value= 1.0000, Table 3.2, Fig. 3.3).

Forest structure post-treatment

After treatment, BA remained constant in control treatments from pre-treatment to post-treatment ($BA_{C\text{-}post}$: $\bar{x}$ = 71.77m^2/ha, SE= 3.49, N= 16; p-value= 1.0000). In treatment transects, due to restoration treatments, BA decreased significantly ($BA_{T\text{-}pre}$: $\bar{x}$ = 79.96m^2/ha, SE= 6.03, N= 18; $BA_{T\text{-}post}$: $\bar{x}$ = 48.02m^2/ha, SE= 4.33, N=18; Tukey Kramer HSD, p-value= <0.0001, Table 3.1, Fig. 3.2).

SPH also remained constant in control transects post-treatment ($SPH_{C\text{-}post}$: $\bar{x}$ = 494stems/ha, SE= 46.52, N= 16; p-value= 1.0000). In treatment transects, due to restoration treatments, SPH also decreased significantly ($SPH_{T\text{-}pre}$: $\bar{x}$ = 483stems/ha, SE= 39.82, N= 18; $SPH_{T\text{-}post}$: $\bar{x}$ = 182stems/ha, SE= 41.10, N=54; Tukey Kramer HSD, p-value= <0.0001, Table 3.2, Fig. 3.3).

Forest structure one-year-post

Forest structure did not change as much as expected due to wind events over the year. Basal area in control transects showed a small and insignificant change from post-treatment to one-year-post ($BA_{C\text{-}yrpost}$: $\bar{x}$ = 72.45m^2/ha, SE= 3.35, N=17; Tukey Kramer HSD, p-value= 1.0000; Table 3.1, Fig. 3.2). Treatment transects experienced very small and insignificant change of BA from post-treatment to one-year-post ($BA_{T\text{-}yrpost}$: $\bar{x}$ = 47.83m^2/ha, SE= 4.37, N=18; Tukey Kramer HSD, p-value= 1.0000; Table 3.1, Fig. 3.2).

Stand density (SPH) in control transects also did not change from post-treatment, to one-year-post ($SPH_{C\text{-}yrpost}$: $\bar{x}$ = 494stems/ha, SE= 46.52, N=16; t-test, p-value= 1.000, Table 3.2, Fig. 3.3). SPH in treatment transects also showed a small and insignificant decrease from post-treatment to one-year-post ($SPH_{T\text{-}post}$: $\bar{x}$ = 182stems/ha, SE= 41.10, N=54; $SPH_{T\text{-yrpost}}$: $\bar{x}$ = 179stems/ha, SE= 41.10, N=18; t-test, p-values= 1.0000; Table 3.2, Fig. 3.3).

Although there was no significant change in BA or SPH from post-treatment to one-year-post, there were noticeable impacts from the wind events over the year. A few small snags and trees fell across the plots, many branches came down within the transects (more so in treatment transects), and a number of trees at the mouth of the stream had fallen.

Light Environment

Light environment in Sandy Creek pre-treatment

Before treatment, mean percent Full Sun (FS) was homogeneously low throughout Sandy Creek ($\bar{x}$ = 11.36%, SD= 2.03); there was no significant difference in the light environment in Sandy Creek between control (C-pre) and treatment (T-pre) transects ($FS_{C\text{-pre}}$: $\bar{x}$ = 10.63%, SE= 0.24, N= 45; $FS_{T\text{-pre}}$: $\bar{x}$ = 11.97%, SE= 0.30, N= 54; Tukey Kramer HSD, p-value= 0.2655, Table 3.3, Fig. 3.4). For further consideration of the homogeneity of the canopy conditions in Sandy Creek, we also compared mean percent FS pre-treatment conditions in our control and treatment transects to that in the small mammal (SM) study grids and found no significant difference (FS_{SM}: $\bar{x}$ = 12.19%, SE= 0.41, N= 33; Tukey Kramer HSD, FS_{SM} and $FS_{C\text{-pre}}$: p-value= 0.2363, FS_{SM} and $FS_{T\text{-pre}}$: p-value= 1.00, Table 3.3, Fig. 3.4).

Mean percent Canopy Openness (CO) was 7.84% (SD= 1.23) throughout Sandy Creek pre-treatment (Table 3.4, Fig. 3.5). Mean Leaf Area (LAI) was $3.01 m^2 m^2$ (SD= 0.28; Table 3.5, Fig. 3.6)

Light environment in Sandy Creek post-treatment

After treatment, mean percent FS did not change significantly within control transects ($FS_{C\text{-pre}}$: $\bar{x}$ = 10.63%, SE= 0.24, N= 45; $FS_{C\text{-post}}$: $\bar{x}$ = 10.63%, SE= 0.24, N= 54; Tukey Kramer HSD, p-value= 1.0000, Table 3.3, Fig. 3.4). Within treatment transects, mean percent FS post-treatment was significantly different from pre-treatment conditions ($FS_{T\text{-pre}}$: $\bar{x}$ = 11.97%, SE= 0.30, N= 54; $FS_{T\text{-post}}$: $\bar{x}$ = 17.42%, SE= 0.35, N= 54; p-values= <0.0001, Table 3.3, Fig. 3.4).

After treatment, mean percent CO followed the same trend as FS; it did not change significantly in control transects (p-value= 1.0000), but did change significantly with treatment transects ($CO_{T\text{-}pre}$: $\overline{x}$ = 8.17%, SE= 0.19, N= 54; $CO_{T\text{-}post}$: $\overline{x}$ = 11.79%, SE= 0.22, N= 54; p-values= <0.0001, Table 3.4, Fig. 3.5). Mean LAI also did not change significantly in control transects (1.0000), but changed significantly in treatment transects ($LAI_{T\text{-}pre}$: $\overline{x}$ = 3.00m^2m^2, SE= 0.04, N= 54; $LAI_{T\text{-}post}$: $\overline{x}$ = 2.51, SE= 0.04, N= 54; p-values= <0.0001, Table 3.5, Fig. 3.6).

Light environment in Sandy Creek one-year-post-treatment

One year after treatment, mean percent FS in control transects was significantly different between post-treatment and one-year-post ($FS_{C\text{-}post}$: $\overline{x}$ = 10.63%, SE= 0.24, N= 45; $FS_{C\text{-}yrpost}$: $\overline{x}$ = 12.52%, SE= 0.35, N= 45, p-value= 0.0333, Table 3.3, Fig. 3.4). However, there was no significant difference in treatment transects between post-treatment and one-year-post ($FS_{T\text{-}post}$: $\overline{x}$ = 17.42%, SE= 0.35, N= 54; $FS_{T\text{-}yrpost}$: $\overline{x}$ = 17.24%, SE= 0.52, N= 54; p-value= 1.0000, Table 3.3, Fig. 3.4). There remained a significant difference between control and treatment transects one-year-post ($FS_{C\text{-}yrpost}$: $\overline{x}$ = 12.52%, SE= 0.35, N= 45; $FS_{T\text{-}yrpost}$: $\overline{x}$ = 17.24%, SE= 0.52, N= 54; p-value= <0.0001; Table 3.3, Fig. 3.4).

Mean percent CO was not significantly different between post-treatment and one-year-post in control transects (p-value= 0.0656) or in treatment transects (p-value= 0.9937; Table 3.4, Fig. 3.5). Mean LAI did change significantly in control transects (p-value= 0.0231), but not in treatment transects (0.9999; Table 3.5, Fig. 3.6).

Light environment in Sandy Creek compared to Windy Bay old growth

The overall light environment (mean percent FS) in Sandy Creek pre-treatment (in control transects, treatment transects and small mammal grids) was significantly different from the old growth (OG) light conditions found in Windy Bay (FS_{OG}: $\overline{x}$ = 16.18%, SE= 0.92, N= 32; p-values= <0.0001, Table 3.3, Fig. 3.4). Standard deviations of pre-treatment transects were low ($FS_{C\text{-}pre}$: SD= 1.61, $FS_{T\text{-}pre}$: SD= 2.16, FS_{SM}: SD= 2.35). Mean percent CO was significantly different from OG throughout Sandy Creek pre-treatment (control transects, treatment transects and small mammal study grids; p-values= <0.0001, Table 3.4, Fig. 3.5). LAI followed the same trend (p-values=<0.0001,Table 3.5, Fig. 3.6).

The light environment (mean percent FS) in Sandy Creek post-treatment and one-year-post (in treatment transects) was no longer significantly different from the Windy Bay old growth comparison (FS_{OG} and $FS_{T\text{-}post}$: p-value= 0.5095; FS_{OG} and $FS_{T\text{-}yrpost}$: p-value= 0.7011, Table 3.3, Fig. 3.4). The standard deviation for treatment transects post-treatment is higher than pre-treatment ($FS_{T\text{-}post}$: SD= 2.59) and one-year-post standard deviation is higher yet ($FS_{T\text{-}yrpost}$: SD= 3.81). Although means are not significantly different between post-treatment and one-year-post, the increase of SD indicates a growing spread of values, becoming closer to that of old growth as measured in Windy Bay (FS_{OG}: SD= 5.20). Mean percent CO was no longer significantly different from OG post-treatment (p-value= 0.4061), and was still not significantly different from OG one-year-post (p-value= 0.8392; Table 3.4, Fig. 3.5). Mean LAI was also not significantly different from OG post-treatment (p-value= 0.9964), nor one-year-post (p-value= 1.000; Table 3.5, Fig. 3.6).

Forest Structure and Light Environment

The hypothesis that light increases with decreasing basal area is supported by the data. There was a significant linear relationship between basal area and percent full sun (r^2= 0.22, p-value=<0.0001). Fitting a non-linear regression model appeared to correctly model the data as seen in Figure 3.7. The non-linear analysis shows a slightly better fit as it has smaller values for the sum of squares error (SSE) and root mean square error (RMSE; FS Linear model: SSE= 994.88, RMSE= 3.15, Y= 18.45 – 0.08X; FS Non-linear model: SSE= 890.18, RMSE= 3.00; $Y = 29.02\, e^{(-0.05X)} + 11.65$; Fig. 3.7A). There seems to be an inflection point between approximately 40- 50m^2/ha.

Mean percent canopy openness showed a slightly stronger relationship with basal area (r^2= 0.25, p-value=<0.0001). Again, the non-linear analysis shows a slightly better fit as it has smaller values for the sum of squares error (SSE) and root mean square error (RMSE; CO Linear model: SSE= 370.71, RMSE= 1.93, Y= 12.56 – 0.05X; CO Non-linear model: SSE= 312.91, RMSE= 1.78; $Y = 25.21\, e^{(-0.06X)} + 8.07$; Fig. 3.7B). The inflection point is at the same place.

The hypothesis that understory light increases with decreasing stems per hectare is supported by the data. There was a significant linear relationship between stems per hectare and light, and although it is a slightly stronger relationship than basal area, still relatively weak (r^2=0.31, p-value= <0.0001). The non-linear analysis shows a slightly better fit, again due to a smaller SSE and RMSE (FS Linear model: SSE= 882.96, RMSE= 2.97; Y= 16.81 – 0.01X; FS Non-linear model: SSE= 800.97, RMSE= 2.84; Y= 7.90 $e^{(-0.003X)}$+10.53; Fig. 3.8A). There seems to be an inflection point between approximately 200- 400stems/ha.

Mean percent canopy openness showed a slightly stronger relationship with stand density (r^2= 0.33, p-value=<0.0001). Again, the non-linear analysis shows a slightly better fit as it has smaller values for the sum of squares error (SSE) and root mean square error (RMSE; CO Linear model: SSE= 334.96, RMSE= 1.83, Y= 11.34 – 0.01X; CO Non-linear model: SSE= 298.50, RMSE= 1.74; Y= 5.07 $e^{(-0.003X)}$+7.40; Fig. 3.8B). The inflection point is at the same place.

Light Environment and Vegetation

The data show a relationship between percent shrub cover on stumps and mean percent canopy openness (CO) in both the linear and non-linear analysis. The non-linear analysis for CO shows a slightly better fit than the linear analysis, due to a smaller SSE and RMSE, however both are very similar (CO Linear model: : r^2= 0.30, p-value= 0.0013, SSE= 83.03, RMSE= 1.66, Y = -5.14 + 0.94X; CO Non-linear model: r^2= 0.33, p-value= 0.0031, SSE= 79.09, RMSE= 1.65; $Y = -5.31 + 0.93X + 0.20(X\text{-}7.86)^2$; Fig. 3.9A).

