Hardwood Silviculture Cooperative
Annual Report 2022

Oregon State University
College of Forestry

Contents

Hardwood Silviculture Cooperative

Highlights of 2022

- Two Type 2 installations, Clear Lake Hill (#4202) and Ryderwood (#3202) had the 32-year measurement completed.

- Three more 27-year measurements were collected on Type 2 installations, bringing the total to 21 of the 25 installations with 27-year data.

- One more Type 3 installation had the 27th year measurement, bringing the total to 5 of the 7 installations with 27-year data.

- Second-year data was collected on a red alder clone field trial.

- The HSC and the Center for Intensive Planted-forest Silviculture (CIPS) continued another update of RAP-ORGANON.

- The HSC participated in numerous continuing education and outreach events including: Clackamas Co. Tree School, the WA Farm Forestry Association (WFFA) Forest Owners Field Day, and the Washington Hardwood Commission (WHC) Annual Symposium.

History of the HSC

The Hardwood Silviculture Cooperative (HSC) is a multi-faceted research and education program focused on the silviculture of red alder (*Alnus rubra*) and mixes of red alder and Douglas-fir (*Pseudotsuga menziesii*) in the Pacific Northwest. The goal of the HSC is improving the understanding, management, and production of red alder. The activities of the HSC have already resulted in significant gains in understanding of regeneration and stand management, and have highlighted the potential of red alder to contribute to both economic and ecological forest management objectives.

The HSC, begun in 1988, is a combination of industry and both federal and state agency members, each with their own reasons for pursuing red alder management. For instance, some want to grow red alder for high-quality saw logs, while others want to manage red alder as a component of bio-diversity. What members have in common is that they all want to grow red alder to meet their specific objectives. Members invest in many ways to make the HSC a success. They provide direction and funds to administer the Cooperative. They provide the land for research sites and the field crews for planting, thinning, and taking growth measurements.

The HSC's highest priority is to understand the response of red alder to intensive management. To accomplish this, the HSC has installed 26 variable-density plantations extending from Coos Bay, Oregon to Vancouver Island, British Columbia. The majority of plantations are located in the Coast Range, with a few in the Cascade Range. The plantation distribution covers a wide range of geographic conditions and site qualities. At each site, cooperators planted large blocks of red alder at densities of 100, 230, 525, and 1200 trees per acre. Each block is subdivided into several treatment plots covering a range of thinning and pruning options (twelve total treatments per site).

In addition to the 26 variable-density plantations, the HSC has related studies in naturally regenerated stands. Young stands (less than 15 years old) of naturally regenerated red alder, 5 to 10 acres in size, were pursued as a means of short-cutting some of the lag time before meaningful thinning results could be obtained from the variable-density plantations. It came as a surprise to find only four naturally regenerated stands of the right age and size available in the entire Pacific Northwest.

The HSC has also established seven mixed species plantations of red alder and Douglas-fir. They are located on land designated as Douglas-fir site class III or below. Each plantation is planted with 300 trees per acre with five proportions of the two species. The site layout is designed to look at the interactions between the two species. We are finding that in low proportions and when soil nitrogen is limited, red alder may improve the growth of Douglas-fir. This improvement is due to the nitrogen fixing ability of red alder. The management challenge is to find the right proportion of the two species through time to maintain a beneficial relationship.

Since the HSC was established, we have learned a great deal about seed zone transfer, seedling propagation, stocking guidelines, identification of sites appropriate for red alder, and the effects of spacing on early tree growth (see the HSC website http://hsc.forestry.oregonstate.edu for more information). Furthermore, the data set is now complete enough to begin analyzing the growth response of red alder after thinning and/or pruning. Our ultimate goal is a better understanding of the effects of stand density management on red alder growth and yield, and wood quality and to develop red alder growth and yield models.

The HSC red alder stand management studies are well designed and replicated on a scale rarely attempted in forestry. Over the next 10 years, we will harvest much from our investment. Our data set on growth of managed stands will make red alder one of the better-understood forest trees of the Pacific Northwest.

Red Alder Stand Management Study

The Red Alder Stand Management Study is divided into three specific types of installations. Study installations are predominately located in the coastal mountain ranges of the Pacific Northwest from Coos Bay, Oregon to Vancouver Island, British Columbia (Figure 1).

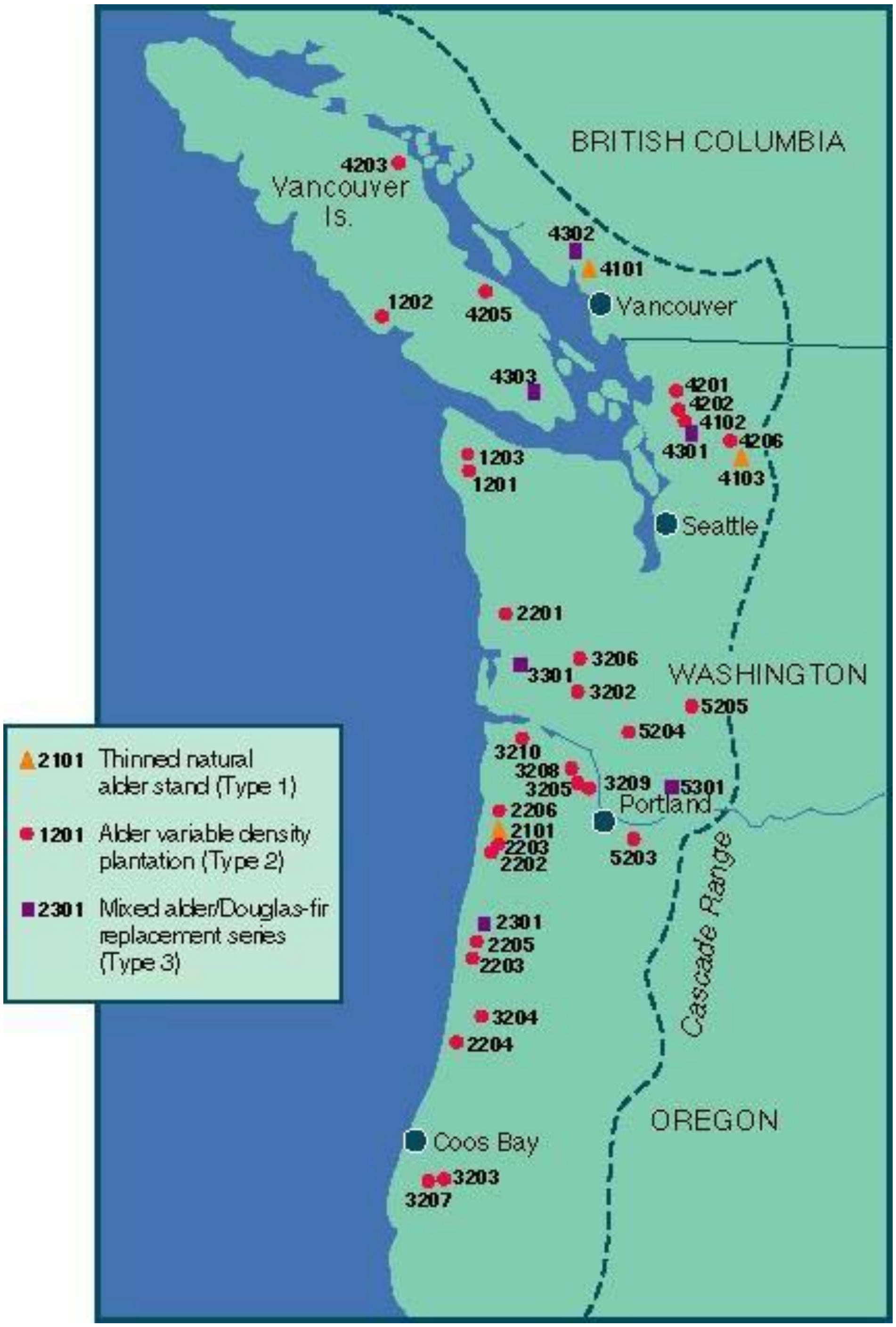

Figure 1. Location of installations for the Red Alder Stand Management Study.

The three types of study installations are as follows:

- Type 1 is a natural red alder stand thinned to 230 and 525 trees per acre. There are four Type 1 installations.
- Type 2 is a variable-density red alder plantation. At each site, red alder is planted in large blocks at densities of approximately 100, 230, 525, and 1200 trees per acre. Each block is subdivided into several thinning and pruning treatments. There are twenty-six Type 2 installations.
- Type 3 is a mixed species plantation of red alder and Douglas-fir. Each site is planted to 300 trees per acre with five proportions of the two species. There are seven Type 3 installations.

The primary focus of the Red Alder Stand Management study continues to be the Type 2 variable-density plantations. Type 2 installations are distributed across a matrix of five ecological regions and three site quality classes (Table 1).

Table 1. Matrix of Type 2 installations. Each installation identified by number, ownership, and year planted.

	Site Quality		
Region	Low SI50 :23-27 M SI20 :14-17 M	Medium SI50 :28-32 M SI20 :18-20 M	High SI50 :33+ M SI20 :21+ M
1) Sitka Spruce North	X	1201 DNR ‘91	1202 BCMin ‘94 1203 DNR ‘96
2) Sitka Spruce South	2202 SNF ‘91 2206 SNF ‘95	2203 ANE ‘92 2204 SNF ‘94	2201 WHC ‘90 2205 ANE ‘94
3) Coast Range	3204 SNF ‘92 3209 BLM ‘95	3202 WHC ‘90 3205 ODF ‘92 3207 BLM ‘94 3208 ODF ‘97	3203 CAM '92 3206 WHC '93 3210 OSU ‘97
4) North Cascades	4205 BCMin ‘94	4202 GYN ‘90 4203 BCMin ‘93 4206 DNR ‘95	4201 GYN ‘89
5) South Cascades	5205 GPNF ‘97	5203 BLM ‘92 5204 WHC ‘93	X

With each passing year, more and more treatments are applied and more data is collected. Tables 2, 3, and 4 describe the data collection schedules for the three installation types. The shaded areas of the tables indicate the activities that have been completed and illustrate the tremendous accomplishments of the HSC to date.

Table 2a. Data Collection Schedule for Type 2 Installations. Shaded areas indicate completed activities.

TYPE 2	**GYN**	**WHC**	**WHC**	**GYN**	**DNR**	**SNF**	**NWH**	**NWH**	**SNF**	**ODF**	**BLM**	**WHC**	**BCmin**
Site Number	**4201**	**2201**	**3202**	**4202**	**1201**	**2202**	**2203**	**3203**	**3204**	**3205**	**5203**	**3206**	**4203**
Site Name	**Humphrey**	**John's R.**	**Ryderwood**	**Clear Lake**	**LaPush**	**Pollard**	**Pioneer**	**Sitkum**	**Keller-Grass**	**Shamu**	**Thompson**	**Blue Mtn.**	**Mohun Ck.**
Year Planted	1989	1990	1990	1990	1991	1991	1992	1992	1992	1992	1992	1993	1993
1st yr Regen	1989	1990	1990	1990	1991	1991	1992	1992	1992	1992	1992	1993	1993
2nd yr Regen	1990	1991	1991	1991	1992	1992	1993	1993	1993	1993	1993	1994	1994
Plot Installation	1991	1992	1992	1992	1993	1993	1994	1994	1994	1994	1994	1995	1995
3rd yr Measure	1991	1992	1992	1992	1993	1993	1994	1994	1994	1994	1994	1995	1995
3-5 yr Thin	1992	1995	1995	1993	1995	1995	1996	1997	1996	1996	1995	1997	1997
Prune Lift 1 6ft	1994	1995	1995	1995	1995	1995	1996	1997	1996	1996	1995	1997	1997
6th yr Measure	1994	1995	1995	1995	1996	1996	1997	1997	1997	1997	1997	1998	1998
15-20' HLC Thin	1994	NA	1998	1995	1998	NA	1999	2000	2000	1999	1999	2001	NA
Prune Lift 2 12ft	1994	2001	1998	1995	2001	1999	1999	2000	1998	1999	1999	2001	2001
9th yr Measure	1997	1998	1998	1998	1999	1999	2000	2000	2000	2000	2000	2001	2001
Prune Lift 3 18ft	1997	2009	2001	1998	2007	2002	2003	2000	2008	2003	2003	2001	2006
12th yr Measure	2000	2001	2001	2001	2002	2002	2003	2003	2003	2003	2003	2004	2004
30-32' HLC Thin	2000	NA	NA	2001	2010	2007	2008	2003	NA	2006	2008	2006	2009
Prune Lift 4 22 ft	2000	NA	2001	2001	2022	2007	2008	2003	2013	2006	2008	2004	2009
17th yr Measure	2005	2006	2006	2006	2007	2007	2008	2008	2008	2008	2008	2009	2009
22nd yr Measure	2010	2011	2011	2011	2012	2012	2013	2013	2013	2013	2013	2014	2014
27th yr Measure	2015	2016	2016	2016	2017	2017	2018	2018	2018	2018	2018	2019	2019
32nd yr Measure	2020	2021	2021	2021	2022	2022	2023	2023	2023	2023	2023	2024	2024

Table 2b. Data Collection Schedule for Type 2 Installations. Shaded areas indicate completed activities.