The data also show a relationship between percent shrub cover on stumps and mean percent full sun (FS) in both the linear and non-linear analysis. In this case, the linear analysis is a slightly better fit, but only very slightly (FS Linear model: : r^2= 0.36, p-value= 0.0003; SSE= 74.98, RMSE= 1.58, Y= -4.89 + 0.64X; FS Non-linear model: r^2= 0.36, p-value= 0.0014, SSE= 74.98, RMSE= 1.61; Y= -4.89 + 0.64X - 0.0003$(X\text{-}11.08)^2$; Fig. 3.9B).

Discussion

Treatment

We targeted a range of openness treatments, rather than following a standard thinning procedure. This technique was well suited to the stand and follows recommendations to mimic old growth gap sizes (Lertzman et al. 1996; Deal 2007). It was more difficult than expected to achieve Category 1 plots and only open the canopy a small amount (1 to 24% of trees in stump plot) due to the dense, Sitka spruce canopy.

Basal area and stems per hectare decreased significantly in treatment transects. Current literature on riparian restoration states that stems per hectare ranging between 150- 800 is desirable (Bancroft & Zielke 2002). Our final measurement in treatment transects one-year-post treatment was on the low side of this spectrum, at 179 stems/ha (SD= 174). Still, an assessment of our treatments one year after the restoration recommended that the gaps could have been bigger (Muise 2011).

Since we reduced density in clusters, the stand now has greater heterogeneity, increasing the possibility for diversity. This follows our understanding of the high heterogeneity of old growth forests; vertical and horizontal structural spatial patterns are more diverse (Franklin et al. 2002), old growth canopies are open, and more heterogeneous in their openness (Frazer et al. 2000a), and heterogeneity of the light environment creates niches for different species (Giesbrecht 2010). The variability present in these aspects of old growth forests can be seen higher interquartile ranges of forest structure and light. Although we reduced BA and SPH to a mean more similar to old growth, the spread of data in our treated plots is much less than that of old growth.

Wind is known to be a driving factor for stand dynamics in the north coast (Nowacki & Kramer 1998; Kramer et al. 2001; DeGayner et al. 2005), and we did experience a number of severe wind events in the winter between “post” and “one-year post” treatment. We expected to see greater change in the forest structure of Sandy Creek between post-treatment and one-year-post due to wind. In the winter between our two field seasons, Gwaii Haanas experienced a number of severe wind events. Nearby islands experienced major blowdown. However, despite this major windstorm over the winter, there were no significant differences in BA and density in our transects between post-treatment and one-year-post samples. In fact, it is interesting, with such a severe wind event, and the magnitude of wind damage in nearby stands that we saw very little impact of the storm on the study stands. Even partial harvesting in this type of stand is often believed to be associated with subsequent windthrow. We did see visual evidence of wind effects in the stand such as downed trees at the mouth of the stream, and many downed small snags and branches throughout the stand. We expect the major wind effect was within the canopy layer via the loss of branches, and therefore was not apparent in measures of BA or SPH. It was, however, captured in the light measurements (see below). Wind storm effects are strongly influenced by topography (Harcombe et al. 2004; Kramer et al Alaksa). Although Gwaii Haanas experienced many wind events throughout the winter, Sandy Creek was mostly sheltered from the dominant wind directions.

Light Environment

Light environment in the understory was successfully increased due to restoration. Means of percent full sun and canopy openness increased significantly after restoration and were not significantly different from old growth. The mean of percent full sun pre-treatment (11.97%) increased to a mean very similar to old growth (17.24% vs. old growth: 16.18%). Alternatively, the mean percent full sun in a restoration project in Spirit Creek, Vancouver Island, BC, changed from 16% to 30% (Hutchinson 2011). It is known that canopy closure can occur after treatment, both from infilling by adjacent canopies and release of saplings in the understory, and may decrease the light environment again (Beaudet & Messier 2002). Creating larger openings could be more effective in the long run, since released conifers may soon close the gaps created by restoration. However, unknown variables such as wind need to be taken into consideration.

Most interestingly, the spread of data, or variability, also changed similar to old growth conditions. The results show that we created a range of light from 8.54- 27.74% full sun in the one-year-post treatment transects, no longer significantly different from the Windy Bay old growth comparison, which has a range of light from 9.97- 30.18% full sun. The Windy Bay old growth benchmark is comparable to recent research for two coastal temperate old growth Sitka spruce floodplain forests. The light environment of these two forests ranges between 9.5- 34% full sun for the Kitlope stand and 5.7- 30% full sun for the Carmanah stand (Giesbrecht 2010). Canopy openness increased and leaf area decreased similar to old growth benchmarks described by Frazer et al. (2000a).

Standard deviations of mean percent full sun also provide noteworthy results. Compared to the standard deviation of Windy Bay old growth (5.20%), the standard deviation in Sandy Creek changed from 1.60% in pre-treatment controls to 2.59% in post-treatment and 3.81% in one-year-post treatment transects. A greater standard deviation of percent full sun, representing a greater spread of the data, or more variability in the light environment, is consistent with our understanding of inherent heterogeneity in old growth characteristics, including light (Franklin et al. 2002; Giesbrecht 2010). For example, the Windy Bay old growth standard deviation is comparable to standard deviations of percent full sun in the old growth forests of the Kitlope (4.8%) and Carmanah Valley (5.0%) as measured by Giesbrecht (2010). The increase in standard deviation for one-year post treatment transects is most likely due to the wind events throughout the winter.

Forest Structure and Light Relationship

Our results illustrate a relationship between forest structure variables and light, best fit by a non-linear relationship. The relationship for SPH and light is stronger than that of BA. It could be suggested that this is difference is due to our treatments, which preferentially cut trees with smaller DBH, thus impacting the change of SPH more than BA. The non-linear regression between SPH and light shows a weak inflection point between approximately 200- 400stems/ha. This corresponds with other studies' findings. Drever and Lertzman (2003) illustrate an inflection point for stand density at approximately 400 stems/ha.

The weakness of the relationship between forest structure variables and light may be due to a number of factors. The fact that the light environment increased over the winter, yet forest structure variables remained constant may be due to the wind events which the site experienced throughout the winter. There was evidence of wind disturbance, including blowdown near the mouth of the stream, and many branches and small snags had fallen on the exclosures. Canopy structure, such as variability in crown structure, can influence understory light environment (Lhotka & Lowoenstein 2006; Schindler et al. 2011). A combination of more forest structure variables would better capture these canopy changes. Values also could have varied depending on the where the gap opening occurred in relation to the sampling point. Furthermore, Haida Gwaii may have a higher DBH to forest age ratio than other coastal forests and this may affect canopy dynamics or comparative structural measures. Lastly, limitations in the data such as small sample sizes and high variability may have caused a lack of power in predicting a relationship.

Other research that has found a stronger relationship between forest structure and light either used different variables to quantify both forest structure and light or had a larger sample size. Clark and Murphy (2011) examined the use of hemispherical photography measurements for estimating forest biomass and found a significant correlation with light, however they focused on crown and branch biomass, rather than BA and SPH. A stronger relationship was found in Drever and Lertzman (2003) with respect to DBH, BA, SPH and volume compared to percent full sun. However, their sample size was larger (N=70).

Estimated Future Vegetation Response

Preliminary analysis shows a relationship between percent shrub cover on stumps and both percent CO and FS. More research is needed to further analyze these relationships. The dynamics of light over stand development likely contributed to the vegetation developing under a different light regime that is no longer evident. Alternatively, confounding relationships could have been more limiting than light, for example, the characteristics of the stump itself, such as decay, species, height or surface area. However preliminary analysis suggests these relationships are insignificant (see Chapter 2). A larger sample size of stumps with a greater variation of percent shrub cover, and percent CO and FS, would provide greater power to resolve this. Since Sandy Creek was strongly homogeneous in all of these characteristics, expanding the study to other watersheds with greater variation would be useful.

It is generally accepted that the diversity of understory vegetation is affected by various overstory characteristics (Alaback & Herman 1988; Tappeiner & Alaback 1989; Brosofske et al. 2001), and that the decline in understory development after canopy closure is related to both basal area and percentage of canopy cover (Alaback 1982; Alaback & Herman 1988; Hanley & Brady 1997; Deal 2001). Kerns and Ohmann (2004) found a negative relationship between shrub cover and basal area in coastal Oregon forests, and used tree models to provide thresholds for predicting shifts in shrub cover. Furthermore, research shows that not only light availability, but also soil moisture content, and throughfall precipitation made available by canopy openings, increases understory biomass (Anderson et al. 1969). Literature shows that ground vegetation cover can indicate recovery of old growth conditions (Alaback 1982; Gerzon 2009). A relationship of this nature would be interesting for managers to understand the vegetation effects of restoration in Sandy Creek. However, due to the effect of deer browse, vegetation will not be able to fill this indicator role, nor show the same relationship as other ecosystems.

This paper does not examine the response of ground vegetation due to canopy opening treatments due to the short time period of the study. Chapter 2 explores growth in exclosures over the one year time period. Perhaps in the future, if exclosures are maintained, we will be able to detect difference in vegetation, distinguishing treatment effect from browse effect. At the present time, we can merely make some educated guesses that understory in all exclosures will thrive more than in open ground plots, and those in treated areas may thrive more than those in control areas.

Management Implications

This research shows that the methodology employed in Sandy Creek successfully created a range understory light conditions similar to old growth conditions. Second growth floodplain spruce forests do not typically reflect the habitat diversity expressed in old growth on similar sites. The light regime in Sandy Creek before restoration illustrates this homogeneity.

Creating gaps of the magnitude we did shifts the light regime in these second growth forests to one which is more similar to nearby old growth and we expect, in the absence of overwhelming herbivory, that this would be reflected in understory plant diversity and productivity. Managers who wish to undertake restoration of second growth floodplain spruce forests so that they provide habitats more similar to the mix in old growth should consider gap creation, but should ensure that gaps are large enough to make a meaningful difference in light regime. In our study, this was reached by a reduction in stem density to around 200-400sph.

More research is needed in a number of areas. First, research is needed to ascertain how this stem density is reflected in actual gap sizes. Second, it would be worthwhile to re-analyze the vegetation and light environment in Sandy Creek in the future to monitor the changes over time. Lastly, these suggested studies as well as the ongoing studies in the area could be effectively integrated to enhance the outcomes of the overall riparian restoration project and efficiency of resource use.

Conclusion

The restoration successfully created a range of openness treatments surrounding stumps. We experienced difficulty in creating smaller canopy gaps, due to the challenge of falling in this type of stand (dense Sitka spruce). However, BA and SPH both were reduced to levels recommended by the literature, and FS increased post treatment due to the restoration and increased in standard deviation one-year post restoration due to wind events. Treatment transects were no longer significantly different in mean FS from old growth conditions after restoration. Furthermore, the standard deviation grew from post to one-year post treatment due to the wind events over the year, becoming more similar to the range of light environments available in our old growth reference condition.

This study investigated the effect of a riparian restoration project on canopy light in Haida Gwaii, British Columbia. There is currently limited published literature investigating this relationship, quantitatively, for this ecosystem. Studies have described old growth canopy conditions, which serve a valuable comparison and benchmark for restoration projects such as this, yet still leave a gap in knowledge of how to achieve this. Other studies have described similar riparian restoration projects. None, however, have focused on a second growth Sitka spruce dominated floodplain ecosystem type. Since this ecosystem type is essential for many salmon bearing streams along the Central and North Coasts of British Columbia, and since so much of this ecosystem type has been logged, it is extremely important that we start documenting restoration attempts and their outcomes to be able to be increasingly effective in these endeavours.

Tables and Figures

Tables

Table 3.1. ***Comparison of basal area for control (C) and treatment (T) transects, pre-treatment (-pre), post-treatment (-post), and one-year-post (-yrpost).***
A. Descriptive statistic results for the Tukey Kramer HSD test (N= sample size).
B. Matrix of p-values from Tukey Kramer HSD means comparisons.

A.

Plot Type	Correlation*		N	Mean	Std Error**	Lower 95%	Upper 95%
C-pre	A		46	71.41	3.08	65.20	77.62
C-post	A		46	71.41	3.08	65.20	77.62
C-yrpost	A		46	71.41	3.08	65.20	77.62
T-pre	A		54	79.96	4.03	71.87	88.06
T-post		B	54	48.02	3.22	41.55	54.48
T-yrpost		B	54	47.83	3.24	41.33	54.34

* Levels not connected by same letter are significantly different.
** Std Error uses a pooled estimate of error variance

B.

	C-pre	C-post	C-yrpost	T-pre	T-post	T-yrpost
C-pre	-	1.000	1.000	0.4697	**<.0001***	**<.0001***
C-post	1.000	-	1.000	0.4697	**<.0001***	**<.0001***
C-yrpost	1.000	1.000	-	0.4697	**<.0001***	**<.0001***
T-pre	0.4697	0.4697	0.4697	-	**<.0001***	**<.0001***
T-post	**<.0001***	**<.0001***	**<.0001***	**<.0001***	-	1.000
T-yrpost	**<.0001***	**<.0001***	**<.0001***	**<.0001***	1.000	-

*Note – p-values in bold are significant

Table 3.2. ***Comparison of stems per hectare in control (C) and treatment (T) transects, pre-treatment (-pre), post-treatment (-post), and one-year-post (-yrpost).***
A. Descriptive statistic results for the Tukey Kramer HSD test (N= sample size).
B. Matrix of p-values from Tukey Kramer HSD means comparisons

A.

Plot Type	Correlation*		Number	Mean	Std Error**	Lower 95%	Upper 95%
C-pre	A		16	494	46.52	395	593
C-post	A		16	494	46.52	395	593
C-yrpost	A		16	494	46.52	395	593
T-pre	A		18	483	39.82	399	567
T-post		B	18	182	41.10	95	268
T-yrpost		B	18	179	41.10	92	265

* Levels not connected by same letter are significantly different.
** Std Error uses a pooled estimate of error variance

B.

	C-pre	C-post	C-yrpost	T-pre	T-post	T-yrpost
C-pre	-	1.000	1.000	1.000	**<.0001***	**<.0001***
C-post	1.000	-	1.000	1.000	**<.0001***	**<.0001***
C-yrpost	1.000	1.000	-	1.000	**<.0001***	**<.0001***
T-pre	1.000	1.000	1.000	-	**<.0001***	**<.0001***
T-post	**<.0001***	**<.0001***	**<.0001***	**<.0001***	-	1.000
T-yrpost	**<.0001***	**<.0001***	**<.0001***	**<.0001***	1.000	-

*Note – p-values in bold are significant

Table 3.3. ***Mean percent full sun in control (C) and treatment (T) transects, pre-treatment (-pre), post-treatment (-post), and one-year-post (-yrpost). Also included are small mammal study grids (SM), used as comparison for pre-treatment conditions, and Windy Bay old growth (OG).***
A. Descriptive statistic results for the Tukey Kramer HSD test (N= sample size).
B. Matrix of p-values from Tukey Kramer HSD means comparisons.

A.

Plot Type	Correlation*			Number	Mean	Std Dev	Std Error**	Lower 95%	Upper 95%
SM	A	B		33	12.20	2.35	0.41	11.36	13.03
C-pre	A			46	10.63	1.60	0.24	10.16	11.11
C-post	A			46	10.63	1.60	0.24	10.16	11.11
C-yrpost		B		46	12.52	2.39	0.35	11.81	13.27
T-pre	A	B		54	11.97	2.17	0.30	11.38	12.57
T-post			C	54	17.42	2.59	0.35	16.71	18.13
T-yrpost			C	54	17.24	3.81	0.52	16.20	18.28
OG			C	32	16.18	5.20	0.92	14.31	18.06

* Levels not connected by same letter are significantly different.
** Std Error uses a pooled estimate of error variance

B.

	SM	C-pre	C-post	C-yrpost	T-pre	T-post	T-yrpost	OG
SM	-	0.2363	0.2363	0.9997	1.0000	**<.0001***	**<.0001***	**<.0001***
C-pre	0.2363	-	1.000	**0.0333***	0.2655	**<.0001***	**<.0001***	**<.0001***
C-post	0.2363	1.000	-	**0.0333***	0.2655	**<.0001***	**<.0001***	**<.0001***
C-yrpost	0.9997	**0.0333***	**0.0333***	-	0.9803	**<.0001***	**<.0001***	**<.0001***
T-pre	1.0000	0.2655	0.2655	0.9803	-	**<.0001***	**<.0001***	**<.0001***
T-post	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	-	1.000	0.5095
T-yrpost	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	1.000	-	0.7011
OG	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	0.5095	0.7011	-

*Note – p-values in bold are significant

Table 3.4. ***Mean percent Canopy Openness in control (C) and treatment (T) transects, pre-treatment (-pre), post-treatment (-post), and one-year-post (-yrpost). Also included are small mammal study grids (SM), used as comparison for pre-treatment conditions, and Windy Bay old growth (OG).***
A. Descriptive statistic results for the Tukey Kramer HSD test (N= sample size).
B. Matrix of p-values from Tukey Kramer HSD means comparisons.

A.

Level	Correlation*			Number	Mean	Std Dev	Std Error**	Lower 95%	Upper 95%
SM		B		33	7.90	1.49	0.26	7.37	8.43
C-pre	A			46	7.47	0.90	0.13	7.20	7.74
C-post	A			46	7.47	0.90	0.13	7.20	7.74
C-yrpost	A	B		46	8.50	1.20	0.18	8.14	8.85
T-pre	A			54	8.17	1.39	0.19	7.79	8.55
T-post			C	54	11.79	1.60	0.22	11.35	12.23
T-yrpost			C	54	11.54	2.47	0.34	10.86	12.21
OG			C	32	11.00	2.64	0.47	10.05	11.96

* Levels not connected by same letter are significantly different.
** Std Error uses a pooled estimate of error variance

B.

	SM	C-pre	C-post	C-yrpost	T-pre	T-post	T-yrpost	OG
SM	-	0.9508	0.9508	0.7665	0.9959	**<.0001***	**<.0001***	**<.0001***
C-pre	0.9508	-	1.000	0.0656	0.4243	**<.0001***	**<.0001***	**<.0001***
C-post	0.9508	1.000	-	0.0656	0.4243	**<.0001***	**<.0001***	**<.0001***
C-yrpost	0.7665	0.0656	0.0656	-	0.9771	**<.0001***	**<.0001***	**<.0001***
T-pre	0.9959	0.4243	0.4243	0.9771	-	**<.0001***	**<.0001***	**<.0001***
T-post	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	-	0.9937	0.4061
T-yrpost	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	0.9937	-	0.8392
OG	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	0.4061	0.8392	-

*Note – p-values are significant

Table 3.5. Mean percent Leaf Area in control (C) and treatment (T) transects, pre-treatment (-pre), post-treatment (-post), and one-year-post (-yrpost). Also included are small mammal study grids (SM), used as comparison for pre-treatment conditions, and Windy Bay old growth (OG).
A. Descriptive statistic results for the Tukey Kramer HSD test (N= sample size).
B. Matrix of p-values from Tukey Kramer HSD means comparisons.

A.

Plot Type	Correlation*		Number	Mean	Std Dev	Std Error**	Lower 95%	Upper 95%
SM	A		33	2.95	0.26	0.05	2.86	3.04
C-pre	A		46	3.02	0.25	0.04	2.94	3.09
C-post	A		46	3.02	0.25	0.04	2.94	3.09
C-yrpost	A		46	2.81	0.24	0.04	2.74	2.88
T-pre	A		54	3.00	0.31	0.04	2.92	3.09
T-post		B	54	2.51	0.28	0.04	2.43	2.58
T-yrpost		B	54	2.53	0.37	0.05	2.43	2.63
OG		B	32	2.55	0.37	0.07	2.42	2.69

* Levels not connected by same letter are significantly different.
** Std Error uses a pooled estimate of error variance

B.

	SM	C-pre	C-post	C-yrpost	T-pre	T-post	T-yrpost	OG
SM	-	0.9689	0.9689	0.4930	0.9896	**<.0001***	**<.0001***	**<.0001***
C-pre	0.9689	-	1.000	**0.0231***	1.000	**<.0001***	**<.0001***	**<.0001***
C-post	0.9689	1.000	-	**0.0231***	1.000	**<.0001***	**<.0001***	**<.0001***
C-yrpost	0.4930	**0.0231***	**0.0231***	-	**0.0321***	**<.0001***	**<.0001***	**<.0001***
T-pre	0.9896	1.000	1.000	**0.0321***	-	**<.0001***	**<.0001***	**<.0001***
T-post	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	-	0.9999	0.9964
T-yrpost	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	0.9999	-	1.000
OG	**<.0001***	**<.0001***	**<.0001***	**<.0001***	**<.0001***	0.9964	1.000	-

*Note – p-values are significant

Figures

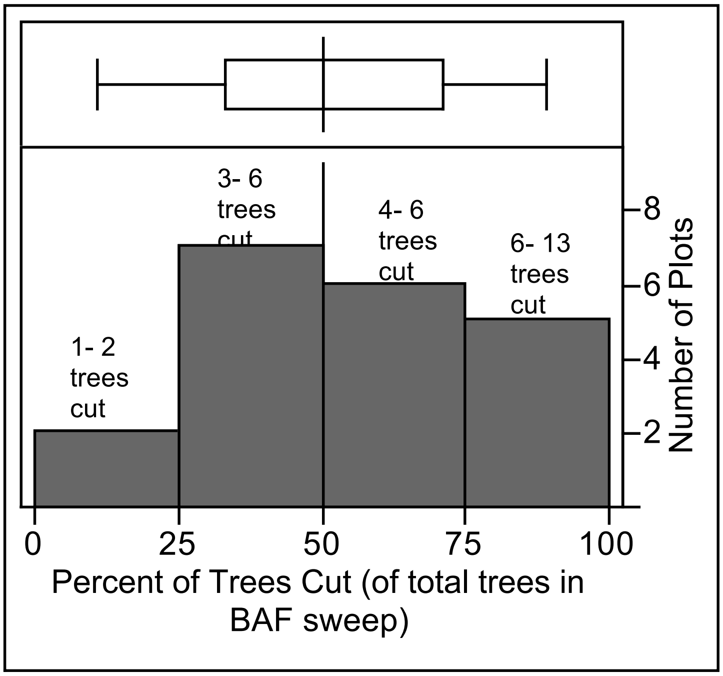


Figure 3.1. Percent of Trees Cut vs. Number of Plots.

Histogram bars represent categories of treatment. For example, the bar on the far left in the histogram represents all plots that had 0 – 25% of its trees counted in the BAF sweep cut. There were two plots in this category. The numbers on the top of the bar represent the minimum and maximum number of trees cut in those plots. The box plot on top shows the sample distribution. The left and right ends of the box are the 25th and 75th quantiles. The line in the middle represents the median sample value. Any point that lies outside the outside lines, or 'whiskers', may be considered possible outliers.

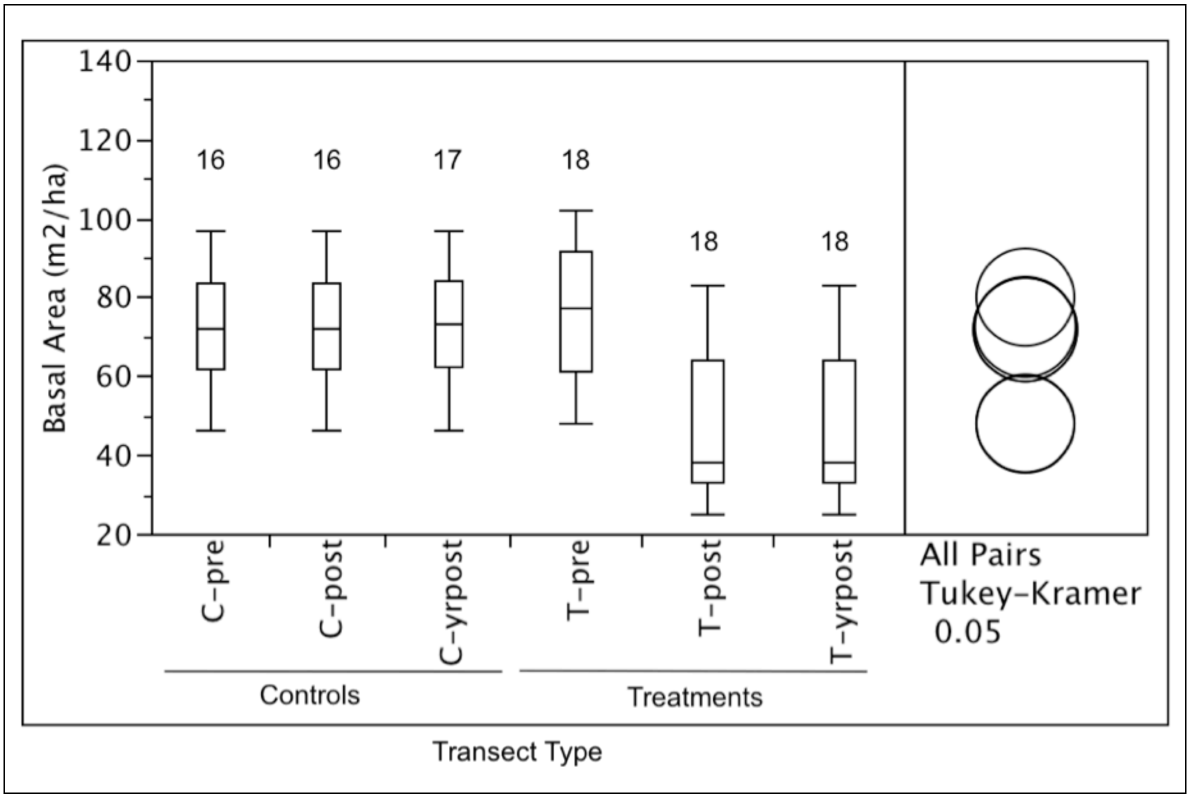


Figure 3.2. Basal Area (BA) pre-treatment, post-treatment, and one-year-post in control and treatment transects.