TYPE 2	**WHC**	**BCmin**	**SNF**	**NWH**	**BLM**	**BCmin**	**SNF**	**BLM**	**DNR**	**DNR**	**ODF**	**OSU**	**GPNF**
Site Number	**5204**	**1202**	**2204**	**2205**	**3207**	**4205**	**2206**	**3209**	**4206**	**1203**	**3208**	**3210**	**5205**
Site Name	**Hemlock Ck.**	**Lucky Ck.**	**Cape Mtn.**	**Siletz**	**Dora**	**French Ck.**	**Mt. Gauldy**	**Scappoose**	**Darrington**	**Maxfield**	**Weebe**	**Wrongway**	**Tongue Mtn.**
Year Planted	1993	1994	1994	1994	1994	1994	1995	1995	1995	1996	1997	1997	1997
1st yr Regen	1993	1994	1994	1994	1994	1994	1995	1995	1995	1996	1997	1997	1997
2nd yr Regen	1994	1995	1995	1995	1995	1995	1996	1996	1996	1997	1998	1998	1997
Plot Installation	1995	1996	1996	1996	1995	1995	1996	1997	1996	1997	1999	1999	1999
3rd yr Measure	1995	1996	1996	1996	1996	1996	1997	1997	1997	1998	1999	1999	1999
3-5 yr Thin	1997	1998	1998	1998	1998	1998	2000	1999	NA	2001	2002	NA	NA
Prune Lift 1 6ft	NA	1998	1998	1998	NA	1998	2000	1999	1999	2001	2002	2002	NA
6th yr Measure	1998	1999	1999	1999	1999	1999	2000	2000	2000	2001	2002	2002	2002
15-20' HLC Thin	2001	NA	2005	NA	2002/17	2002	NA	NA	NA	NA	NA	NA	NA
Prune Lift 2 12ft	NA	2005	2002	2002	NA	2002	2003	2003	2001	2004	2008	2005	NA
9th yr Measure	2001	2002	2002	2002	2002	2002	2003	2003	2003	2004	2005	2005	2005
Prune Lift 3 18ft	NA	2015	2012	2010	NA	2005	2011	2009	2003	2010	2011	2010	NA
12th yr Measure	2004	2005	2005	2005	2005	2005	2006	2006	2006	2007	2008	2008	2008
30-32' HLC Thin	2006	NA	2017	2010	NA	NA	2011	2009	2011	2010	2011	2010	NA
Prune Lift 4 22 ft	NA	NA	2017	2020	NA	2013	2016	2009	2006	2017	2013	2013	NA
17th yr Measure	2009	2010	2010	2010	2010	2010	2011	2011	2011	2012	2013	2013	2013
22nd yr Measure	2014	2015	2015	2015	2015	2015	2016	2016	2016	2017	2018	2018	2018
27th yr Measure	2019	2020	2020	2020	2020	2020	2021	2021	2021	2022	2023	2023	2023
32nd yr Measure	2024	2025	2025	2025	2025	2025	2026	2026	2026	2027	2028	2028	2028

Table 3. Data Collection Schedule for Type 1 Installations. Shaded areas indicate completed activities.

TYPE 1	BCmin	SNF	DNR	MBSNF
Site Number	**4101**	**2101**	**4102**	**4103**
Site Name	**Sechelt**	**Battle Saddle**	**Janicki**	**Sauk River**
Plot Installation	1989	1990	1991	1994
1st yr Measurement	1989	1990	1991	1994
3rd yr Measurement	1992	1993	1994	1997
6th yr Measurement	1995	1996	1997	2000
9th yr Measurement	1998	1999	2000	2003
14th yr Measurement	2003	2004	2005	2008
19th yr Measurement	2008	2009	2010	2013

Table 4. Data Collection Schedule for Type 3 Installations. Shaded areas indicate completed activities.

Owner	BCmin	NWH	GYN	BCmin	DNR	SNF	GPNF
Site Number	**4302**	**2301**	**4301**	**4303**	**3301**	**2302**	**5301**
Site Name	**East Wilson**	**Monroe-Indian**	**Turner Creek**	**Holt Creek**	**Menlo**	**Cedar Hebo**	**Puget**
Year Planted	1992	1994	1994	1994	1995	1996	1997
1st yr Regen Survey	1992	1994	1994	1994	1995	1996	1997
2nd yr Regen Survey	1993	1995	1995	1995	1996	1997	1998
Plot Installation	1993	1995	1995	1995	1997	1998	1999
3rd yr Measurement	1994	1996	1996	1996	1997	1998	1999
6th yr Measurement	1997	1999	1999	1999	2000	2001	2002
9th yr Measurement	2000	2002	2002	2002	2003	2004	2005
12th yr Measurement	2003	2005	2005	2005	2006	2007	2008
17th yr Measurement	2008	2010	2010	2010	2011	2012	2013
22nd yr Measurement	2013	2015	2015	2015	2016	2017	2018
27th yr Measurement	2018	2020	2020	2020	2021	2022	2023
32nd yr Measurement	2023	2025	2025	2025	2026	2027	2028

Field work required this last field season (Winter 2021/22) is shown in Table 5. Three Type 2 installations (Mt. Gauldy, Scappoose, and Darrington) needed their 27th year measurement and two Type 2 installations (Ryderwood and Clear Lake Hill) needed their 32nd year measurement. In addition, one Type 3 installation (Menlo) was due for its 27th year measurement. Many thanks go out to the cooperators who provided personnel for the measurements especially Cascade hardwoods and WA DNR with their assistance measuring the Ryderwood installation.

Table 5. Hardwood Silviculture Cooperative Field Activities, Fall 2021-Spring 2022

Type	Activity	Installation	Cooperator
Type 1		Completed	
Type 2	27yr Measure	2206	SNF- Mt. Gauldy
		3209	BLM- Scappoose
		4206	WADNR- Darrington
	32yr Measure	3202	WHC- Ryderwood
		4202	GYN- Clear Lake Hill
Type 3	27yr Measure	3301	WADNR- Menlo

So, in the big picture:

- All twenty-five Type 2 installations have now had their 22nd year measurement.
- Twenty-one Type 2 sites have their 27th year measurement completed.
- Three Type 2 sites have their 32nd year measurement completed.
- Twenty-four of the twenty-five Type 2 installations have all treatments completed.
- All seven Type 3 installations have had their 22nd year measurement.
- Five of the seven Type 3 installations have had their 27th year measurement.

Field work for the upoming field season (Winter 2022/23) is listed in Table 6. One Type 2 installation (Maxfield) is due for its 27th year measurement and two Type 2 installations (LaPush and Pollard Alder) will need their 32nd year measurement. In addition, LaPush is ready for it's fourth, and final pruning lift. Finally, one Type 3 installation (Cedar Hebo) is due for its 27th year measurement.

Table 6. Hardwood Silviculture Cooperative Field Activities, Fall 2022-Spring 2023

Type	Activity	Installation	Cooperator
Type 1		Completed	
Type 2	27yr Measure	1203	WADNR- Maxfield
	32yr Measure	1201	WADNR- LaPush
		2202	SNF- Pollard Alder
	4th Pruning lift	1201	WADNR- LaPush
Type 3	27yr Measure	2302	SNF- Cedar Hebo

Current HSC Activities

Effects of species mixtures on growth and yield of red alder and Western redcedar

Abstract

In the Pacific Northwest, monocultures have historically been the predominate form of plantation management. However, the management of mixed-species stands of red alder (*Alnus rubra* Bong.) with associated conifers has recently generated interest. The reasons for this are many: often red alder will regenerate naturally into conifer plantations posing a common management scenario, concerns about improving biological diversity in planted conifer stands, improvement of ecosystem resilience, site productivity enhancements due to red alders' nitrogen (N)-fixing ability, and red alder's favorable market value.

The relationships among tree mortality, tree size (DBH, Height, cubic foot volume), and stand yield in planted red alder and western redcedar (*Thuja plicata* Donn. ex D. Don, hereafter referred to as "redcedar") species mixtures were explored at a modified replacement series at a 26 year-old site growing on abandoned agricultural land in northwest Washington, USA. This study is the only one in the USA and the oldest of its kind in existence. Treatments included four species proportions (100% red alder, 25% red alder/75% redcedar, 50% red alder/50% recedar, 100% redcedar) planted at 680tpa (8' x 8' spacing). An additional treatment of pure red alder was planted at 170tpa (16' x 16' spacing) was also included. Redcedar was planted in 1990 and the red alder planting was delayed for seven years (1997 and interplanting in 1998). However, due to early seedling mortality from *Septoria alnifolia*, four of the 13 treatment plots failed and the only pure red alder treatment plot was compromised.

By 2016, redcedar had much higher survival than red alder. The survival of both species was greater in the mixtures than in the pure species treatments. Red alder DBH and height was greatest at the lowest densities of red alder and was independent of the mixed or pure treatments. Redcedar DBH and height were reduced when grown in species mixtures compared to pure species treatments (19% and 10%, respectively). Red alder individual tree cubic foot volume was greatest at the lowest densities and redcedar individual tree volume was greatest in the pure species treatment. Total merchantable stem volume was greatest in the treatments that contained a redcedar component, whether pure or mixed species. Volume in the pure red alder treatments was less than half of that of the treatments that contained redcedar.

In the mixed species treatments, relative yield (RY) of the red alder was >1 (indicating growth enhancement) whereas for redcedar RY was <1 (indicating a growth penalty). Relative land output (RLO) for the mixed species treatments was <1, indicating a substantial increase in per acre productivity as measured by merchantable volume. These positive yield improvements over the pure species treatments were observed mainly as the result of increased survival of both species, increased volume of red alder in the mixed species treatment, and shade tolerance of the redcedar allowing the development of a distinct stratified (two-storied) stand structure. These results demonstrate that there is potential for mixedwood management and that forest managers should consider species mixtures as a means to enhance productivity, yield, and other management objectives.

Introduction

Red alder (*Alnus rubra* Bong.) is a common component of most low-elevation forests in the Pacific Northwest, forming both pure stands and mixed species stands. Usual associates are Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Sitka spruce (*Picea sitchensis* [Bong.] Carr), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), grand fir (*Abies grandis* [Dougl. ex Don] Lindl.), and western redcedar (*Thuja plicata* Don. ex D. Don). The distributions of these species overlap significantly with red alder's distribution. Despite this overlap vast areas of land continue to be managed as conifer monocultures (Cox and Atkins 1979) and in these intensively managed conifer plantations, red alder can threaten full and uniform stocking of the conifer target species (Newton and Cole 1994). Although young red alder is relatively easy to control with some herbicides (Peterson *et al*. 1996), continuing public concern and prohibitions on using herbicides on certain ownerships jeopardizes or limits this use, resulting in a situation where red alder is viewed as a "competitor" in conifer monocultures.

One goal of mixed-species plantation research and management is to determine whether species mixtures can provide greater yields and/or other benefits that may outweigh the advantages of the management simplicity of monocultures. The objective is to mix certain species that will increase stand-level productivity or individual-tree growth rates relative to monocultures, allow the harvest of products from different species on different rotations, potentially reduce the risks of insect or disease impacts, or achieve some combination of these (Forrester *et al*. 2006, Kelty 2006). Furthermore, commitments to improve biological diversity and resiliency (Kelty *et al*. 1992) and the potential for climate change effects (Messier *et al*. 2013) now create interest in management opportunities for more complex multi-species stands. When mixed with even-aged conifer stands in the Pacific Northwest, red alder can increase forest understory plant and wildlife biodiversity and abundance, enhance productivity and biological function of streams (Wipfli *et al*. 2003), and increase conifer growth and total forest growth on certain sites (Binkley 2003). Species mixtures may improve ecosystem resilience by offering some protection from disease and insect outbreaks, resistance to wind damage and other abiotic stresses, and conservation of native plant and animal species (Messier *et al*. 2013).

It is important to identify the effects of species mixtures on growth and stand development. The oft resulting lower timber yields are often considered a necessary sacrifice that accompanies the use of species mixtures unless the component species have good ecological combining ability—that is, the differences in growth characteristics reduce competition or one species has a positive effect on the growth of the other species (Kelty *et al*. 1992). On one hand, as an early- successional, shade-intolerant species, red alder is often an aggressive competitor with young conifer stands; Douglas-fir growth in mixed species stands is often less than in pure stands because of lower light levels. On the other hand, red alders' nutrient cycling characteristics and nitrogen fixing ability can improve the growth of conifers on nutrient poor sites. Tree and stand growth responses vary because the competitive and facilitative effects of red alder differ by associated species and site quality. These processes (competition and facilitation) have been the subject of numerous early investigations (Berntsen 1961, Tarrant and Miller 1963, Newton *et al*. 1968, Trappe *et al*. 1968 (and references within), Miller and Murray 1978, Briggs *et al*. 1978 (and references within), Tarrant *et al*. 1983, Hibbs and DeBell 1994, Miller and Murray 1978, *etc*.). These studies most always investigated red alder and Douglas-fir interactions.

There has been less focus on species mixtures of red alder and other conifer species such as Sitka spruce (Courtin and Brown 2001, Gara *et al*. 1980), western redcedar (Deal *et al*. 2004, Thomas *et al*. 2005), and western hemlock. Of special note, these mentioned species are all more shade tolerant than Douglas-fir (Minore 1979). Ecological theory suggests that species having very different growth characteristics such as height, form, photosynthetic efficiency of foliage, and root structure may have a good ecological combining ability, which allows them to coexist in mixtures with high productivity (Harper 1977, Kelty *et al*. 1992). The relationship between juvenile growth rates and shade tolerance plays an important role in mixed species plantations (Menalled *et al*. 1998). In general, intolerant species grow rapidly in height and have crowns with low leaf area density. These species can form an upper canopy stratum that transmits some light to shade tolerant species that form a lower stratum (Kelty 2006). Canopy stratification of this kind is an important aspect of complementary resource use.

Because of the promising ecological combining ability of redcedar with red alder and because of both species high-value wood products, redcedar could be grown with red alder as a mixed species plantation and harvested in two stages (Stubblefield and Oliver 1978). Understanding relationships between these species may enable silviculturists to design specific mixtures that provide ecosystem resilience while maintaining or surpassing timber yields or other ecosystem goods and services at greater levels than monocultures (de Montigny and Nigh 2007). For instance, the red alder component could be removed when it reaches commercial size and the redcedar left growing as a second crop. The advantage of this system is that the understory redcedar would reduce the size and number of limbs, sweep and lean of the red alder (Grotta *et al*. 2004), thus improving wood quality. In addition, the growth of the redcedar might be improved due to the added nitrogen fixed by the red alder (Shainsky and Radosevich 1992, Binkley 2003). The disadvantages of this system is that there is likely some reduction in growth of either or both species, and the increased management and harvesting difficulties and cost.

Decisions about planting mixtures require an understanding of the survival and growth rates of the different species when grown together at different proportions and densities (de Montigny and Nigh 2007). To better understand both the competitive and facilitative effects of a red alder and redcedar species mixture, a modified replacement series experiment was established near Mt. Vernon, WA. The redcedar was planted in 1990 and the red alder planted in 1997 and 1998. In this replacement series, total stand density remained constant (680tpa) with four species proportions (100% red alder, 25% red alder/75% redcedar, 50% red alder/50% recedar, 100% redcedar). The site was measured in 2003 (when the redcedar was 13 years old and the red alder 6 years old), in 2016 (when the redcedar was 26 years old and the red alder 19 years old) , and again in 2021 (when the redcedar was 31 years old and the red alder 24 years old). The objective of this research is to examine the effects of species proportion on 1) survival, 2) diameter at breast height (DBH), 3) height (HT), 4) individual tree volume, 5) volume per acre, and 6) relative yields of both the red alder and the redcedar.