I used Tukey-Kramer HSD to compare the means of basal area pre-treatment, post-treatment and one-year-post across control and treatment transects. The circles illustrate the comparison of means tests; the closer the circles are together, the more similar the groups are. If the outside edge of the circles intersect by an angle more than 90 degrees or are nested, the means are not significantly different. If the outside edge of the circles either do not intersect or slightly intersect so that the outside angel of intersection is less than 90 degrees, the means are significantly different. For example, the bottom circle identifies basal area in treatment transects post-treatment and one-year-post as significantly different from control transects pre-treatment, post-treatment and one-year-post, as well as from treatment transects pre-treatment. Please refer to Figure 2.4 for boxplot details, and Table 3.1 for test results (means, standard errors, p-values).

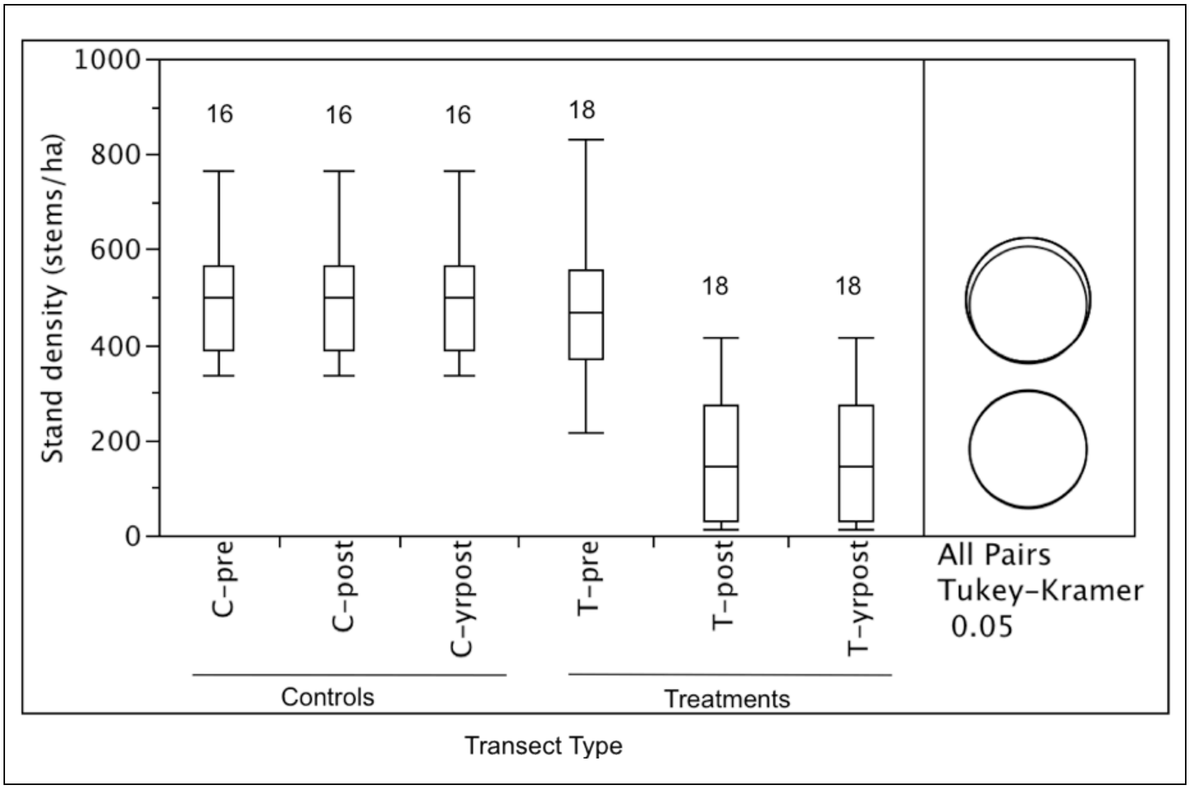


Figure 3.3. Stand density (stems/ha) pre-treatment, post-treatment, and one-year-post in control and treatment transects.

I used Tukey-Kramer HSD to compare the means of SPH pre-treatment, post-treatment and one-year-post across control and treatment transects. Please refer to Fig 3.2 for details on how to read comparison circles. For this graph, the bottom circle identifies SPH in treatment transects post-treatment and one-year-post as significantly different from control transects pre-treatment, post-treatment and one-year-post, as well as from treatment transects pre-treatment. Please refer to Figure 2.4 for boxplot details, and Table 3.2 for test results (means, standard errors, p-values).

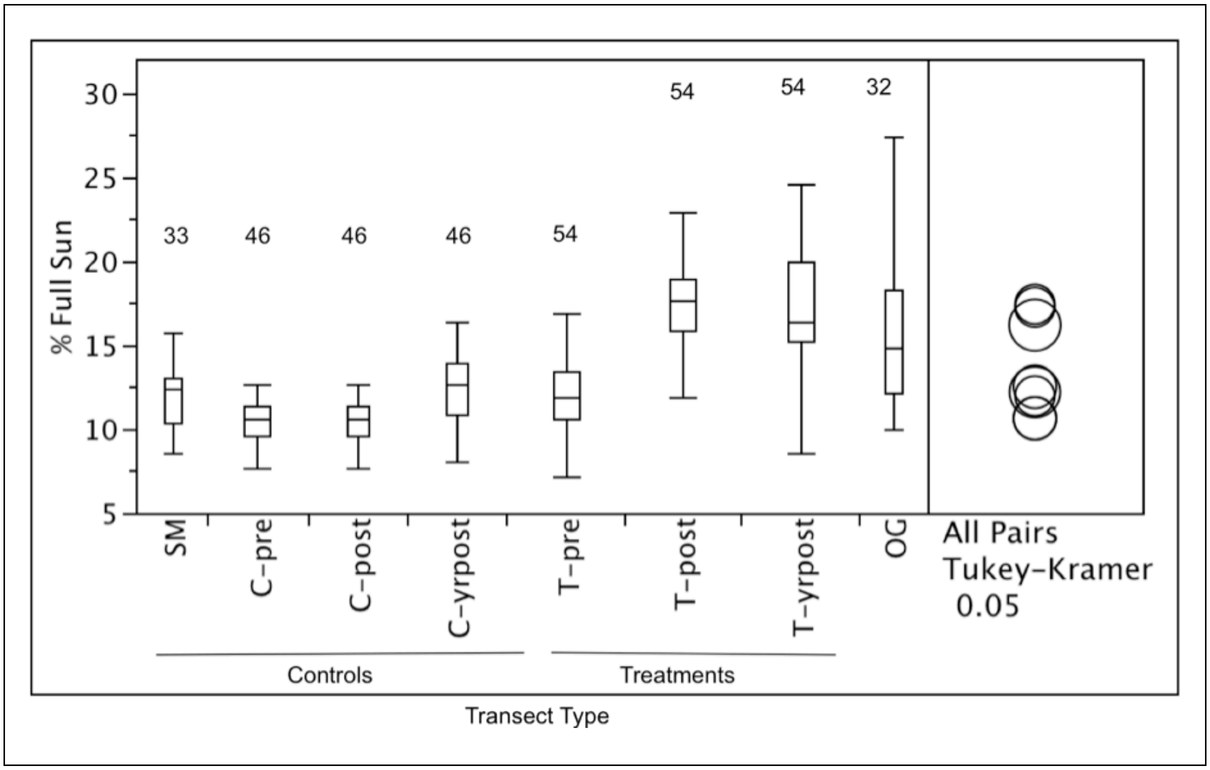


Figure 3.4. Percent Full Sun (%FS) in pre-treatment, post-treatment, and one-year-post conditions in control and treatment transects, compared to the small mammal grids pre restoration (SM), and the old growth stand in Windy Bay (OG).

I used Tukey-Kramer HSD to compare the means of %FS pre-treatment, post-treatment and one-year-post across control and treatment transects. Please refer to Fig 3.2 for details on how to read comparison circles. For this graph, the top cluster of circles identifies %FS in treatment transects post-treatment and one-year-post as well as old growth as significantly different from control transects pre-treatment, post-treatment and one-year-post, as well as from treatment transects pre-treatment. Please refer to Figure 2.4 for boxplot details, and Table 3.3 for test results (means, standard errors, p-values).

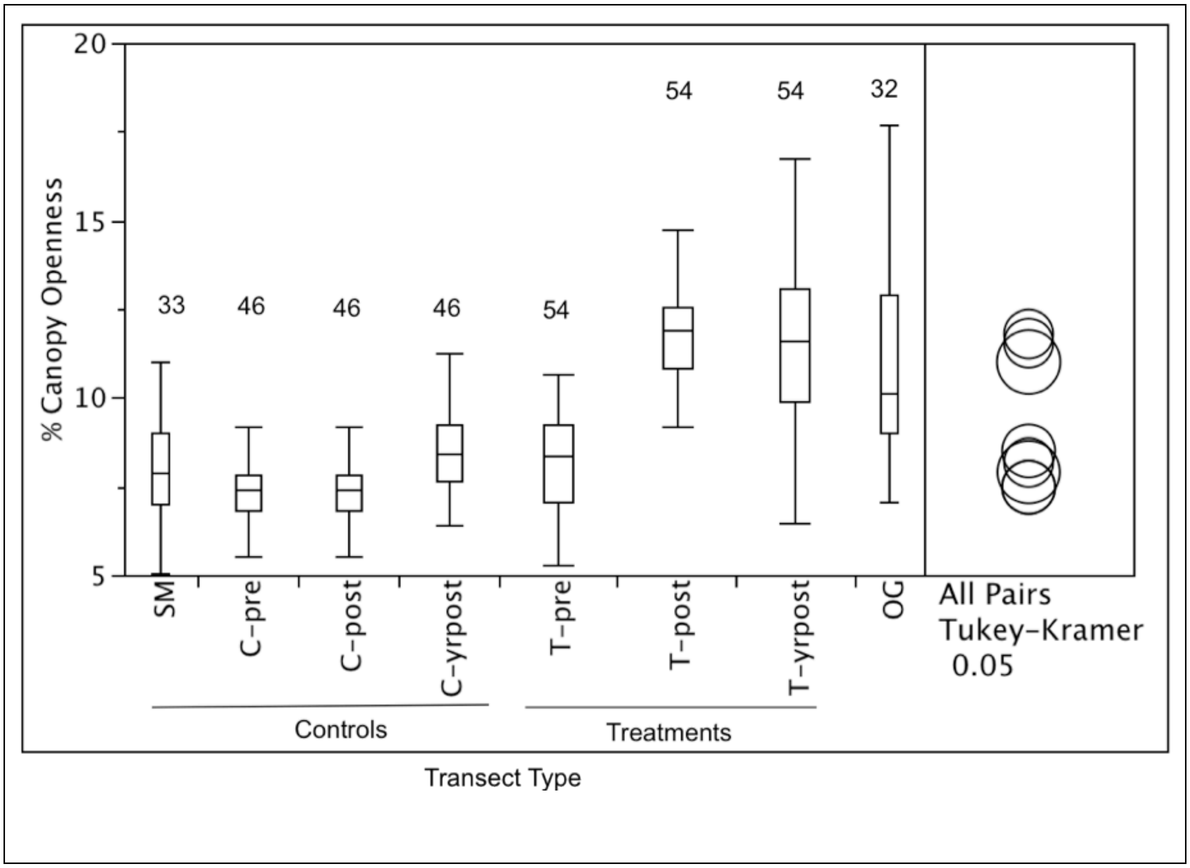


Figure 3.5. Percent Canopy Openness (%CO) in pre-treatment, post-treatment, and one-year-post conditions in control and treatment transects, compared to the small mammal grids pre-treatment (SM), and the old growth stand in Windy Bay (OG).

I used Tukey-Kramer HSD to compare the means of %CO pre-treatment, post-treatment and one-year-post across control and treatment transects. Please refer to Fig 3.2 for details on how to read comparison circles. For this graph, the top cluster of circles identifies %CO in treatment transects post-treatment and one-year-post as well as old growth as significantly different from control transects pre-treatment, post-treatment and one-year-post, as well as from treatment transects pre-treatment. Please refer to Figure 2.4 for boxplot details, and Table 3.4 for test results (means, standard errors, p-values).

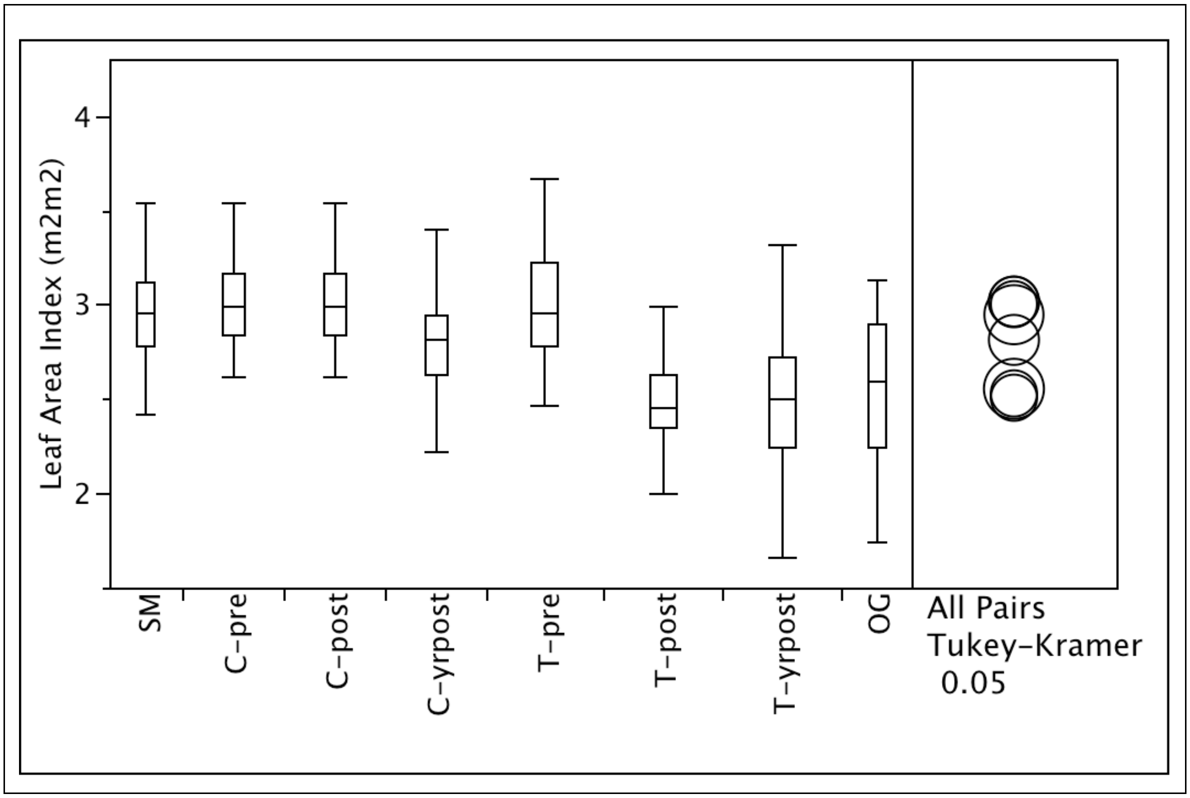
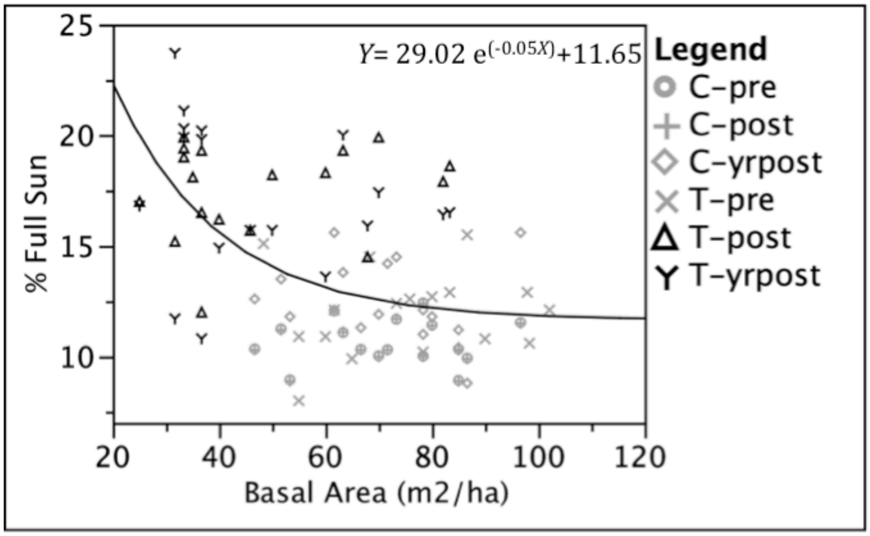


Figure 3.6. Leaf Area Index (LAI) in pre-treatment, post-treatment, and one-year-post conditions in control and treatment transects, compared to the small mammal grids pre-treatment (SM), and the old growth stand in Windy Bay (OG).

I used Tukey-Kramer HSD to compare the means of LAI pre-treatment, post-treatment and one-year-post across control and treatment transects. Please refer to Fig 3.2 for details on how to read comparison circles. For this graph, the bottom cluster of circles identifies LAI in treatment transects post-treatment and one-year-post as well as old growth as significantly different from control transects pre-treatment, post-treatment and one-year-post, as well as from treatment transects pre-treatment. Please refer to Figure 2.4 for boxplot details, and Table 3.5 for test results (means, standard errors, p-values).

A.



B.

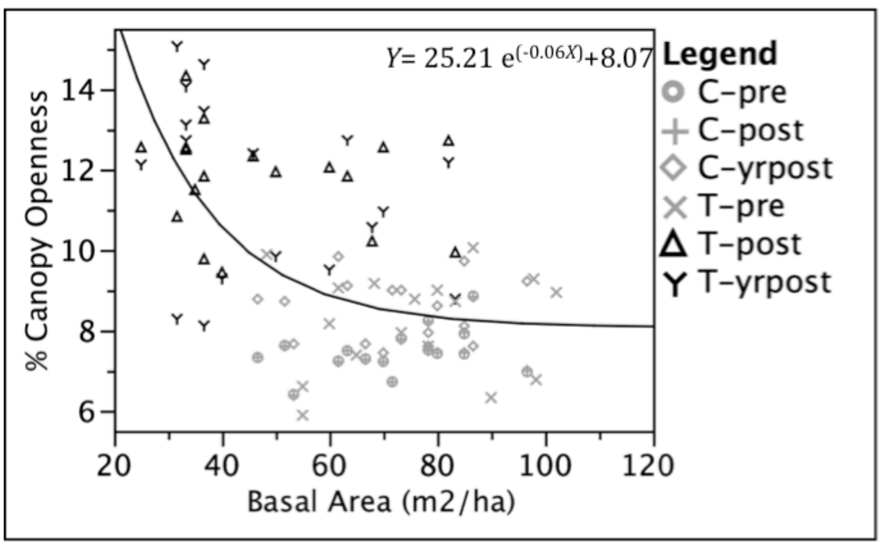


Figure 3.7. Non-linear regression between A. percent Full Sun (%FS) and basal area (BA), and B. percent Canopy Openness (%CO) and BA.

The black 'Y' and 'Δ' signify the treatment transect post and one-year post treatment. Treated plots are generally clustered in the top left corner. BA, FS, and CO data are averaged among each stump and its associated ground plots.

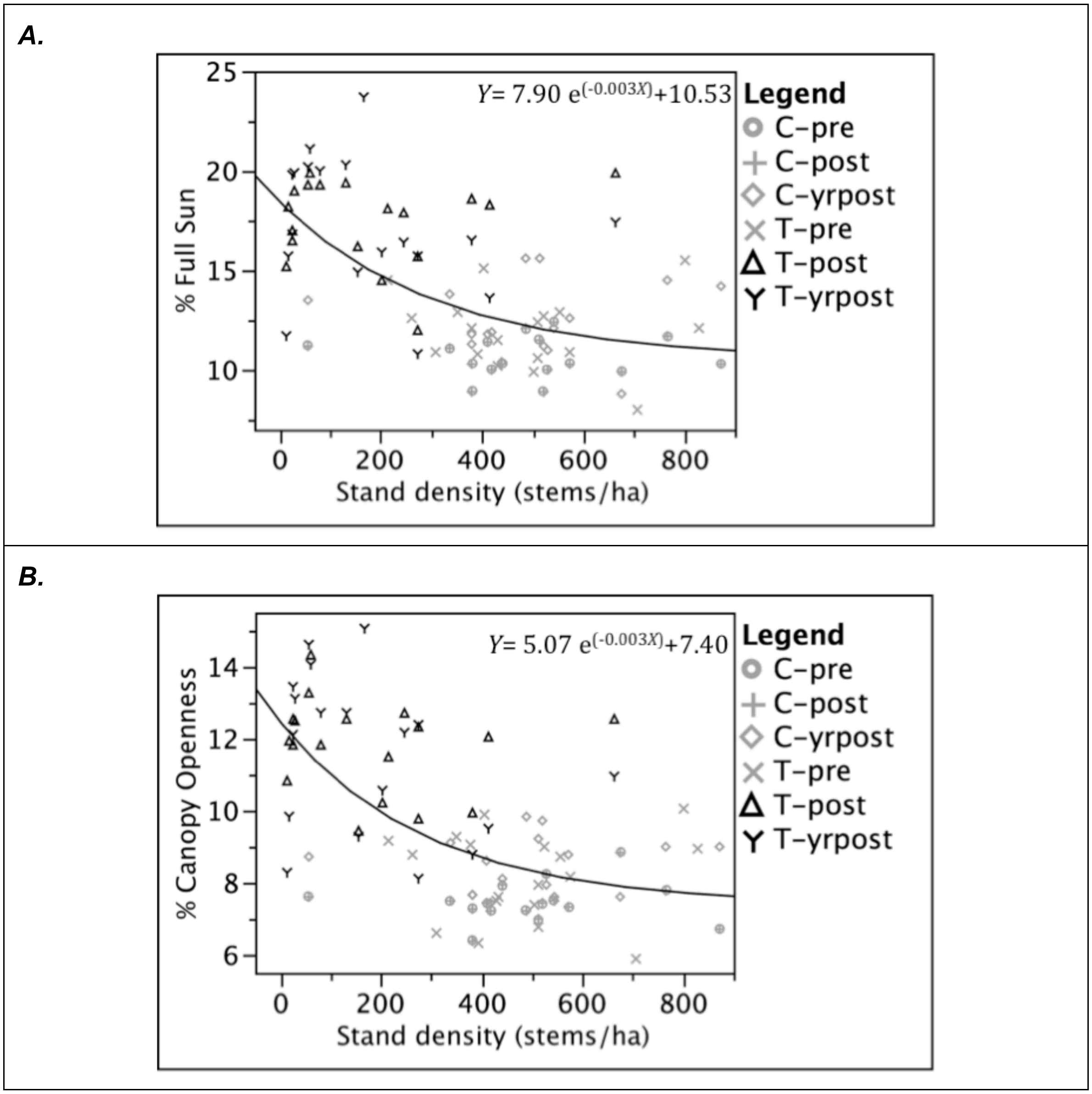
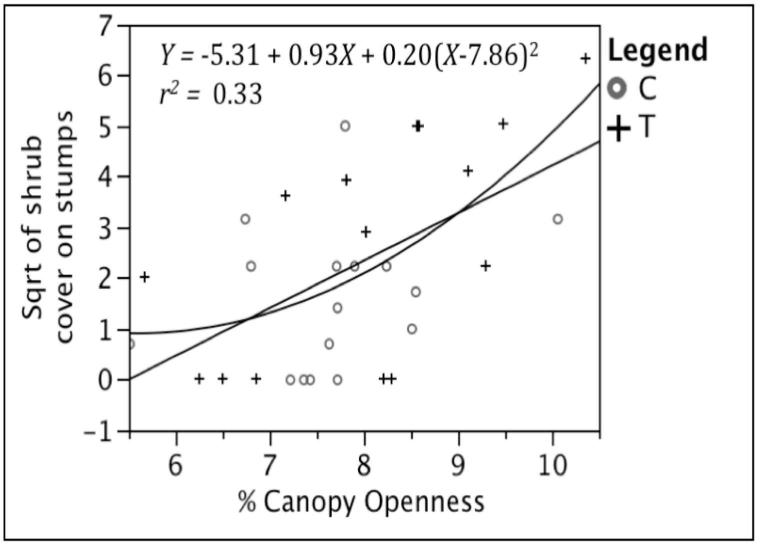


Figure 3.8. Non-linear regression between percent A. Full Sun (%FS) and stand density (SPH), and B. Canopy Openness (%CO) and SPH.