Material and methods

Site Characteristics

This long-term experiment was established on Pacific Denkmann Co. property south of Mt. Vernon, WA. The site is located at longitude and latitude of 48.316^0, -122.280^0 (T33N R4E Sec 27) within four miles of the Puget Sound at 350ft elevation. Average minimum and maximum temperatures are 42^0 F and 59^0 F, respectively. Average annual precipitation is 65in, which occurs primarily between October and May (growing season precipitation 10.7in). The growing season has relatively mild temperatures and a high percentage of cloudy days even during summer. The soil is Norma silt loam; a poorly drained gravelly sandy loam overlain with ashy silt loam. Previous vegetation was pasture/old field. According to the Natural Resources Conservation Service (NRCS) ‘Web soil survey’ this soil type is “prime farmland if drained”. Douglas-fir site index is unknown. Red alder site index of 50 years (Worthington *et al*. 1960) is given to be 90ft (NRCS). Using the red alder soil/site evaluation method of Harrington (1986), site index was estimated at 69ft (converted to base age 20 years as in Thrower and Nussbaum 1991). Using the measured 26 year-old dominant tree heights (H40) site index (base age 20 years) was calculated as 86ft for 100% 16’RA and 73ft for the 100% 8’RA treatments (Weiskittel *et al*. 2009).

Site preparation consisted of digging drainage ditches in the spring of 1988, sprayed with glyphosate in the summer of 1988 and then rototilled in the early fall of that year. In 1989, the site was sprayed with glyphosate in early summer and then rototilled again in the fall.

Redcedar seed was gathered from second growth stands in previous years. The plug-1 cedar were grown at an unknown nursery and planted in February to March of 1990. They were hand sprayed with glyphosate around the base several times during the summers between 1990 and 1998. Red alder seed was gathered from an adjacent stand in the fall of 1995. The 1-0 red alder seedlings grown by Weyerhaeuser Company were planted in March of 1997. Heavy mortality occurred the first year from *Septoria alnifolia*. More red alder seedlings were interplanted in the winter of 1998. Between the two successive plantings, satisfactory survival was attained in most of the mixed species plots but in few of the pure red alder plots. Looking at historical photos, four of the fifteen plots failed just after stand establishment and an additional two were excluded prior to the 2021 measurements.

Some red alder ingrowth is currently present but not as much as the author would expect (personal observation) indicating the removal of any red alder ingrowth in the past. In 2012 the redcedar was pruned to approximately 6ft.

Due to the presence of multiple stems the red alder does not appear to have been form pruned.

Experimental Design

In a replacement series experiment (Jolliffe *et al*. 1984), two species are planted together in a succession of different proportions, while keeping the total number of trees per acre constant. In this experiment red alder and redcedar were planted in a series of four proportions (Table 1). Each treatment was planted to an initial target density of 680 trees per acre (8ft by 8ft spacing), in a plot consisting of a sixteen by sixteen tree grid (0.38 acre), surrounded by a single tree buffer (8ft) on all sides. In addition to these replacement series treatments, there is an additional treatment where red alder is planted to an initial target density of 170 trees per acre (16ft by 16ft spacing), consisting of a twelve by twelve tree grid (0.85 acre) and a single tree buffer (Figure 1). This wider spacing resulted in the same density of red alder as the 25% red alder/75% redcedar treatment.

The desired pattern and density was strictly controlled, the trees are in exact rows, columns, and proportions. Three replications of each treatment were established, for a total of fifteen plots (5 treatments x 3 replications), however severe mortality resulted in six plots to be dropped from the study.

Table 1. Treatment description [1] used in the Pilchuck replacement series experiment.

Treatment	Proportion of red alder	Proportion of redcedar	Trees/acre	Spacing (ft)
A- 100%RC	0.00	1.00	680	8
B- 25%RA/75%RC	0.25	0.75	680	8
C- 50%RA/50%RC	0.50	0.50	680	8
D- 8'RA	1.00	0.00	680	8
E- 16'RA	1.00	0.00	170	16

[1]The letters correspond to the treatment letters in Figure 1.

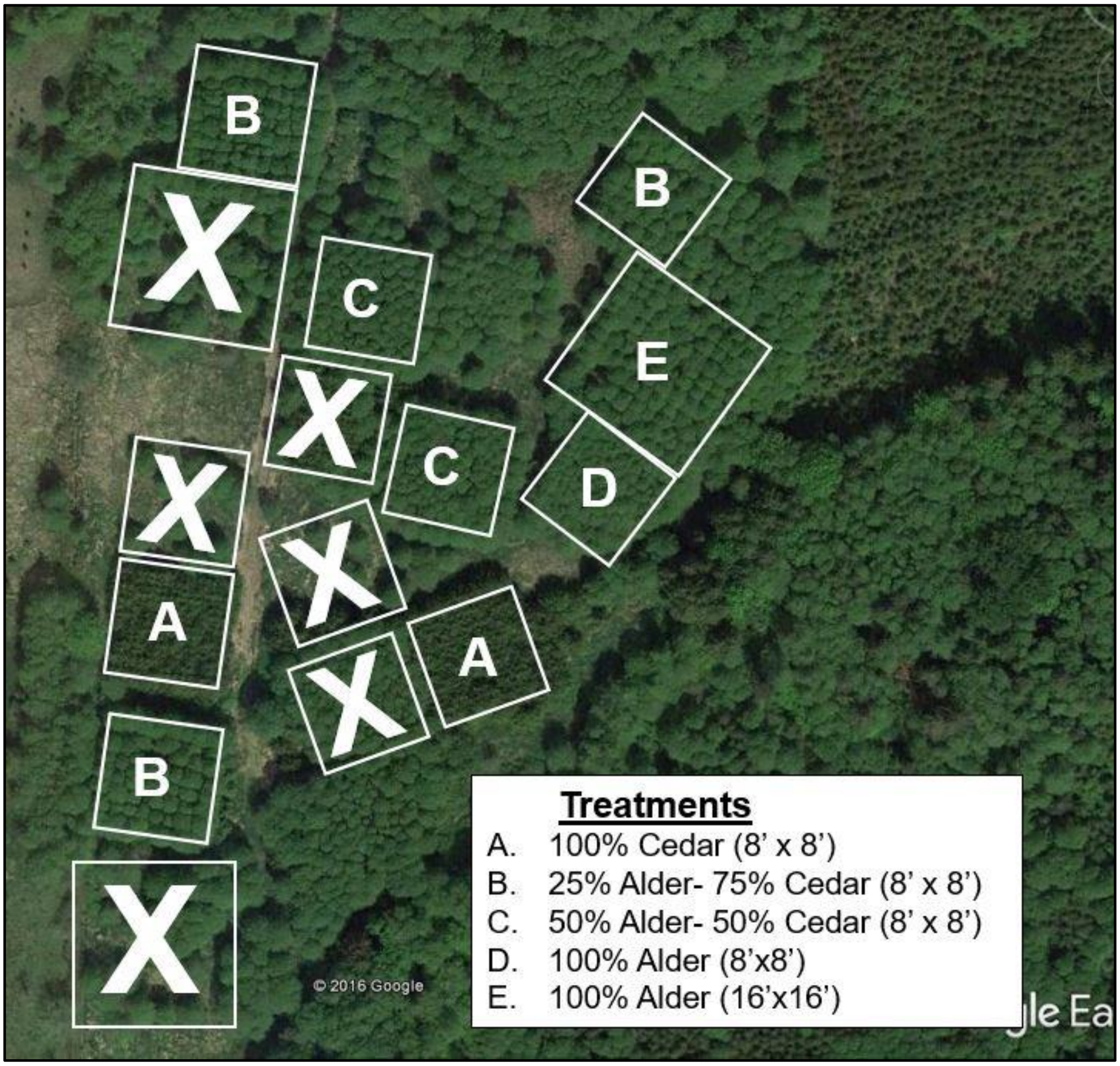

Figure 1- Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Measurements

In December 2003, the site was monumented, trees were tagged, and DBH (stem diameter at 4.5ft) was measured on all trees (Jeffery DeBell, WA DNR, personal communication). Height and height to live crown was not measured. In December 2016 and again in December 2021, the site was remeasured by the Hardwood Silviculture Cooperative (HSC). For every tree, DBH, stem defect (fork, lean, sweep) and presence or absence of damage was recorded. Height (HT) was systematically measured on a subsample of approximately 35 trees/species/plot. Thus, the number of height samples varied by treatment and mortality (Table 2). Height to live crown (HLC) was measured for all height trees.

116	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
115	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
114	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
113	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
112	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
111	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
110	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
109	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
108	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
107	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
106	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
105	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
104	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
103	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
102	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
101	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516

Figure 2- Example plot (Treatment C- 50%RA/50%RC) layout for the Pilchuck Tree Farm red alder/redcedar replacement series experiment. A=red alder. C=redcedar. Trees inside the bold square were used in this analysis.

To minimize edge effects, all trees in the outer perimeter of the measurement plots were excluded from analysis (see the bold line in Figure 2) resulting in 196 sample trees per plot for treatments A-D and 100 sample trees per plot for treatment E. Red alder, missing 2021 HTs and crown ratios were estimated using the RAP-ORGANON growth model. The model was then used to calculate individual tree (INDVOL) and per acre volume [(PAVOL) ft^3 and ft^3/acre, respectively]. For redcedar, missing 2021 HTs were estimated by using the parameters obtained by linear regression of HT vs. DBH of the sample trees (data not shown). Individual tree, merchantable volume (6in stump & 4in top [INDVOL]) and per acre volume (PAVOL [ft^3 and ft^3/acre, respectively]) for redcedar was calculated using the taper equation from Kozak (1988).

Statistical Analysis

The total number of trees used in the analysis was 430 red alder and 1043 redcedar. Survival was calculated as the number of living trees present (in 2003 and 2021) divided by the expected number of trees for the given treatment. Forks below DBH were excluded from survival calculations. DBH (2003 and 2021) was calculated as the treatment quadratic mean diameter. HT, HLC, Height/Diameter ratio (HD) and INDVOL (2016 only) was calculated as the treatment arithmetic mean. PAVOL was calculated by summing INDVOL for each species/treatment combination multiplied by the plot expansion factor. Analysis was done on each species separately and for PAVOL on both species combined.

PAVOL (2016) was then used to calculate relative yield (RY); defined as species mixture yields relative to yields in pure species treatments (Harper 1977). Effects on RY were examined using two methods. Total relative yield (RYT) = (the yield of Douglas-fir in mixture + the yield of red alder in the mixture)/ (the yield of Douglas-fir in pure stand + the yield of red alder in pure stand) and relative land output (RLO) = (the yield of Douglas-fir in mixture + the yield of red alder in the mixture)/ (the equivalent fraction of Douglas-fir in pure stand + the equivalent fraction of red alder in pure stand). Relative yield total (RYT) was obtained as the sum of RY of both species.

Treatment differences by species were tested using the GLM (general linear model) procedure in SAS. Pairwise comparisons between the treatments were tested using least significant differences and to control the overall type 1 error rate. Pairwise comparisons compare the responses across all treatment levels to determine which responses are statistically different.

Results and Discussion

Survival

Overall survival by treatment ranged from 59% to 94% in 2003, between 51% and 92% in 2016, and between 31% and 92% in 2021 (Figure 3). For all measurement years, survival in the 8’RA treatment was significantly lower than all other treatments. In 2016, the 16’RA survival was significantly lower than the 25%RA/75%RC. In 2021 survival in the treatments with redcedar (8’RC, 25%RA/75%RC and 50%RA/50%RC) were not significantly different from each other but were significantly greater than survival in the two pure red alder treatments.

Red alder survival by year and treatment is shown in Figure 4. For all measurement years, survival was lowest in the 8’RA, then the 16’RA, followed by the mixed species treatments. However, this significant reduction in survival is likely not an effect of density. First, by age 6, survival was below 60%- much lower than the self-thinning line would suggest (Puettman *et al*. 1993). Second, mortality appears to be a combination of sunscald/heat stress (since most mortality is confined to the unprotected, south edge of the plot) and the canker, *Neonectria major* (Figure 5). Third, the crown ratio of trees in this plot, although significantly lower than the other treatments, was 39% (data not shown) - indicating a still vigorous crown condition before the onset of density dependent, intraspecific mortality. Fourth, relative density was 0.40 (data not shown) – far below the self-thinning line. This plot would normally not be used in this analysis, however, this treatment is not replicated. This analomy /irregularity severely limits the usefulness of this plot for further comparisons of treatment effects (DBH, HT, VOL, etc.).

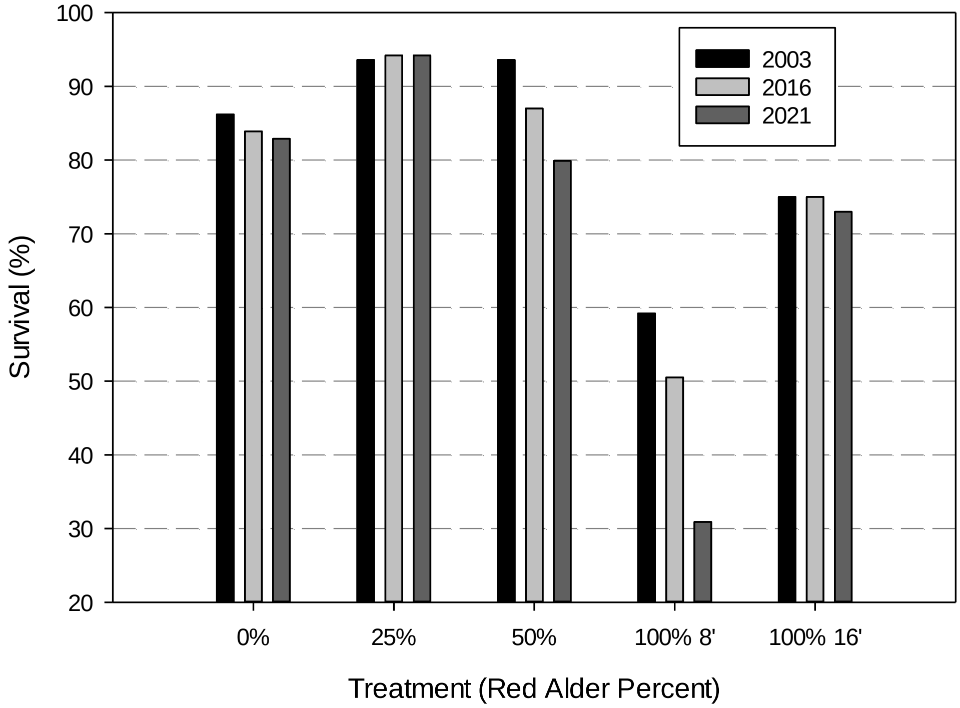

Figure 3- Overall survival by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