The black triangle and 'Y' signify the treatment transect post and one-year post treatment. Treated plots are generally clustered in the top left corner. SPH and % Full Sun data are from stump plots only, not ground plots.

A.



B.

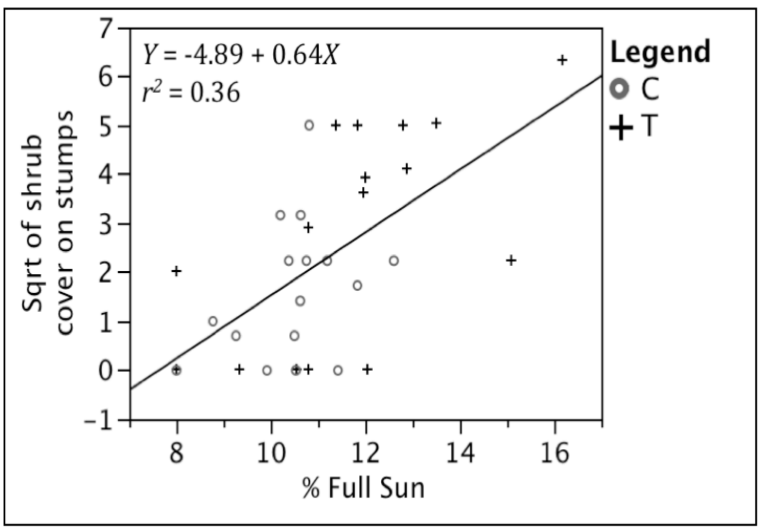


Figure 3.9. ***Relationship between percent stump shrub cover A. percent Canopy Openness (CO), and B. percent Full Sun (FS).***

The grey circle represents control transects and the black cross represents treatment transects, however all data is from 2010 pre-treatment. CO is best fit by the non-linear polynomial, whereas FS is best fit with a linear model.

References

Abrahamsson, M. 2007. High-stumps and wood living beetles in the Swedish production forest landscape. PhD Thesis, Southern Swedish Forest Research Center, Swedish University of Agricultural Sciences, Alnarp. 34 pp.

Acker, S.A., Harcomb, P.A., Harmon, M.E., Greene, S.E. 2000. Biomass accumulation over the first 150 years in coastal Oregon *Picea- Tsuga* forest. Journal of Vegetation Science 11 (5): 725-738.

Acker, S.A., Gregory, S.V., Lienkaemper, G., McKee, W.A., Swanson, F.J., Miller, S.D. 2003. Composition, complexity and tree mortality in riparian forests in the central Western Cascades of Oregon. Forest Ecology and Management. 173: 293-308.

Alaback, P.B. 1982. Dynamic of understory biomass in Sitka spruce – Western hemlock forests of southeast Alaska. Ecology 63(6): 1932-1948.

Alaback, P.B., Herman, F.R. 1988. Long-term response of understory vegetation to stand density in *Picea- Tsuga* forests. Can. J. For. Res. 18: 1522- 1530.

Alaback, P.B. and G.P. Juday. 1989. Structure and composition of low elevation old-growth forests in research natural areas of southeast Alaska. Natural Areas Journal 9: 27-39.

Anderson, R.C., Loucks, O.L., Swain, A.M. 1969. Herbaceous response to canopy cover, light intensity, and throughfall precipitation in coniferous forests. Ecology 50(2): 255-263.

Arsenault, A. and Bradfield, G.E. 1995. Structural-compositional variation in three age-classes of temperate rainforests in southern coastal British Columbia. Can. J. Bot 73: 54-64.

Arsenault, A. and Goward, T. 2000. Ecological characteristics of inland rainforests. In: Darling, L.M . (editor). Proceedings of the Biology and Management of Species and Habitats At Risk, Kamloops, BC, 15 - 19 Feb. 1999. B.C. Min. Environ., Lands and Parks, Victoria,B.C. and University College of the Cariboo, Kamloops, B.C. Pp. 437-439

Arsenault, A. 2002. Managing Course Woody Debris in British Columbia's Forests: A Cultural Shift for Professional Foresters? USDA Forest Service Gen. Tech. Rep. PSW-GTR-181.

Bailey, J. D., C. Mayrsohn, P. S. Doescher, E. St Pierre, and J. C. Tappeiner. 1998. Understory vegetation in old and young Douglas-fir forests of western Oregon. Forest Ecology and Management 112: 289-302.

Bancroft, B. and K. Zielke. 2002. Guidelines for riparian restoration in British Columbia -- Recommended riparian zone silviculture treatments. Prep. for B.C. Ministry of Forests, Watershed Restoration Program, Victoria, B.C. March 2002. URL: http://www.for.gov.bc.ca/hfp/publications/00077/riparian_guidelines.pdf

Banner, A., and LePage, P. 2008. Long-term recovery of vegetation communities after harvesting in the coastal temperate rainforests of northern British Columbia. Canadian Journal of Forest Research 38: 3098- 3111.

Bartier, P.M., Burles, D.W., Johnston, B., Lee, P., Robinson, C.L.K., Sloan, N.A. (Ed.), Walker, I.J. 2007. Technical Compendium to the 2007 State of the Park Report. Gwaii Haanas National Park Reserve and Haida Heritage Site.

Beaudet, M., Messier, C. 2002. Variation in canopy openness and light transmission following selection cutting in northern hardwood stands: an assessment based on hemispherical photographs. Agricultural and Forest Meteorology 110: 217- 228.

Beaudet, M., Messier, C., Leduc, A. 2004. Understory light profiles in temperate deciduous forest: recovery process following selection cutting. Journal of Ecology 92(2): 328-338.

Bergeron, Y., and Fenton, N.J. 2012. Boreal forests of eastern Canada revisited: old growth, nonfire disturbances, forest succession and biodiversity. Botany 90: 509-523.

Bigley, R.E. and F.U. Deisenhofer. 2006. Implementation Procedures for the Habitat Conservation Plan Riparian Forest Restoration Strategy. DNR Scientific Support Section, Olympia, Washington.

Bilby, W.E. and Ward, J.E. 1991. Characteristics and functions of large woody debris in streams draining ild-growth, clear-cut, and second-growth forests in southwestern Washinton. Can. J. Fish. Aquat. Sci. 48: 2499- 2508.

Bray, R.J. 1956. Gap phase replacement in a maple-basswood forest. Ecology, 37: 598-600.

Brosofsky, K.D., Chen, J., Naimen, R.J., Franklin, J.F. 1997. Harvesting Effects on Microclimatic Gradients from Small Streams to Uplands in Western Washington. Ecological Applications 7(4): 1188- 1200.

Brown, N., Jennings, S., Wheeler, P., Nabe- Nielson, J. 2000. An improved method for the rapid assessment of forest understory light environments. Journal of Applied Ecology 37(6): 1044-1053.

Bunnell, F.L., I. Houde, B. Johnston and E. Wind. 2002. How Dead Trees Sustain Live Organisms in Western Forests. USDA Forest Service Gen. Tech. Rep. PSW-GTR-181.

Calder, J.A and Taylor, R.L 1968. Flora of the Queen Charlotte Islands, Part 1-systematic of the vascular plants. Research Branch, Canada Department of Agriculture, Monograph No. 4, Part 1:659 p. Ottawa, ON.

Canham, C.D., J.S. Denslow, W.J. Platt, J.R. Runkle, T.A. Spies, and P.S. White. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. Can. J. For. Res. 20: 620-631.Chan, S., Mass-Heber, K., and

Chollet, S. 2010. Personal communication. Queen Charlotte City, Haida Gwaii, BC.

Clarke, P.J. 2002. Habitat islands in fire-prone vegetation: do landscape features influence community composition? Journal Of Biogeography, 29(5/6), 677-684.

Clark, J., and Murphy, G. 2011. Estimating forest biomass components with hemispherical photography for Douglas fir stands in northwest Oregon. Can J For Res 41: 1060-1074.

Clayoquot Sound Scientific Panel. 1995. Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practices. Available at: http://www.for.gov.bc.ca/hfd/library/documents/bib12571.pdf

(CIT) Coast Information Team. 2004. Scientific Basis of EBM. Available at: http://www.citbc.org/ebm.html

Collinson, T. unpubl. Light Availability's Effect on Biomass, Height and Abundance of Vaccinium *parvifolium* in an Immature Spruce-Hemlock Forest. Written for: CONS 354: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

Coombs, D.A., Allen, R.B., Forsyth, D.M., Lee, W.G. 2003. Factors preventing the recovery of New Zealand forests following control of invasive deer. Conservation Biology 17(2): 450-459.

Côté, S.D., Rooney, T.P., Tremblay, J.P, Dussault, C., Waller, D.M. 2004. Ecological impacts of deer overabundance. Annual Review of Ecology, Evolution and Systematics 35: p 113 – 147.

Curzon, M.T., Keeton, W.S. 2010. Spatial characteristics of canopy disturbances in riparian old-growth hemlock - northern hardwood forests, Adirondack Mountains, New York, USA. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 40(1): 13-25.

Daniels, L.D., and Gray, R.W. 2006. Disturbance Regimes in Coastal British Columbia. BC Journal of Ecosystems and Management 7(2):44–56.URL: http://www.forrex.org/publications/jem/ISS35/vol7_no2_art6.pdf

Daufresne, T., and J. L. Martin. 1997. Changes in vegetation structure and diversity as a result of browsing by a large herbivore: The impact of introduced black tail deer in the primary forest of Haida Gwaii, British Columbia. Laskeek Bay Res. 7:2–26.

Deal, R.L., 2001. The effects of partial cutting on forest plant communities of western hemlock – Sitka spruce stands in southeast Alaska. Can. J. For. Res.31: 2067-2079.

Deal, R.L. 2007. Management strategies to increase stand structural diversity and enhance biodiversity in coastal rainforests of Alaska. Biological Conservation 137: 520- 532.

DeGayner, E.J., Kramer, M.G., Doerr, J.G., Robertsen, M.J. 2005. Windstorm disturbance effects on forest structure and black bear dens in Southeast Alaska. Ecological Applications 15(4): 1306-1316.

DellaSala, D. (ed). 2010. Temperate and Boreal Rainforests of the World; Ecology and Conservation. Island Press.

De Montigny, L., and de Jong, R. 1998. Effects of Thinning and Fertilizing Mixed Western Hemlock- Sitka Spruce Stands. Ministry of Forests Research Program. Forestry Division Services Branch.

Diamond. J. 1975. The island dilemma: lessons of moden biogeographic studies for the design of natural reserves. Biological Conservation 7: 129-146.

Drever, R., Lertzman, K. 2003. Effects of a wide gradient of retained tree structure on understory light in coastal Douglas- fir forests. Can. J. For. Res 33: 137-146.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management. 61(3): 603-610.