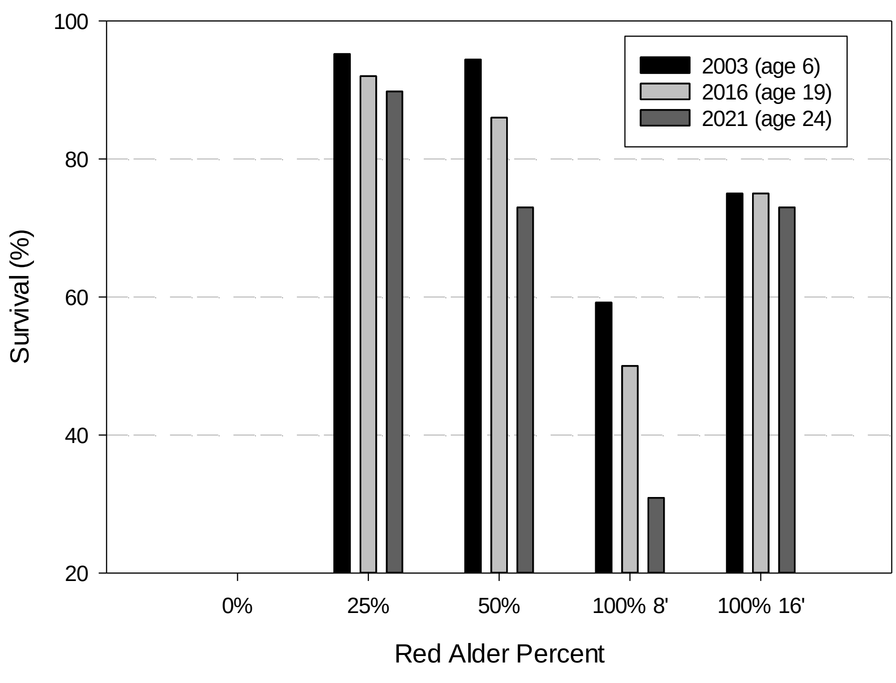

Figure 4- Red alder survival by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Figure 5- Example of *Neonectria major* found in the 8’RA treatment at the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

The best red alder survival was found in the mixed species treatments. 2021 survival of red alder in the mixed species treatments was significantly greater than survival in the pure species treatments. Although the red alder component is identical for the 25%RA/75%RC and the 16’RA, survival was greater (but not significantly) for the red alder grown with the cedar (90%) compared with the pure treatment (73%). This result- a positive effect on red alder survival by redcedar- was unexpected. The increased survival may be attributed to the shading/cooling effect the cedar may have had on the young red alder.

Redcedar survival was very high across treatment and measurement year despite no browse protection (Figure 6). In 2021, the pure 8’RC treatment had lower survival (83%) than both mixed species treatments, being significantly lower than the 75%RA/25%RC treatment (94%). So, like red alder, redcedar survival was greater in the mixed species treatments. This result is in contrast to the results found in de Montigny and Nigh (2007) where there was no effect on redcedar survival after 14 years when grown as a pure species or grown with varying proportions of Douglas-fir.

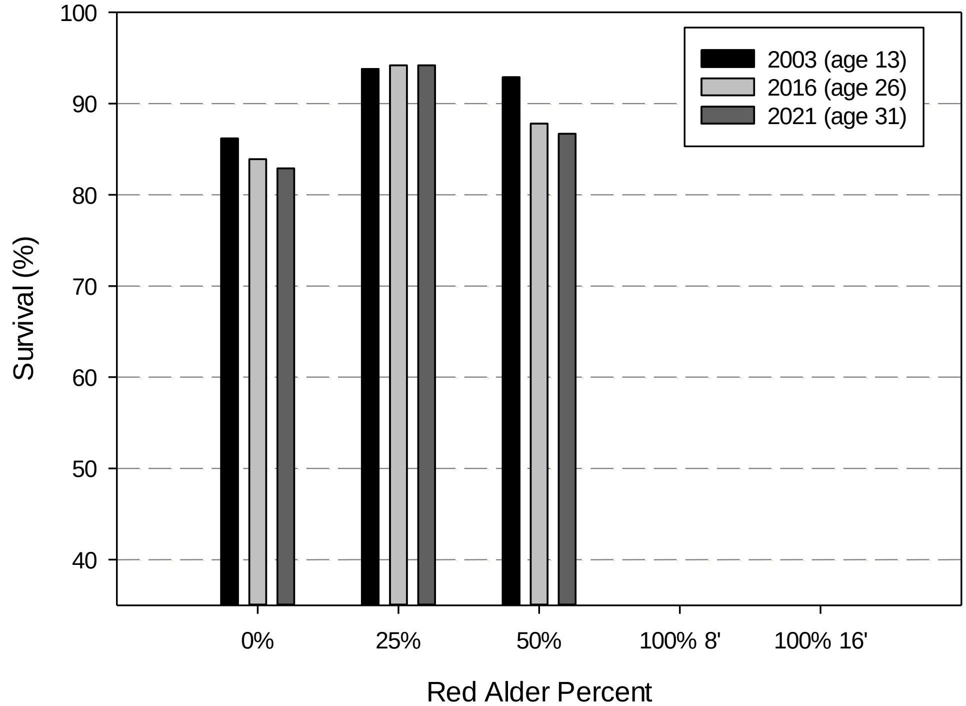

Figure 6- Redcedar survival by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Diameter (DBH)

By 2021, red alder DBH ranged from 8.5in to 12.1in with the greatest DBH now occurring in the 16'RA and the 25%RA/75%RC treatment (Figure 7). These treatments correspond to the lowest red alder densities possibly indicating that red alder DBH is more sensitive to intraspecific competition than interspecific competition with the redcedar. The 100% 8'RA had the smallest DBH of all treatments as discussed above. These results are consistent with the Thomas *et al*. (2005) replacement series (red alder/Douglas-fir), where 12 year old red alder DBH was greater in the mixed species treatment (150tpa red alder/150tpa Douglas-fir) than in the pure red alder treatment. It is also consistent with the findings of Radosevich *et al*. (2006) where red alder DBH was greater in mixed species treatments with Douglas-fir as compared to the pure red alder treatments on both high- and low-quality sites.

As shown in Figure 8, DBH of redcedar in 2021 was significantly greater in the pure treatment (8'RC), averaging 10.9in than in either of the mixed species treatments (~9.0in for both the 25%RA/75%RC and 50%RA/50%RC). This result indicates that there is a "penalty" of a 16% reduction of redcedar DBH when grown in any proportion with red alder. This reduction in redcedar DBH in mixed species treatments is in contrast to the findings of Thomas *et al*. (2005) in their additive series experiments (redcedar/Douglas-fir and added red alder) where redcedar DBH at age 12 was greatest when red alder was present in either 40tpa or 80tpa densities.

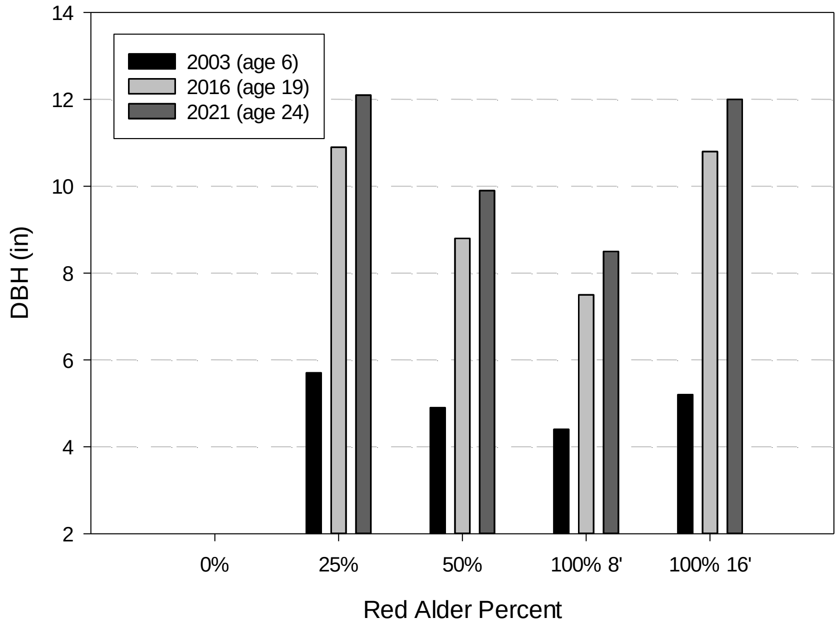

Figure 7- Red alder DBH by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

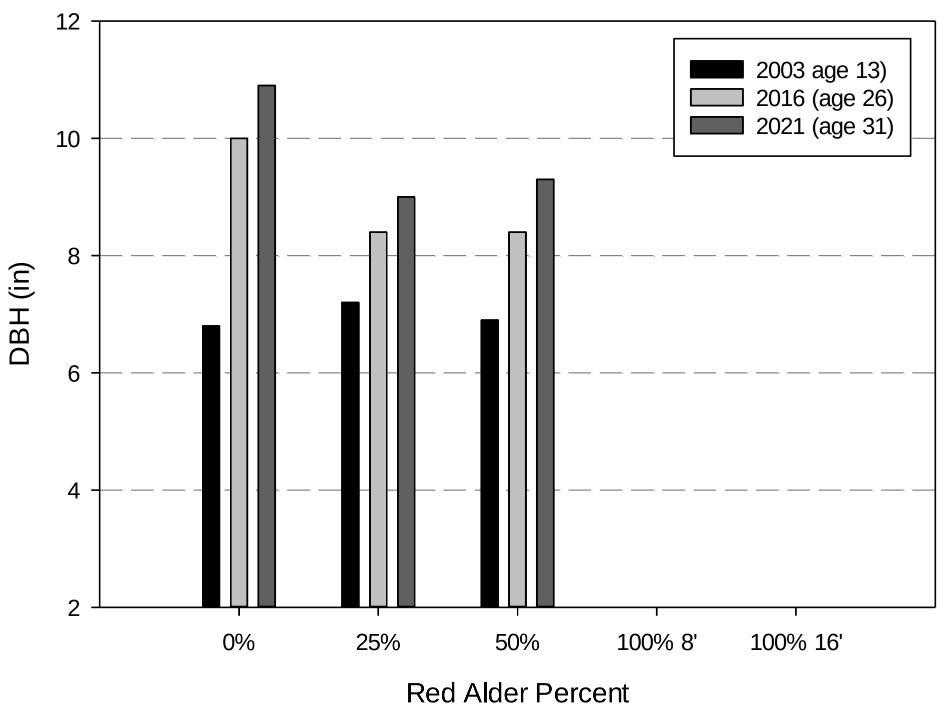

Figure 8- Redcedar DBH by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Tree height (HT)

Red alder clearly overtopped the redcedar (Figure 9). After 26 years, the redcedar averaged 42.0ft while after 19 years, the red alder was 73.1ft (1.7 times greater). HT differed significantly by treatment, ranging from 44.7ft for the 100% 8’RC to 76.3ft for the 100% 16’RA treatment. HT increased as the proportion of red alder in the plot increased (data not shown).

Figure 9- A 2016 example of the 25% red alder/75% redcedar treatment clearly showing the height stratification by species for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

In 2021, red alder height ranged from 63.2ft to 77.8ft (Figure 10). Like DBH, red alder HT was greatest for the treatments with the lowest densities of red alder- regardless whether of pure (16’RA) or mixed (25%RA/75%RC) species. However, unlike DBH, red alder HT is either insensitive to density or positively correlated with density (Bluhm, unpublished) up until about this age. It is the author’s hypothesis that the 8’RA treatment would have the greatest height if it did not suffer the severe damage and that red alder HT would decrease with decreasing proportion of red alder. This relative insensitivity in red alder HT to mixed or pure species treatment is consistent with the findings of Thomas *et al*. (2005) in their replacement series experiment.

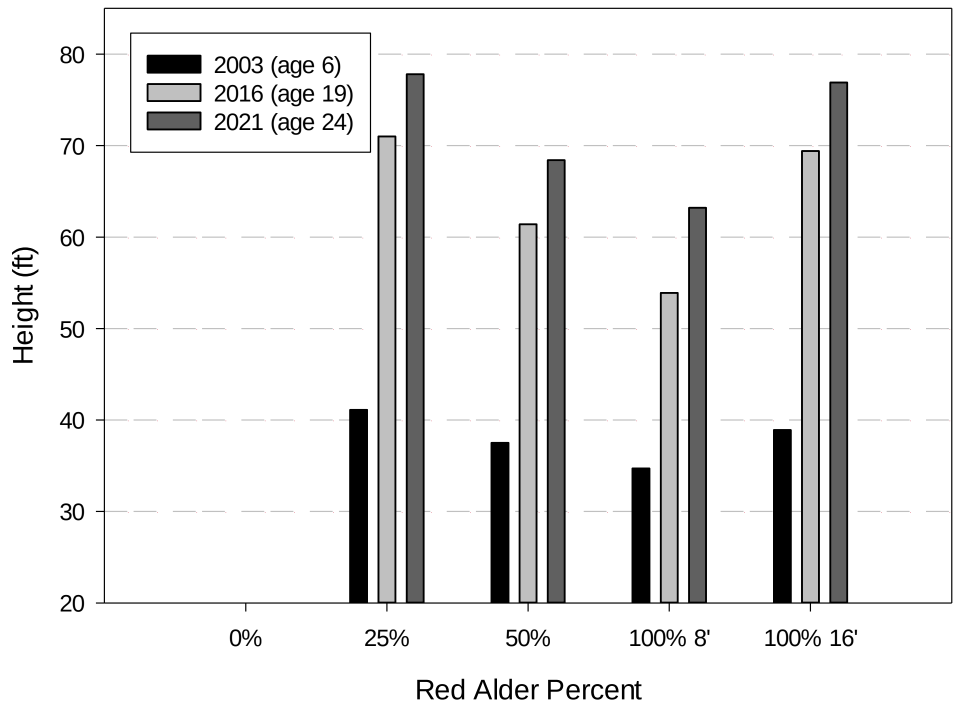

Figure 10- Red alder height by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

As seen in Figure 11, redcedar HT was significantly greater in the pure treatment (100% 8'RC), averaging 47.1ft, than in either of the mixed species treatments (42.5ft and 42.4ft for the 25%RA/75%RC and 50%RA/50%RC, respectively). This pattern is similar to that of DBH where HT is greatest in pure stands as compared to species mixtures. There is a redcedar height growth "penalty" of about 10% when grown with red alder in species mixtures. Like DBH, this reduction in redcedar HT is in contrast to the findings of Thomas *et al*. (2005) in their additive series experiments where they found the height of redcedar at age 12 was greatest when red alder was present in either 40tpa or 80tpa densities and in contrast with de Montigny and Nigh (2007) who found that redcedar HT at age 14 was not affected whether growing in pure or mixed species treatments with Douglas-fir. At least statistically, however, redcedar height continued to decrease with increased red alder proportion. This indicates that redcedar height growth may be more sensitive than DBH growth when grown with various proportions of red alder. Practically, however, redcedar height varied by less than 4ft.

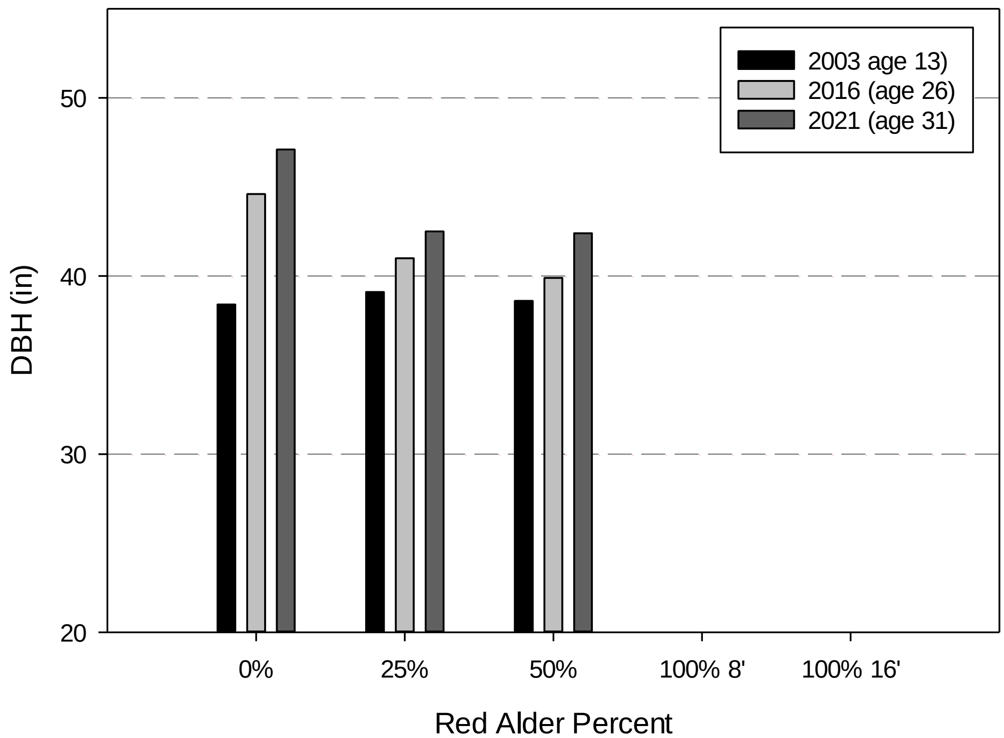

Figure 11- Red cedar height by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Relative Growth Rate (RGR)

During the first growth period (2003 to 2016) red alder DBH RGR ranged between 4% and 6%, with the greatest RGR occurring in the RA 16’ (Figure 12). This difference was significantly greater than all other treatments (pure or mixed species). Whereas during the second growth period (2003 to 2016) red alder DBH RGR ranged between 2% and 3%, with the greatest RGR occurring in the RA 8’ (not statistically significant).

Red alder height RGR followed the same patterns as red alder DBH RGR (Figure 13). During the first growth period (2003 to 2016) red alder height RGR ranged between 3.4% and 4.6%, with the greatest RGR occurring in the RA 16’. During the second growth period (2016 to 2021) red alder height RGR ranged between 1.8% and 3.2%, with the greatest RGR occurring in the RA 8’ (significantly greater than all other treatments).

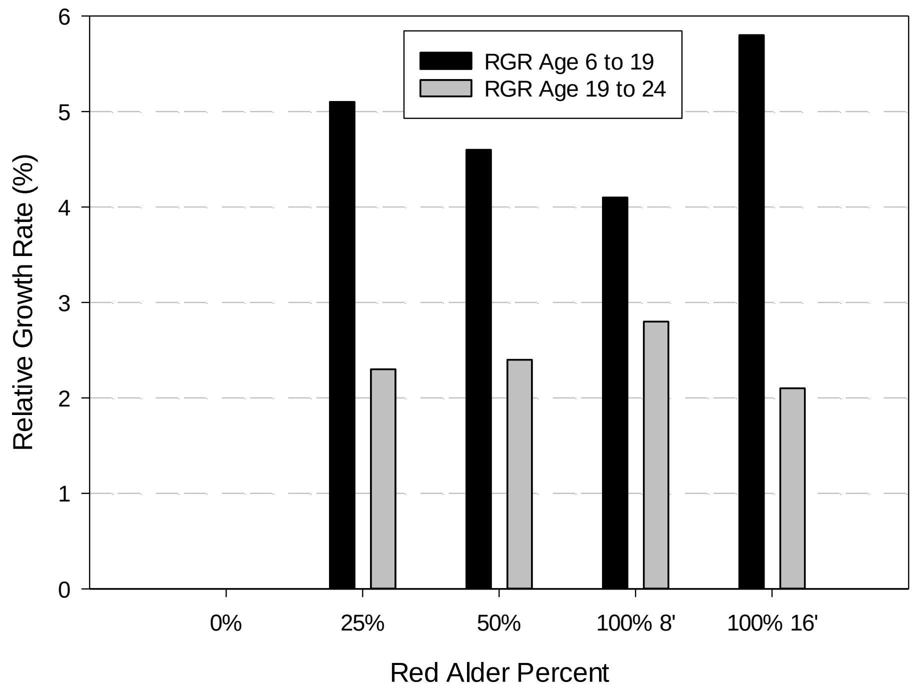

Figure 12- Red alder DBH relative growth rate (RGR) by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

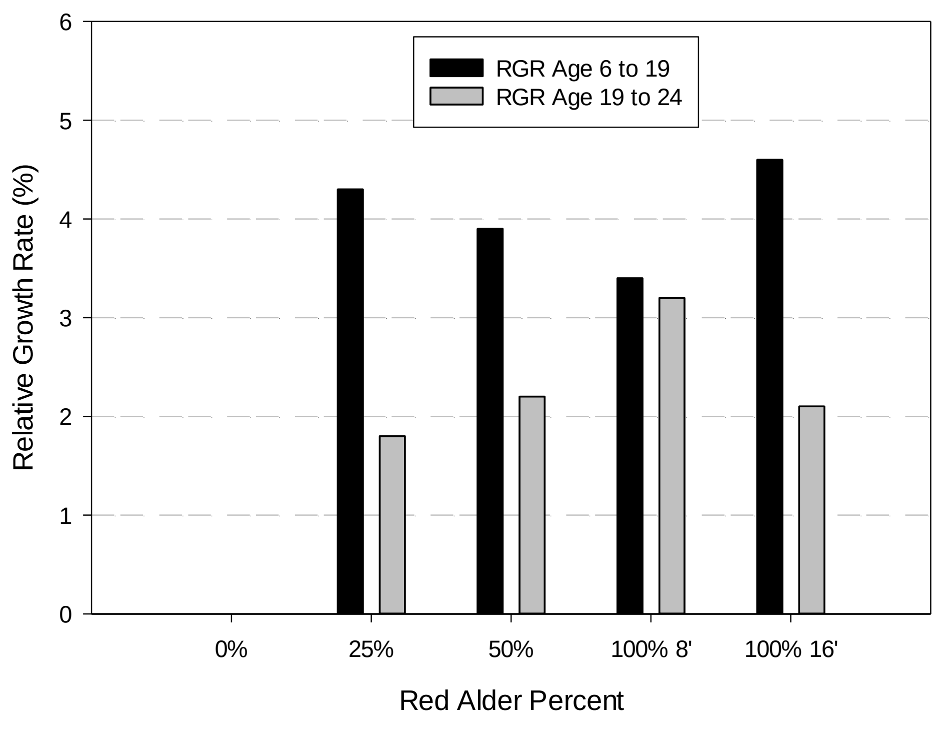

Figure 13- Red alder Height relative growth rate (RGR) by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

As expected, RGRs for red cedar were less than red alder RGRs. During the first growth period (2003 to 2016) red cedar DBH RGR ranged between 1.2% and 3.0%, with the pure RC 8” treatment being significantly greater than both mixed species treatments (Figure 14). However, surprisingly, red cedar Dbh RGRs were greater in the mixed species treatments during the second growth period (2016 to 2021) as compared to the first growth period (1.4% vs. 1.2% for 25%RA/75%RC and 2.0% vs. 1.6% for 50%RA/50%RC).

Red cedar height RGR followed the same patterns as red cedar DBH RGR (Figure 15). During the first growth period (2003 to 2016) red cedar height RGR was significantly greater for the pure treatment when compared to the mixed species treatments. But during the second growth period (2016 to 2021) red cedar height RGR was greatest for the 50%RA/50%RC (1.2%) and the RC 8’ pure species treatments (1.1%). The 25%RA/75%RC red cedar height RGR was significantly less than the other treatments (0.7%).

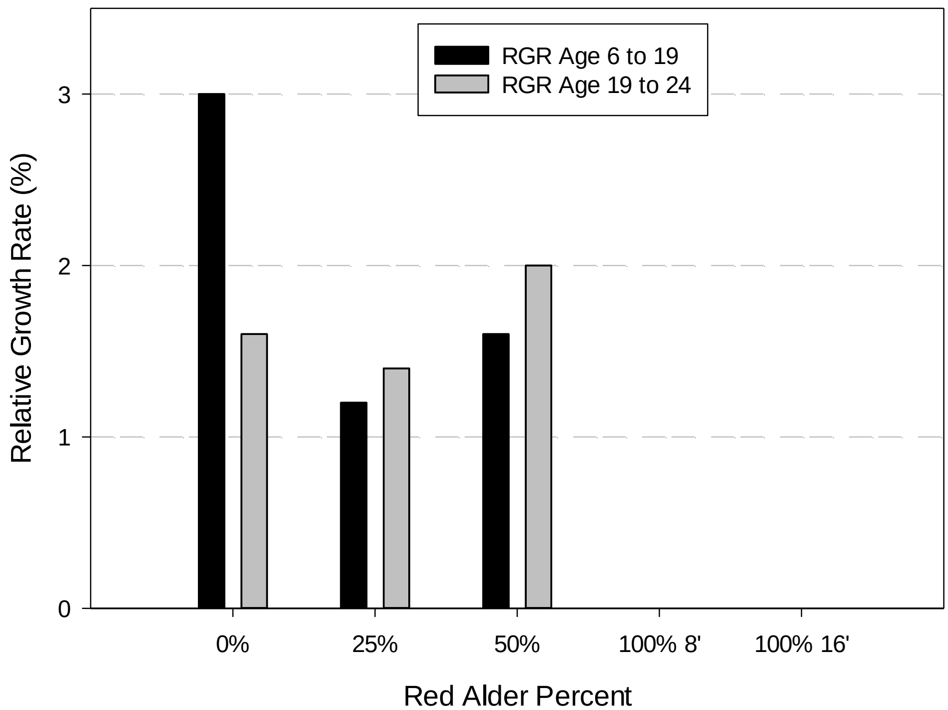

Figure 14- Red cedar DBH relative growth rate (RGR) by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

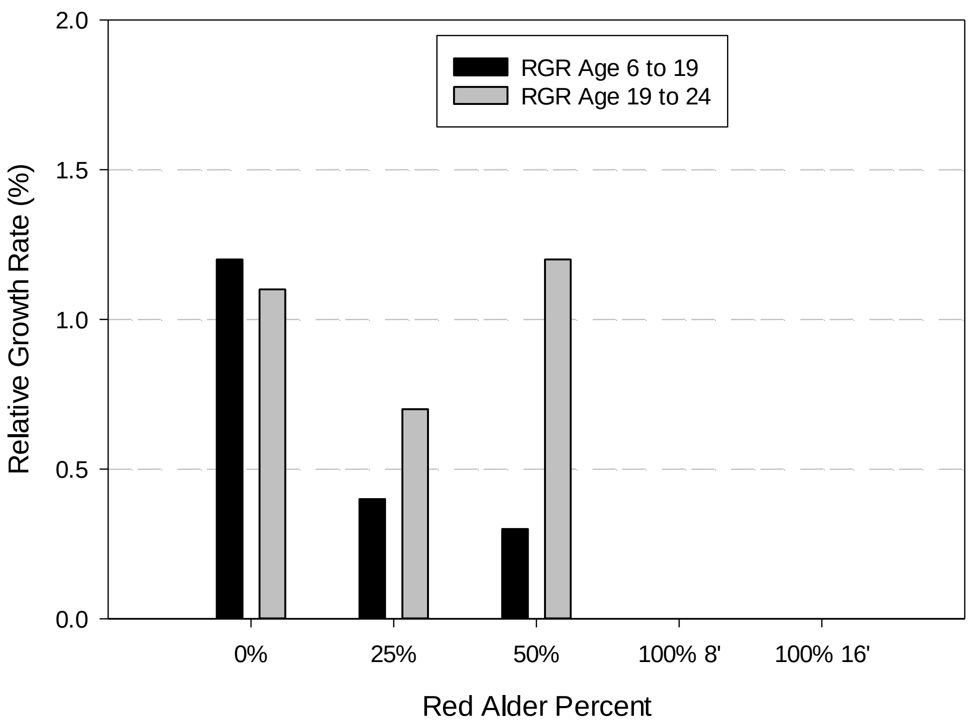

Figure 15- Red cedar Height relative growth rate (RGR) by treatment and year for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Per Acre Tree Volume (PAVOL)

Total PAVOL by treatment is shown in Figure 16. The 8'RA treatment had one quarter to one half the volume of any other treatment due to substantial mortality. The 16'RA treatment had approximately half the stand yield as the mixed species treatments. This is not an unexpected result- these mixed-species treatments are essentially stratified with the red alder in the overstory and the redcedar in the understory, the pure red alder treatments lacked the second component of stand volume. Further comparisons of the pure species treatments, shows that the pure redcedar treatment had a striking 2.1 and 3.5 times more volume than the 16' RA and the 8' RA treatments, respectively. The pure redcedar treatment contained a high density of large trees. Even if the 8'RA treatment did not suffer damage, the pure redcedar treatment would still have substantially more volume (pers. obs.). The mixed species treatments had slightly more PAVOL (7714 ft^3/acre for the 25%RA/75%RC) or somewhat less (6374 ft^3/acre for the 50%RA/50%RC) than the pure redcedar treatment. However, these differences were not statistically significant (data not shown).