Field, R., and Reynolds, J. 2011. Sea to sky: impacts of residual salmon-derived nutrients on estuarine breeding bird communities. Proceedings of the Royal Society of London B.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Q. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management 155:399-423.

Franklin, J. F. and R. Van Pelt. 2004. Spatial aspects of structural complexity. J. For. April/May: 22-28.

Frazer, G.W., Canham, C.D., and Lertzman, K.P. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Copyright © 1999: Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

Frazer, G.W., J.A. Trofymow, and K.P. Lertzman. 2000a. Canopy openness and leaf area in chronosequences of coastal temperate rainforests. Can. J. For. Res. 30: 239-256.

Frazer, G.W., C.D. Canham, K.P. Lertzman. 2000b. Gap Light Analyzer Version 2.0. Bull. Ecol. Soc. Amer. 81: 191-197.

Frazer, G.W., Fournier, R.A., Trofymow, J.A., and Hall, R.J. 2001. A comparison of digital and film fisheye photography for analysis of forest canopy structure and gap light transmission. Agric. For. Meteorol. 109(4): 249–263.

Fyles, L. unpubl. ReBUTTing Stump Refugia: Assessing Vascular Plant Richness and Cover on Stumps in the Temperate Rainforest. Written for: CONS 343: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

Gaston, A. J., Stockton, S.A., and Smith, J. L. 2006. Species-area relationships and the impact of deer-browse in the complex phytogeography of the Haida Gwaii archipelago (Queen Charlotte Islands), British Columbia. Ecoscience 13:511-522.

Gaston, A.J.; Golumbia, T.E.; Martin, J.-L.; Sharpe, S.T. (eds). 2008. Lessons from the Islands: introduced species and what they tell us about how ecosystems work. Proceedings from the Research Group on Introduced Species 2002 Symposium, Queen Charlotte City, Queen Charlotte Islands, British Columbia. Canadian Wildlife Service, Environment Canada, Ottawa

Gavin, D.G., Brubaker, L.B., Lertzman, K.P. 2003. Holocene fire history of a coastal temperate rainforestbased on soil charcoal radiocarbon dates. Ecology 84(1): p.186-201.

Gerzon, M. 2009. Modelling the recovery of old-growth attributes in coastal western hemlock forests following management and natural disturbances. MSc thesis. University of British Columbia, BC.

Gerzon, M., Seely, B., MacKinnon., A. 2011. The temporal development of old-growth structural attributes in second-growth stands: a chronosequence study in the Coastal Western Hemlock Zone in British Columbia. Canadian Journal of Forest Research 41: p. 1534- 1546.

Giesbrecht, I.J.W. 2010. Understory light and vegetation in two floodplain forests in coastal British Columbia. MRM research project. Simon Fraser University, Burnaby, BC. Report No. 508.

Golumbia, T.E. 1999. Introduced Species Management in Haida Gwaii (Queen Charlotte Islands). Proc. Biology and Management of Species and Habitats at Risk, Kamloops, B.C., 15-19 Feb. 1999.

Golumbia, T.E. 2007. Terrestrial Plant Communities and Ecosystems of Gwaii Haanas National Park Reserve and Haida Heritage Site- Report 047. Parks Canada Technical Reports in Ecosystem Science.

Gowgaia Institute, 2007. Forest Economy Trends and Economic Conditions on Haida Gwaii. Accessed on March 8, 2010 at URL: http://www.spruceroots.org/Booklets/ForTrends.pdf

Green, R.H., and Klinka, K. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. British Columbia Ministry of Forests, Research Branch, Victoria, BC. 285p.

Gregory, S.V., Swanson, F.J., McKee, W.A., Cummins, K.W. 1991. An ecosystem perspective of riparian zones. Bioscience 41(8): 540-551.

Griffiths, R.P., A.N. Gray, and T.S. Spies. 2010. Soil properties in old-growth Douglas- fir forest gaps in the western Cascade Mountains of Oregon. Northwest Sci. 84: 33-45.

Gwaii Haanas. 2008. Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay (Lyell Island). Request for Proposal Approval. Management Unit: Gwaii Haanas.

Haida Gwaii Land Use Objectives Order. 2010. Haida Gwaii Land Use Objectives Order, Background. URL: http://ilmbwww.gov.bc.ca/sites/default/files/resources/public/PDF/LRMP/haidaGwaii/168520_HG_LUOO_Signed.pdf

Hanley, T.A. and Hoel, T. 1996. Species composition of old-growth and riparian Sitka-spruce – western hemlock forests in southeastern Alaska. Can. J. For. Res. 26:1703- 1708.

Hanley, T.A., Brady, W.W. 1997. Understory species composition and production in old-growth western hemlock – Sitka spruce forests of southeastern Alaska. Can. J. Bot. 75: 574- 580.

Hannam, K. 2012. The use of stumps for biomass in British Columbia – a problem analysis. Prov. B.C. Victoria, B.C. Tech. Rep. 066. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tro66.htm

Hanson, J.J., Lorimer, C.G., Halpin, C.R., Palik, B.J. 2012. Ecological forestry in an uneven-aged, late-successional forest: Simulated effects of contrasting treatments on structure and yield. Forest Ecology and Management 270: 94-107.

Harcombe, P.A., Greene, S.E., Kramer, M.G., Acker, S.A., Spies, T.A., Valentine, T. 2004. The influence of fire and windthrow dynamics on a coastal spruce-hemlock forest in Oregon, USA, based on aerial photographs spanning 40 years. Forest Ecology and Management 194: 71 – 82.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromak Jr., K.W. Cummins. 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. Advances in Ecological Research 15: pp 133-302.

Hartley, E. unpubl. An exploration of the drivers behind temperate rainforest decomposition regimes. Written for: CONS 343: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

Hobbs, N.T.1996. Modification of ecosystems by ungulates. Journal of Wildlife Management 60(4): 695- 713.

Hobbs R.J., Higgs E., Harris J.A. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24:599-605.

Holmes, D. 2010. Stumping deer: are old-growth stumps providing refugia for understory plants on Haida Gwaii? MFC Research Project. University of Toronto.

Holt, R. 2005. Environmental Conditions Report for the Haida Gwaii/Queen Charlotte Islands Land Use Plan. Veridian Ecological Consulting. URL: http://srmwww.gov.bc.ca/cr/qci/hgqci_env.htm

Holt, R., Price, K., Kremsater, L., MacKinnon, A., Lertzman, K. 2008. Defining old growth and recovering old growth on the coast: a discussion of options. For the Ecosystem Based Management Working Group.

Hilbert, J., Wiensczyk, A. 2007. Old-growth definitions and management: A literature review. BC Journal of Ecosystems and Management 8(1):15–31.

Jackson, L.L., Lopoukhine, N., Hillyard, D. 2006. Ecological Restoration: A Definition and Comments. Restoration Ecology 3(2) p.71-75.

Kanowski, P.J., Williams, K.J.H. 2009. The reality of imagination: Integrating the real and imagined values of old forests. Forest Ecology and Management 258(4):341-346.

Keane, R.E., Reinhardt, E.D., Scott, J., Gray, K., and Reardon, J. 2005. Estimating forest canopy bulk density using six indirect methods. Can. J. For. Res. 35(3): 724–739. doi:10.1139/x04-213.

Kellogg, E.L. (Ed.), 1995. The Rain Forests of Home: An Atlas of People and Place. Ecotrust, Pacific GIS and Conservation International, Portland, OR.

Kennedy, P.G., Quinn, T. 2001. Understory plant establishment on old-growth stumps and the forest floor in western Washington. Forest Ecology and Management 154: 193-200.

Kerns, B.K., Ohmann, J.L. 2004. Evaluation and prediction of shrub cover in coastal Oregon forests (USA). Ecological Indicators 4: 83- 98.

Kramer, C. Y., 1956. Extension of multiple range tests to group means with unequal number of replications. Biometrics. 12, 307{310.

Kramer, M.G., Hansen, A.J., Taper, M.L., Kissinger, E.J. 2001. Abiotic controls on long-term windthrow disturbance and temperate rainforest dynamics in Southeast Alaska. Ecology 82(10): 2749-2768.

Leblanc, S.G., Chen, J.M., Fernandes, R., Deering, D.W., and Conley, A. 2005. Methodology comparison for canopy structure parameters extraction from digital hemispherical photography in boreal forests. Agric. For. Meteorol. 129(3–4): 187–207. doi:10. 1016/j.agrformet.2004.09.006.

Lertzman, K.P., Sutherland, G.D., Inselberg, A., Saunders, S.C. 1996. Canopy gaps and the landscape mosaic in a coastal temperate rainforest. Ecology 77(4): 1254-1270.

Lertzman, K.; Spies, T.A.; Swanson, F.J. 1997. From ecosystem dynamics to ecosystem management. In: Schoonmaker, P.K.; von Hagen, B.; Wolf, E.C., eds. The rain forests of home: portrait of a North American bioregion. Island Press.

Lertzman, K., D. Gavin, D. Hallett, L. Brubaker, D. Lepofsky, and R. Mathewes. 2002. Long-term fire regime estimated from soil charcoal in coastal temperate rainforests. Conservation Ecology 6.

Lertzman, K. 2010. Personal communication. Vancouver, BC.

Lertzman, K., MacKinnon, A. In Press. Why Watersheds: Evaluating the Protection of Undeveloped Watersheds as a Conservation Strategy in Northwestern North America. In: Orians, G.H. and J.W. Schoen (editors). Ecology and Conservation of North Pacific Rainforests. (in press) University of Washington Press, Seattle, WA.

Lhotka, J.M., Loewenstein, E.F. 2006. Indirect measures for characterizing light along a gradient of mixed-hardwood riparian forest canopy structures. Forest Ecology and Management 226: 310-318.

Lieffers, V.J., Messier, C., Stadt, K.J., Gendron, F., Comeau, P.G. 1999. Pridicting and managing light in the understory of boreal forests. Can. J. For. Res. 29: 796-811.

Lienkaemper, G.W., Swanson, F.J. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Can. J. For. Res. 17: 150-156.

Longland, W.S., Bateman, S.L. 2002. The ecological value of shrub islands on disturbed sagebrush rangelands. Journal of Range Management 55(6): 571-575.

Lutz, J.A., Larson, A.J., Swanson, M.E., Freund, J.A. 2012. Ecological Importance of Large-Diameter Trees in a Temperate Mixed-Conifer Forest. PLoS ONE 7(5): e36131. doi:10.1371/journal.pone.0036131

Luxenberg, M. unpubl. The effects of environmental and stump characteristics on bryophyte diversity on mosses. Written for: CONS 343: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

MacArthur, R.H., Wilson, E.O. 1967. The Theory of Island Biogeography. Princeton University Press.

MacKinnon, A., 2003. West coast, temperate, old-growth forests. The Forestry Chronicle 79 (3), 475–484.

Machado, J.L., Reich, P.B. 1999. Evaluation of several measures of canopy openness as predictors of photosynthetic photon flux density in deeply shaded conifer-dominated forest understory. Can. J. For. Res. 29:1438-1444.

Marshall-Hill, E. unpubl. A study of the importance of nurse logs as a substrate to support tree seedling growth in relation to soil substrate and with reference to the presence of mosses and particular vascular plants and deer disturbance heights. Written for: CONS 343: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

Martin, J. L., S. A. Stockton, S. Allombert, and A. J. Gaston. 2010. Top-down and bottom-up consequences of unchecked ungulate browsing on plant and animal diversity in temperate forests: lessons from a deer introduction. Biological Invasions 12:353-371.

Martin, J.L., Arcese, P., Scheerder, N. 2011. Browsing down our natural heritage: Deer impacts on vegetation structure and songbird populations across an island archipelago. Biological Conservation. 144: 459-469.

McCune, B. and J.B. Grace. 2002 Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon.

McCune, B. and M. J. Mefford. 2011. PC-ORD. Multivariate Analysis of Ecological Data.Version 6.0 MjM Software, Gleneden Beach, Oregon, U.S.A.

Meggs, J., Van Schubert, R., Redden, I. in progress. Biodiversity sustainability and woody biomass harvest in British Columbia's forests: A synthesis of current knowledge. EDI Environmental Dynamics Inc. EDI Project #: 11-N-0504

Meidinger, D., and Pojar, J. 1991. Ecosystems of British Columbia. Research Branch, British Columbia Ministry of Forests, Vicotria, B.C.

(MIEDS) Misty Isles Economic Development Society. 2011. Haida Gwaii Agriculture Strategy, Background Document. Queen Charlotte City.

BC Ministry of Forests and Range and British Columbia Ministry of Environment. 2010. Field manual for describing terrestrial ecosystems. 2nd ed. Forest Science Program, Victoria, B.C. Land Manag. Handb. No. 25. British Columbia Ministry of Forests and Range and British Columbia Ministry of Environment.

Muise, S. 2011. Yahgudang dlljuu: a respectful act. Restoring the land and honouring the history of Tllga Kun Gwaayaay – Athlii Gwaii (Lyell Island). Riparian Forest Assessment and Stand Structure Restoration for Identified Creeks. Prepared for: Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site.

Muller, R. (2006) Spacing coastal riparian forests to speed their recovery: Vancouver Island, British Columbia. Accessed on March 10 at URL: http://www.unepwcmc.org/forest/restoration/docs/Vince_Riparian_HR.pdf.

Naiman, R.J., R.E. Bilby, and P.A. Bisson. 2000. Riparian ecology and management in the pacific coastal rain forest. BioScience, 50: 996-1011.

Naiman, R.J., J.S. Bechtold, T.J. Beechie, J.J. Latterell, and R. Van Pelt. 2010. A process-based view of floodplain forest patterns in coastal river valleys of the Pacific Northwest. Ecosystems, 13: 1-31.

Newton, M., R. Willis, J. Walsh, E. Cole, and S. Chan. 1996. Enhancing riparian habitat for fish, wildlife, and timber in managed forests. Weed Technology 10:429-438.

Nowacki, G.J., Kramer, M.G. 1998. The effects of wind disturbance on temperate rainforest structure and dynamics of southeast Alaska. Gen. Tech. Rep. PNW-GTR-421. Portland, Oregon: U.S. Dept of Agriculture, Forest Service, Pacific Northwest Research Station. 25p. Abstract only.

Pabst, R.J. and T.A. Spies. 1998. Distribution of herbs and shrubs in relation to landform and canopy cover in riparian forests in coastal Oregon. Can. J. Bot. 76: 298-315.

Pabst, R.J. and T.A. Spies. 1999. Structure and composition of unmanaged riparian forests in the coastal mountains of Oregon, U.S.A. Can. J. For. Res. 29: 1557-1573.

Pearson, A.F. 2010. Natural and logging disturbances in the temperate rain forests of the Central Coast, British Columbia. Can. J. For. Res. 40: 1970-1984.

Poulin, V.A. and Simmons B. 1999. Restoration of fish habitat and water quality requires riparian silviculture. Forest Renewal BC. Streamline: BC's Watershed Restoration Technical Bulletin. Volume 4, Number 1, pp. 17–19.

Poulin, V.A., Harris, C., Simmons, B. 2000a. Riparian Restoration in British Columbia: What's Happening Now, What's Needed for the Future. For: Ministry of Forests.

Poulin, V.A., Simmons, B., Harris, C. 2000b. Riparian Silviculture: An Annotated Bibliography for Practitioners of Riparian Restoration. For: Ministry of Forests.

Prescott-Allen, R., 2005. Coast Information Team Review Report [online] URL: http://www.citbc.org/c-citreview-jan05.pdf.

R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Ray, D. and Vigneault, L. 2010. Lyell Island Instream Channel Restoration Preliminary Channel Inspection Report. Northwest Hydraulic Consultants. For: Gwaii Haanas National Park Reserve and Haida Heritage Site.

Reimchen, T. E. D. Mathewson, M. D. Hocking, J. Moran and D. Harris. 2003. Isotopic evidence for enrichment of salmon-derived nutrients in vegetation, soil and insects in riparian zones in coastal British Columbia. American Fisheries Society Symposium 34: 59-69

Reimchen, T., E. and A. Byun. 2005. The evolution of endemic species on Haida Gwaii in Haida Gwaii: Human history and environment from the time of Loon to the time of the Iron people (D. Fedje and R. Mathewes, eds). pp 77-95. UBC press.

Roburn, A. 2003. Light transmission and understory vegetation in two old-growth riparian stands: a study in spatial pattern. MRM research project, Simon Fraser University, Burnaby, BC. Report No. 331.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M., and Pess G.R. 2002. A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds, North American Journal of Fisheries Management, 22: 1-20.

Rooney, T.P., Waller, D.M. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. Forest Ecology and Management 181: 165-176.

Rudolphi, J., A. Caruso, M. von Crautlein, S. Laaka-Lindberg, R. Ryoma and H. Berglund. 2011. Relative importance of thinned and clear-cut stands for bryophyte diversity on stumps. For. Ecol. Mgmt. 261: 1911-1918 (abstract only).

Ryland, A., and Thomas, S. 2012. Monitoring riparian restoration to ensure recruitment of large woody debris in Haida Gwaii, British Columbia. The Forestry Chronicle 88(2): 131- 139.

Schindler, D.E., Scheuerell, M.D., Moore, J.W., Gende, S.M., Francis, T.B., Palen, W.J. 2003. Pacific salmon and the ecology of coastal ecosystems. Front Ecol Environ 1(1): 31-37.

Schindler, D., Bauhus, J., Mayer, H. 2011. Wind effects on trees. Eur. J. Forest Res. 131: 159- 163.

Sherlock, A. unpubl. Old- Growth Stumps Providing Refuge for Today's Plants. Written for: CONS 343: Rainforest Ecology, 2012. Haida Gwaii Higher Education Society.

Shoonmaker, P.K., von Hagen, B., Wolf, E.C. (eds). 1997. The Rain Forests of Home: Profile of a North American Bioregion. Island Press.

Smithwick, E.A.H., Harmon, M.E., Remillard, S.M., Acker, S.A., Franklin, J.F. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest

Stevens, V. 1997. The ecological role of coarse woody debris: an overview of the ecological importance of CWD in BC forests. Res. Br., BC Min. For., Victoria, BC. Work. Pap. 30/1997.

Stewart, G.H. 1988. The influence of canopy cover on understory development in forests of the western Cascade Range, Oregon, USA. Vegetation 76: 79-88.

Stroh, N., C. Baltzinger, and J. L. Martin. 2008. Deer prevent western redcedar (Thuya plicata) regeneration in old-growth forests of Haida Gwaii: Is there a potential for recovery? Forest Ecology and Management 255:3973-3979.

Sucre, E.B., Fox, T.R. 2009. Decomposing stumps influence carbon and nitrogen pools and fine-root distribution in soils. Forest Ecology and Management 258: 2242-2248.

Tappeiner, J.C. II; Alaback., P.B. 1989. Early establishment and vegetative growth of understory species in the western hemlock Sitka spruce forests of Southeast Alaska. Can J. Bot. 67:318-326.

Trofymow, J.A. Stinson, G., Kurz, W.A. 2008. Derivation of spatially explicit 86-year retrospective carbon budget for a landscape undergoing conversion from old-growth to managed forests on Vancouver Island, BC. Forest Ecology and Management 256: 1677-1691.

Tukey, J. W., 1953. The problem of multiple comparisons. Unpublished manuscript. Princeton University.

Turner, D.P., Franz, E.H. 1986. The influence of canopy dominants on understory vegetation patterns in an old-growth cedar-hemlock forest. American Midland Naturalist 116(2): 387-393.

Turner, N. 2004. Plants of Haida Gwaii. Winlaw, BC: Sonosis Press.

Van Pelt, R., O'Keefe, T.C., Latterell, J.J., Naiman, R.J. 2006. Riparian forest stand development along the Queets River in Olympic National Park, Washington. Ecological Monographs 76(2): 277-298.

Vasquez, D.P. 2002. Multiple effects of introduced mammalian herbivores in a temperate forest. Biological Invasions 4: 175- 191.

Vila, B., Torre, F., Guibal, F., Martin, J-L. 2004. Can we reconstruct browsing history and how far back? Lessons from Vaccinium parvifolium Smith in Rees. Forest Ecology and Management 201(2-3): 171-185.

Vila, B., Torre, F., Guibal, F., Martin, J-L. 2003. Growth change of young *Picea sitchensis* in response to deer browsing. Forest Ecology and Management 180: 413-424.

Vila, B., Torre, F., Martin, J-L. 2002. Response of young Tsuga heterophylla to deer browsing: developing tools to assess deer impact on forest dynamics. Trees 17: 547-553.

Wang, T., Hamann, A., Spittlehouse, D., and Aitken, S. N. 2006. Development of scale-free climate data for western Canada for use in resource management. International Journal of Climatology, 26(3):383-397.

Watts, S.B., and Tolland, L. (eds). 2005. Forestry Handbook for British Columbia, Fifth Edition. Faculty of Forestry. University of British Columbia.

Wells, R.W., Lertzman, K.P., Saunders, S.C. 1998. Old-Growth Definitions for the Forests of British Columbia, Canada. Natural Areas Journal 18(4): 279-292.

Westland Resource Group. 1994. Ecological land classification of Gwaii Haanas: land classification. Report prepared for Gwaii Haanas National Park Reserve and Haida Heritage Site, Queen Charlotte, B.C. 229 p. + appendices.

Wilson, E.O. 1992. The Diversity of Life. W.W. Norton & Company Inc. New York, N.Y., U.S.A.

Wojtatzek, B. 2010. Personal communication. Haida Gwaii, BC.

Zar, J.H., 1996. Biostatistical Analysis, 3rd Edition, Prentice Hall, New Jersey.

Appendix

Appendix A. Complete Species List

Code	Scientific Name	Common Name	Present in Ground (G), Stump (S), or both (G/S)
SEEDLINGS			
WESTHEM	*Tsuga heterophylla*	Western hemlock	G/S
SITKSPR	*Picea sitchensis*	Sitka spruce	G/S
SHRUBS			
GAULSHA	*Gaultheria shallon*	Salal	S
MENZFER	*Menziesia ferruginea*	False azalea	G/S
RUBU SPE	*Rubus spectabilis*	Salmonberry	G/S
SAMBRAC	*Sambucus racemosa*	Red elderberry	S
VACCALA	*Vaccinium alaskaense*	Alaskan blueberry	S
VACCOVA	*Vaccinium ovalifolium*	Oval-leaved blueberry	S
VACCPAR	*Vaccinium parvifolium*	Red huckleberry	G/S
FERNS			
ATHYFIL	*Athyrium filix-femina*	Lady fern	G
BLECSPI	*Blecnum spicant*	Deer fern	G
DRYOEXP	*Dryopteris expansa*	Spiny wood fern	G/S
POLYGLY	*Polypodium glycyrrhiza*	Licorice fern	S
POLYMUN	*Polystichum munitum*	Sword fern	G
HERBS			
CLAYSIB	*Claytonia siberica*	Siberian miner's lettuce	G
CLINUNI	*Clintonia uniflora*	Queen's cup	G
GALITRI	*Galium triflorum*	Sweet-scented bedstraw	G
LINNBOR	*Linnaea borealis*	Twinflower	G
LIST	*Listera sp.*	Twayblade	G/S
MAIADIL	*Maianthemum dilatatum*	False lily-of-the-valley	S
MONEUNI	*Moneses uniflora*	Single delight	G/S
STACCOO	*Stachys cooleyae*	Cooley's hedge-nettle	G
TIARTRI	*Tiarella trifoliata*	Foamflower	G
VIOLBC	*Viola biflora* ssp. *carlottae*	Queen Charlotte twinflower violet	G
MOSSES			
CLIMDEN	*Climacium dendroides*	Tree moss	
CONOCON	*Conocephalum conicum*	Snake liverwort	
DICR	*Dicranum sp*		
HOOKLUC	*Hookeria lucens*	Clear moss	
HYLOSPL	*Hylocomium splendens*	Step moss	
KINDORE	*Kindbergia oregana*	Oregon Beaked moss	
LYCO	*Lycopodium sp.*	Clubmoss	
PLAGPOR	*Plagiochila porelloides*	Cedar-shake liverwort	
PLAGUND	*Plagiothecium undulatum*	Wavy-leaved Cotton moss	
POLY	*Polytrichum sp*	Haircap moss	
RADUCOM	*Radula complanata*	Flat-leaved liverwort	
RHIZGLA	*Rhizomnium glabrescens*	Fan moss	
RHYTLOR	*Rhytidiadelphus loreus*	Lanky moss	
RICC	*Riccardia sp*	Comb liverwort	
SPHAG	*Sphagnum sp*	Peat moss	