Species PAVOL by treatment is also presented in Figure 16. For red alder, the pure treatments (8'RA and 16' RA) had 2096 ft^3/acre and 3368 ft^3/acre, respectively. In fact, the 8'RA treatment had less volume in 2021 than in 2016. In the lowest densities of red alder (170tpa) volume was less in the pure treatment (3368 ft^3/acre for 100% 16'RA) than the comparable density in the mixed treatment (4196 ft^3/acre for 25%RA/75%RC). In addition to this 24% increase in red alder volume in the mixed-species treatment, the stem (log) quality was greatly improved due to the shading of the lower bole by the redcedar.

Not surprisingly, redcedar PAVOL was significantly greater in the pure treatment (8'RC), averaging 7255 ft^3/acre. In the mixed species treatments, redcedar PAVOL was 3545 ft^3/acre and 2494 ft^3/acre for the 25%RA/75%RC and 50%RA/50%RC, respectively. Yet these differences between these two yields were not significantly different due to the limited number of replications and high plot variability.

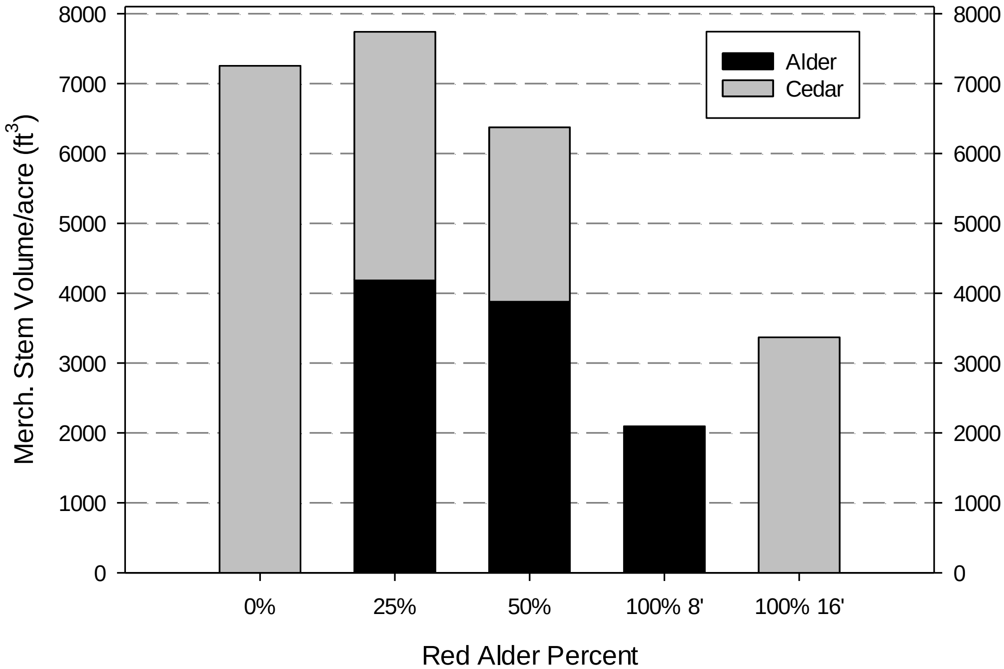

Figure 16- Merchantable volume per acre (PAVOL) by species and treatment for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Relative Yield

Relative yield is an indicator of the production enhancement (>1) or penalty (<1) when species are planted in mixtures (Jolliffe 1997). Three measures of relative yield are used here:

1) Relative Yield (RY) is the yield of a given species in mixture/ the equivalent fraction of said species in pure stand.
2) Relative yield total (RYT) compares the yields of both species when planted separately. RYT = (the yield of red alder in mixture + the yield of redcedar in the mixture)/ (the yield of red alder in pure stand + the yield of redcedar in pure stand).
3) Relative Land Output (RLO) is the sum of the individual species RYs. RLO = (the yield of red alder in mixture + the yield of redcedar in the mixture)/ (the equivalent fraction of red alder in pure stand + the equivalent fraction of redcedar in pure stand).

The very low PAVOL for the severely damaged pure red alder treatment (RA 8') significantly affected the relative yield comparisons (except for RY of redcedar). Red alder RY and the mixed species treatment RYT and RLO values were much >1 (data not shown). Usually these results indicate heightened production of these species mixtures compared to pure stands of either species. However, in this case, these results were much greater than reported elsewhere (Binkley *et al*. 2003, Radosevich *et al*. 2006, de Montigny and Nigh 2007, Bluhm, 2012), overwhelmingly the result of the damage to the unreplicated RA 8' treatment, and are thus, suspect.

To circumvent the effects of the abovementioned damage and to help make these results more useful for forest managers, relative yield values were calculated based on the PAVOL estimates from the 2003 tree list. This volume estimate was obtained by projecting the 6-year tree list 18 years (total age=24) using CIPSANON-RA. This projection resulted in 4378 ft^3/acre (vs. 2096 ft^3/acre for the actual, severely damaged treatment).

Figure 17 shows RY by species and treatment. For red alder, RY was >1 for both of the mixed species treatments (3.83 for the 25%RA/75%RC and 1.77 for the 50%RA/50%RC) indicating that red alder volume growth was greater in the mixed species treatments as compared to the pure treatment. For redcedar, the results were the opposite: RY was <1 for both of the mixed species treatments (0.65 for the 25%RA/75%RC and 0.69 for the 50%RA/50%RC).

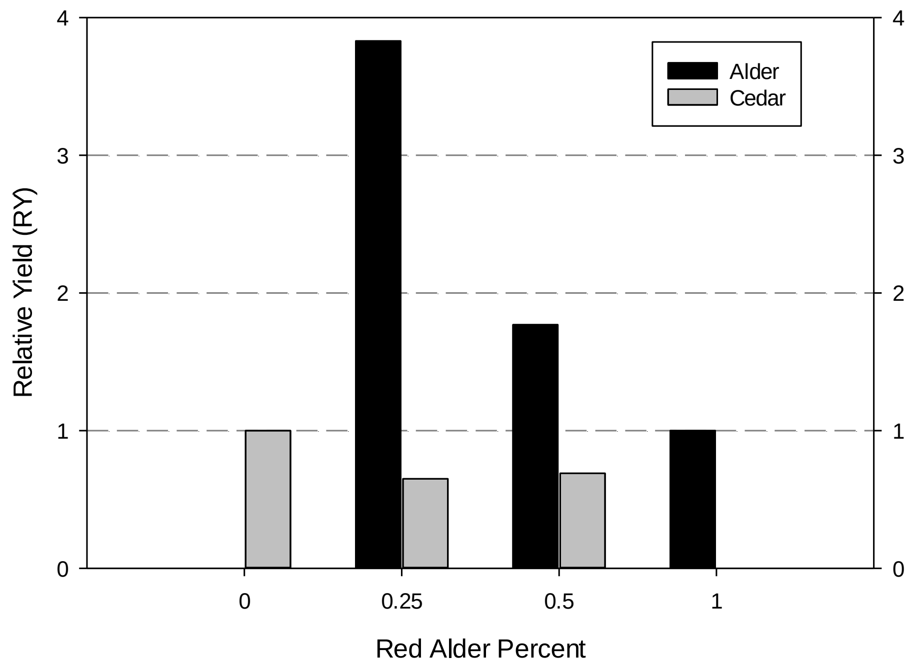

Figure 17- Relative yield (RY) by species and treatment for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

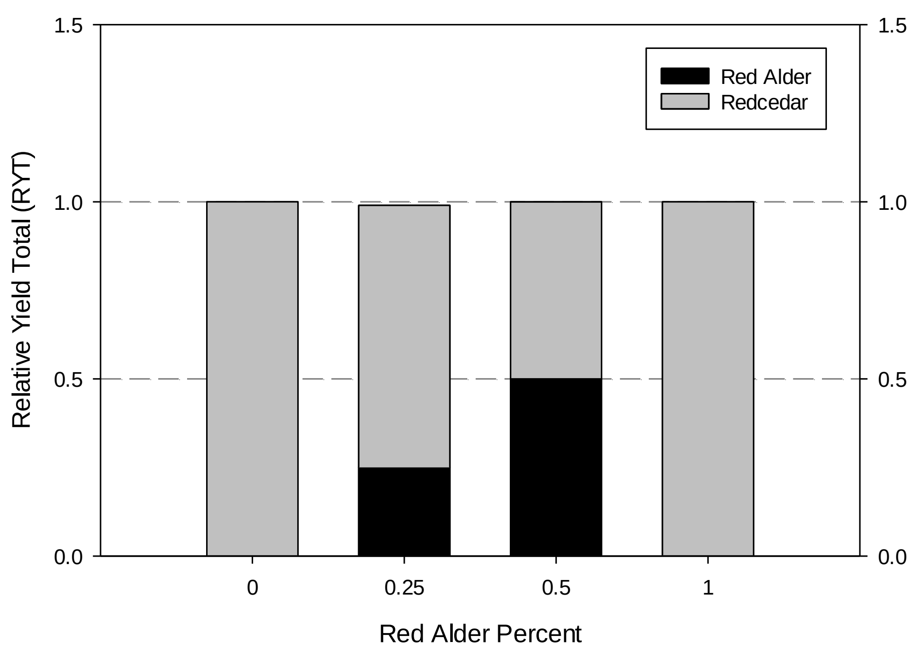

Figure 18- Relative yield total (RYT) and relative land output (b) by treatment for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Relative yield total (RYT) by treatment is shown in Figure 18. RYT was 0.99 for the 25%RA/75%RC treatment and 1.00 for the 50%RA/50%RC treatment. These RYT values indicate no production penalty (=1) in these species mixtures (proportions) compared to pure stands of either species.

Using relative land output (RLO) as a measure of relative yield indicates an enhancement in productivity (>1) of mixed species treatments as compared to pure species treatments (Figure 19). RLO was 4.48 for the 25%RA/75%RC treatment and 2.46 for the 50%RA/50%RC treatment. This enhancement in productivity is due to: 1) the large PAVOL values of the red alder in the species mixtures, 2) the low volume (due to mortality) in the pure red alder treatment, and 3) there were minimal competitive effects from the red alder on the understory redcedar (Forrester *et al*. 2006). These minimal competitive effects are in contrast to what is observed when Douglas-fir is grown with red alder in most mixed species situations Radosevich, *et al*. 2006).

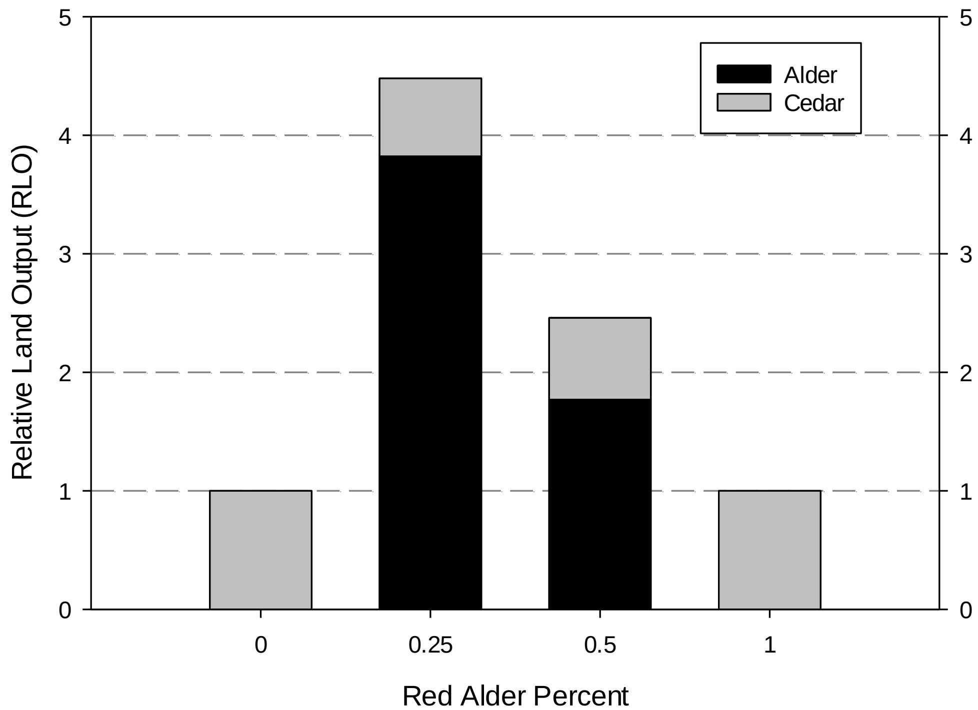

Figure 19- Relative land output (RLO) by treatment for the Pilchuck Tree Farm red alder/redcedar replacement series experiment.

Conclusion/Management Applications

There is warranted interest in mixed red alder–conifer stands in the Pacific Northwest. Reasons for this include the use of red alder to increase biodiversity or improve the growing conditions of conifers (*e.g.*, replace artificial fertilization with nitrogen fixation on low-nitrogen sites), or the economic benefit of including a high value species. Nitrogen fixation can be a major objective for growing red alder in mixed species stands since it improves site productivity and sustainability on low-nitrogen sites. Because of its N-fixing ability, red alder can actually improve the growth of associated conifers on low-nitrogen sites, but in other cases it may lead to reduced growth compared with pure conifer stands (Binkley 2003). Also, mixing red alder into conifer stands seems to improve conditions for a variety of ecosystem functions (Deal and Wipfli 2004).

Therefore, under the right conditions, appropriate silvicultural practices can yield a production advantage from mixtures of red alder and conifer species (Khom and Franklin 1997). The time of establishment is critical because of the difference in growth pattern between red alder and associated conifer species. Red alder's fast initial height growth allows it to overtop all of its associated conifers (Harrington and Curtis 1986, Peterson *et al*. 1996). During this period, shade tolerant conifers such as redcedar can coexist in the understory. These redcedar will then act as "training trees," shading lower parts of the red alder crowns causing natural pruning (Stubblefield and Oliver 1978) and improving red alder wood quality (Grotta *et al.* 2004).

The shade tolerance of redcedar allows it to survive and continue growing slowly (Stubblefield and Oliver 1978, Minore 1990, Thomas *et al*. 2005). Surprisingly, in this study, the mixed species treatments had better survival of both red alder and redcedar than the pure, single species treatments. Furthermore, because this study was on a productive site, the reduced growth of the redcedar was expected. However, what was unexpected was the production enhancement of the red alder in the species mixtures.

The removal of the red alder should allow the redcedar to continue productive growth until the final harvest. Yet how much of the redcedar size, allometry, and yield is affected by the competitive effect of shading and by the facilitative effect of nitrogen fixation by the red alder remains unknown. This type of mixed species stand increases the logistical difficulty in management. Plans for harvest and removal need to be developed. During the harvest process, damage to the thin barked redcedar needs to be avoided from logging damage.

So, although the results here are only a case study and the amount of treatment replications were limited, the results show promise. Although the redcedar in the mixed species treatments suffered reductions in volume, this management scenario (or one like it) could have applications in forest management. First, in this scenario, the harvesting of the red alder at a rotation of 25 to 30 years would be economically profitable and second, the remaining redcedar after harvest should respond well (Cole and Newton 1986) and continue growing until its final rotation age. Third, although stand establishment costs would be higher in this scenario, not only are two crops produced, but no costs would incur from a precommercial thinning. This is a difficult area of study as mixedwood management in forestry is complex. However, there is a gradual acceptance of the idea that there is a place for silviculture management strategies which include mixes of red alder and redcedar.

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Red Alder Clone Trial

History

As described in the HSC 2020 and 2021 Annual Report, a red alder clone trial was established on the OSU Blodgett tract (near Mist, OR) to compare the performance of red alder clones with a woods run control.

Study Design

The trial was planted on April 3, 2020 in an unfenced area in the Newton Survivor harvest unit on the Blodgett Forest (46.065472°, -123.344099°). Elevation is 830'-1070'. Aspect is East to Southeast. Slopes are mild, ranging from flat to 20%. Soil type is Scapponia-Braun silt loam and estimated red alder site index (base age 50 years) is 92ft.

The clone trial area was planted on a 9 x 9' grid (537tpa). Four sources of seedlings were used in this trial: 1) Eighteen clones from the WSU program and grown as PSB 615A plugs, 2) Woods run bare root seedlings from the Weyerhaeuser Aurora nursery, 3) Woods run 615 plugs grown by PRT Hubbard from the 041 seed source (SW WA), bought from WA DNR, and 4) an "Open pollinated" plugs (lot #249) from a WSU clone trial grown as plugs by the WSU program. These four sources are hereafter known as "Clones", "WeyCo", "DNR", and "Hancock".

The study design was a randomized complete block design with four blocks (i.e. replications). Each block contained 21 treatments: 18 clones plus the three comparison sources (WeyCo, DNR, & WSU) included twice to account for its expected higher inter-tree variation (Table 1). Each treatment within each block is represented by an individual-tree plot, with planting locations randomly assigned. Each block had 144 planting spots- six individuals for each of the 18 clones, and 12 individuals for the three comparison sources (Figure 1). The trial was bordered by 5-tree row plots of randomly assigned 20 treatments all of which was surrounded by a red alder operational planting.

Immediately after planting (Year 0), initial tree size (height and caliper) was measured on all 576 trees. Height and caliper were also collected in in the Winter 2020/21 and Winter 2021/22 (Year 1 and Year 2, respectively).

Table 1. Planting stock, map code and number of individuals planted in the red alder clone trial.

Clone	Code	Count	Caliper (mm)	Height (cm)
101	A	24	5.0	67.3
114	B	24	3.8	44.2
154	C	24	4.8	72.6
228	D	24	3.6	39.8
242	E	24	4.2	55.8
243	F	24	4.4	55.5
249	G	24	5.2	61.9
250	H	24	4.5	52.5
309	I	24	4.1	47.4
321	J	24	4.1	52.4
426	!K!	24	5.1	64.5
433	L	24	3.9	53.9
602	M	24	4.7	76.8
621	N	24	4.4	67.2
631	O	24	3.7	48.0
633	P	22	3.0	48.2
635	Q	24	4.8	65.1
639	R	24	5.6	96.8
DNR	T	55	4.6	44.1
WSU	S	47	4.1	38.6
Weyco	U	44	5.1	52.5
Total		576	4.4	55.8

	!K!	B	B	B	B	B	R	R	R	R	R	C	C	C	C	C	D	D	D	D	D	H	H	H	H	H
24	!K!	U	T	Q	T	Q	G	N	S	L	A	C	G	D	D	A	J	U	U	G	I	G	D	S	N	A
23	!K!	T	B	S	Q	T	F	A	E	L	C	S	O	I	A	N	B	T	L	T	S	N	T	U	U	A
22	!K!	T	J	H	Q	G	Q	C	U	P	N	N	R	T	A	T	R	H	T	F	A	S	J	F	N	A
21	!K!	!K!	L	D	S	P	F	R	A	J	H	B	J	!K!	L	U	B	J	U	U	S	E	H	Q	P	A
20	J	C	L	E	D	D	R	F	B	G	P	D	!K!	M	M	T	T	A	R	I	G	Q	Q	G	O	A
19	J	M	T	U	U	D	U	T	I	C	E	T	H	R	!K!	Q	F	U	M	O	F	S	S	H	!K!	P
18	J	B	N	O	U	E	S	D	R	F	N	!K!	S	C	R	U	B	H	I	S	J	M	O	H	O	P
17	J	E	S	T	B	F	L	G	F	H	E	B	I	E	P	T	T	O	O	T	!K!	H	G	I	P	P
16	J	T	!K!	T	O	U	J	A	U	H	I	Q	M	P	A	M	B	Q	!K!	F	T	C	R	L	E	P
15	N	L	A	R	S	!K!	R	U	O	I	M	G	H	!K!	S	J	E	T	E	E	U	D	S	B	C	P
14	N	S	J	U	I	U	M	S	P	I	N	P	T	I	L	D	N	S	C	L	F	U	R	D	T	E
13	N	O	C	M	!K!	A	S	J	O	S	M	U	P	Q	S	G	P	J	B	U	C	N	C	M	L	E
12	N	C	L	M	N	B	F	D	P	S	N	F	J	R	T	A	G	U	S	H	P	L	T	S	D	E
11	N	J	R	U	R	C	I	B	U	N	U	S	U	I	R	C	H	U	Q	Q	S	U	H	F	J	E
10	G	T	S	P	Q	B	S	S	J	U	E	O	N	O	N	P	S	G	U	G	R	H	M	D	E	E
9	G	R	I	H	I	F	A	H	B	G	J	U	R	R	L	F	R	S	Q	Q	P	U	S	F	M	L
8	G	Q	!K!	L	N	H	C	A	N	D	J	O	E	M	E	U	T	T	H	P	U	A	L	D	!K!	L
7	G	P	J	I	T	T	T	R	O	T	A	G	P	Q	I	A	S	U	I	C	H	D	I	N	Q	L
6	G	F	!K!	C	C	S	O	S	T	M	!K!	L	P	S	M	J	S	L	J	T	A	I	T	P	T	L
5	O	F	L	D	T	P	T	T	H	Q	M	G	T	L	T	G	G	F	C	C	E	!K!	A	J	N	L
4	O	G	U	E	Q	T	S	D	I	M	Q	S	H	U	C	T	B	!K!	R	O	N	F	B	F	O	U
3	O	A	E	S	T	T	L	H	!K!	B	L	!K!	S	E	A	J	T	B	M	I	S	N	T	N	!K!	U
2	O	G	I	M	R	A	!K!	D	B	S	C	A	T	B	E	U	O	O	E	B	O	D	B	U	J	U
1	O	E	M	O	G	T	O	T	D	F	E	Q	U	S	T	T	S	M	U	!K!	C	L	!K!	G	D	U
	M	M	M	M	M	Q	Q	Q	Q	Q	I	I	I	I	I	S	S	S	S	S	F	F	F	F	F	U
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

Figure 1. The red alder clone trial experimental design. Each color (and letter) is an individual seedling of a particular clone or seedling source.

Survival

In the Fall of 2020 and 2021, all trees were remeasured to quantify year 1 and year 2 survival, caliper and height. Overall, first year survival was very good- averaging 89.7% and ranging from a low of 63.6% to a high of 100% (Figure 6). The survival of the non-clonal sources (WeyCo, DNR, Hancock) was very high (93.2%- 97.9%)- statistically greater than the average for all the clonal sources combined (88.7%).

Year 2 survival was much lower- averaging 72.8% and ranging from a low of 54.1% to a high of 95.8% (Figure 2). The survival of the non-clonal sources (WeyCo, DNR, Hancock) was 73.0%- not statistically different than the average for all the clonal sources combined (72.7%).

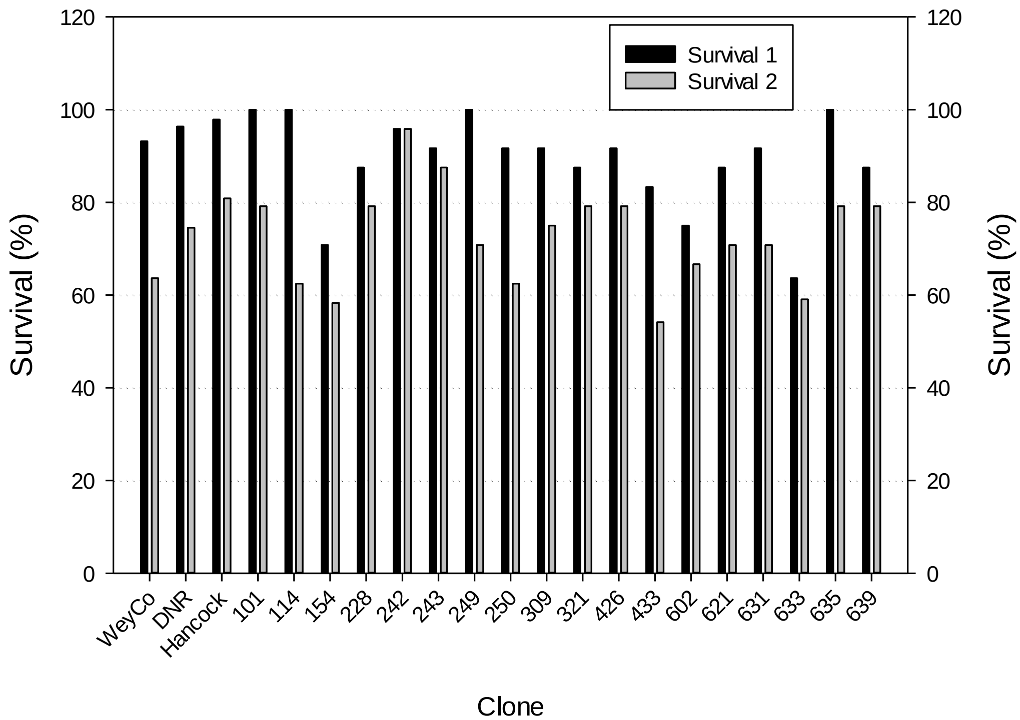

Figure 2. Year 1 and Year 2 survival by source type.

Caliper

Mean caliper in year 1was 10.8mm and ranged from a low of 7.4mm to a high of 13.1 (Fig. 3). There were no statistical difference in mean caliper between the non-clonal sources (11.0mm) and all the clonal sources combined (10.7mm). Year 2 mean caliper was 20.1mm and ranged from a low of 14.7mm to a high of 27.4. There were no statistical difference in mean caliper between the non-clonal sources (19.5mm) and all the clonal sources combined (20.2mm).

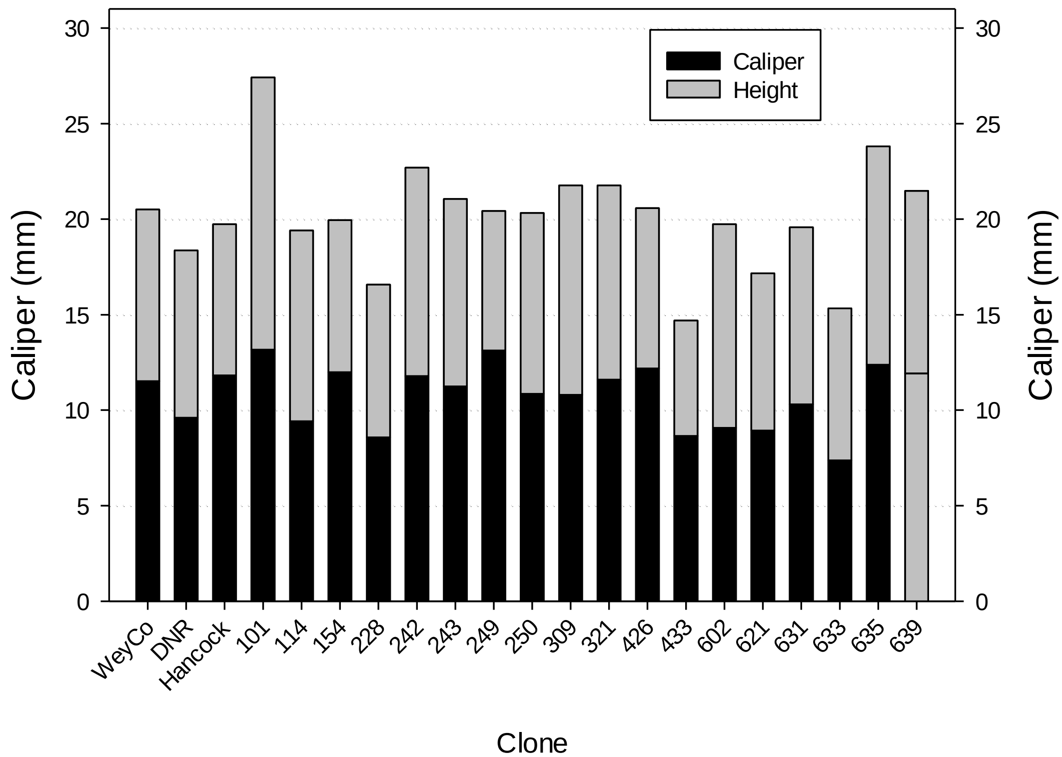

Figure 3. Year 1 and Year 2 caliper (mm) by source type.

Height

Height differences among sources can be seen in Figure 4. Year 1 Mean height was 91.2cm and ranged from 66.8cm to 121.7cm. Unlike caliper, the clonal sources were significantly taller (94.7cm) than the non-clonal sources (77.9cm). Year 2 Mean height was 162.0cm and ranged from 101.8cm to 238.8cm. Again, year 2 height of the clonal sources was significantly greater (164.8cm) than the non-clonal sources (144.9cm). However, considerable variation existed in year one height among individual clones.

Of surviving trees at the end of year 2, 60.9% of the non-clonal sources had trees that reached breast height or above while 72.6% of the sources had trees that reached breast height or above (data not shown).

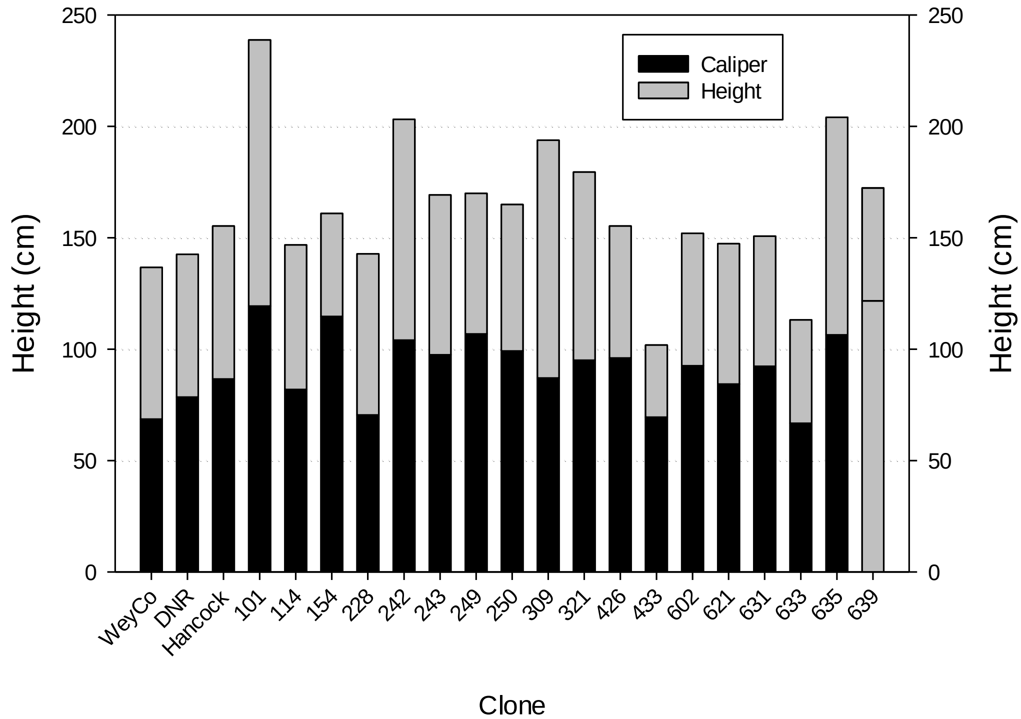

Figure 4. Year 1 and Year 2 height (cm) by source type.

Red Alder Clone Bank

As reported previously, the Hardwood Silviculture Cooperative, with assistance from the Washington Hardwoods Commission and Hancock Forest Management established a red alder clone bank at the J.E. Schroeder Seed Orchard (Oregon Department of Forestry) in November 2019. The initial purpose of the clone bank was to preserve the improved genetic materials developed by Washington State University's tree improvement program run by Barri Hermann.

Three ramets each from 20 production clones were planted at an 18' x 12' spacing with randomized planting spots. Early mortality was replaced in April 2020 and April 2021. The clones are still doing well and they are now 10-15 feet tall. They have the potential to provide a source of vegetative material and/or seed for further propagation. The concurrent alder clone trial established with this same genetic material will shed some light on early growth potential. Annual costs for maintaining the clones at Schroeder are in the range of $3,000.

Beyond the initial goal of preserving some of the improved genetic material, the HSC needs to decide on the longer-term objectives for these clones. This will depend on the interests and priorities of current HSC members along with any additional cooperators who have an interest in red alder tree improvement. Following up on discussion last year, we need to 1) assemble an interest group to discuss needs for an Alder Tree Improvement program and 2) investigate possible collaboration with the established BC Ministry alder breeding program. This will be discussed further at the 2022 Annual Meeting.

Red Alder Growth Model and Yield Tables

The HSC has continued to add recent measurements from 27- and 32-year old installations of the Red Alder Stand Management Study to the database. Working with Doug Mainwaring and the Center for Intensive Planted Forest Silviculture (CIPS), we have updated the growth and mortality equations in the *ORGANON Red Alder Plantation (RAP)* growth and yield model with data from older stands. Details on *Updates to the ORGANON Red Alder Plantation (RAP) equations* were presented last year in the HSC Annual Report 2021. Ultimately, HSC needs an updated working version of the model in order to proceed with development of Yield Tables and other products to improve understanding of likely outcomes from management of red alder.

After updating the growth and mortality equations in 2019, CIPS and the HSC presented the updated equations to David Hann, the architect of ORGANON. Dr. Hann decided to undertake his own full review and update of the model (pro bono). We are grateful for his efforts and willingness to do this work. However, progress working with Dr. Hann to develop a working version of the updated RAP ORGANON model has been slow, which has delayed our work to develop yield tables for red alder. In order to develop the yield tables and other products for HSC, we need an updated version that includes our more recent data from installations 22-years and older. Fortunately, work being done for a new project with CIPS (See *Red Alder: A Natural Climate Solution for the Pacific Northwest* in this report) will provide us with an updated working version of the red alder growth and yield model (written in R-code), which we are calling *Red Alder CIPSANON*.

It is important to note that both the tree data and personal observations during re-measurements of many of the red alder installations show increasing mortality over the last 15 years. The uncharacteristic mortality exceeds normal density-dependent self-thinning. This has resulted in some reductions in yield compared to expectations based on early performance. For example, observed volume in selected treatments for two of our oldest installations (age 32-33 years) in NW Washington is quite a bit lower than volume predicted based on site index and earlier performance in these stands (Figure 1 and Figure 2). Causes of this decline appear to be related to drought, heat, bark beetles, and stem cankers. This is consistent with what we know about red alder physiology and alder's vulnerability to insects and disease when trees are stressed by drought and heat.

As we update the growth and mortality equations with the most recent measurements from older stands, we expect resulting yield estimates to decline somewhat. Once the model is updated with the latest data, the growth model and yield tables will accurately reflect the average performance of alder in response to site quality (site index) across the range of our installations over the last 33 years. Since climate is a major driver of site quality, accounting for effects of climate variability and climate change on red alder and other tree species will be a major consideration in evaluating species selection and silvicultural options going forward.

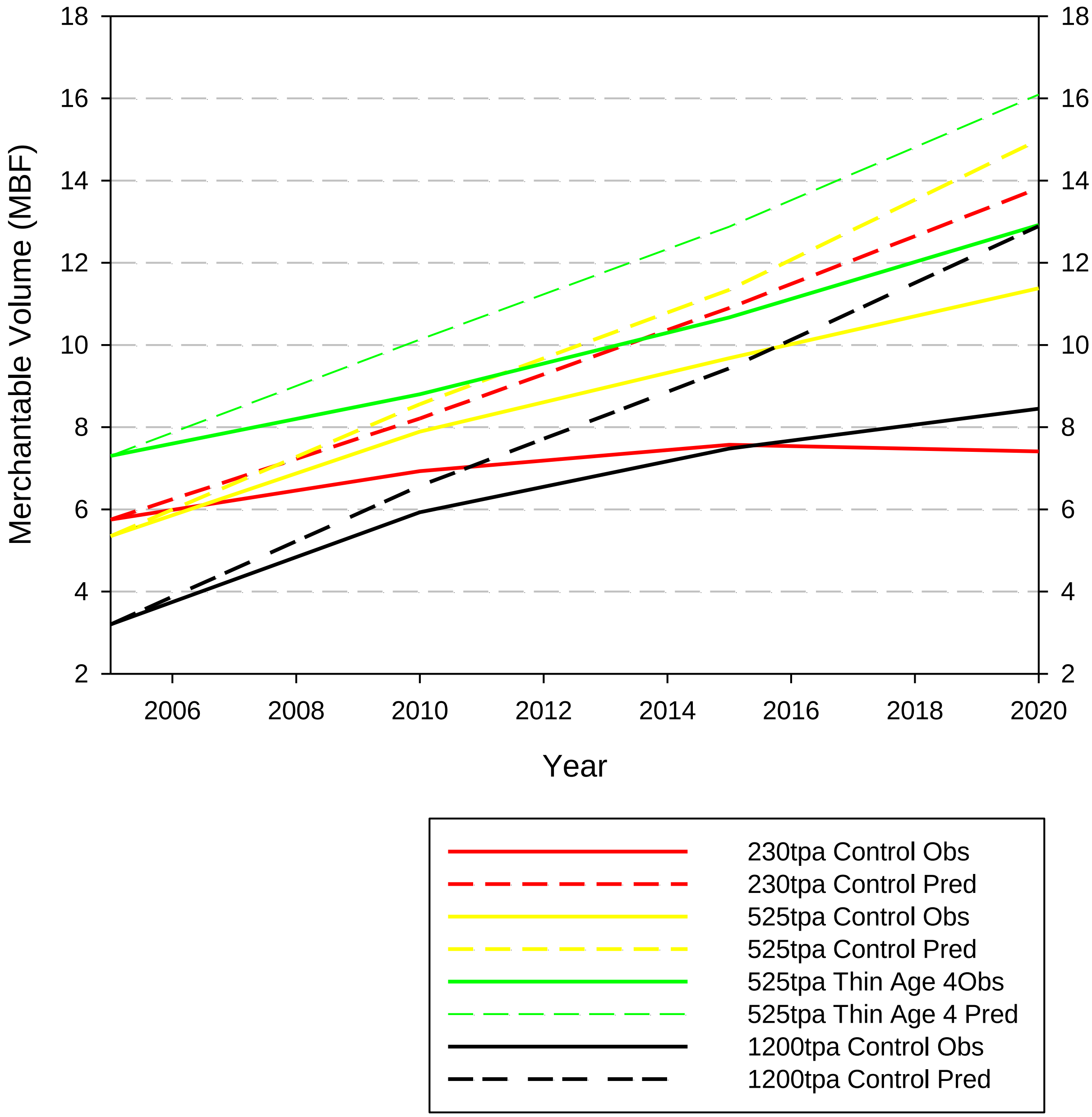

Figure 1. Humphrey Hill (#4201) Observed vs. Predicted Merchantable Volume (30ft target log length, 6-inch min. top).

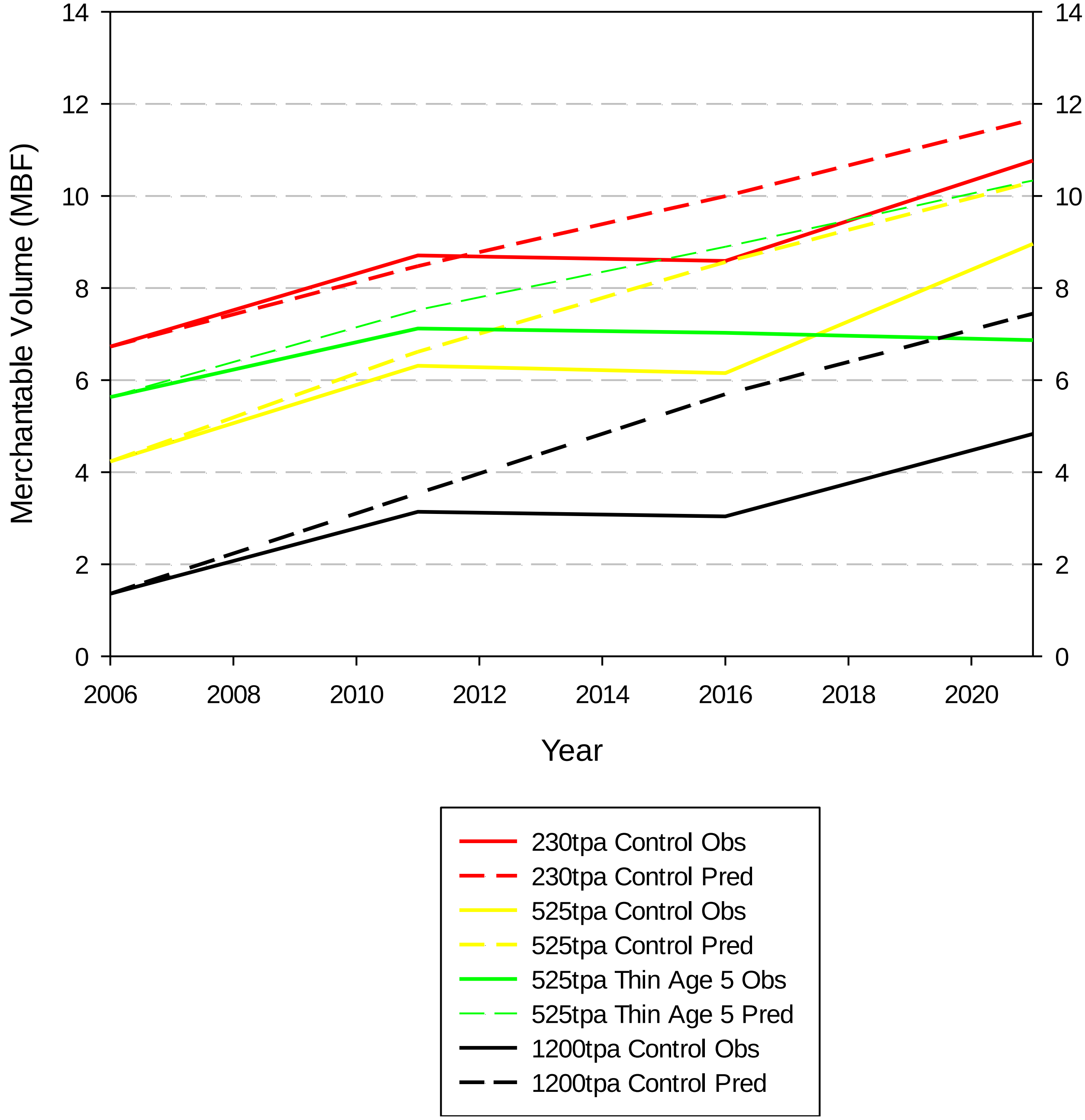

Figure 2. Clear Lake Hill (#4202) Observed vs. Predicted Merchantable Volume (30ft target log length, 6-inch min. top).

Red Alder Lumber Recovery Study

Assessing lumber recovery from managed plantations of red alder is one of the long-term goals for the HSC's Red Alder Stand Management Study. Plans were developed in 2021 to begin the study of lumber recovery on some of the oldest installations that are expected to reflect rotation-age yield. Two sites were proposed for initiating this study, both of which are in NW Washington, owned by Swaner Hardwoods. These sites are two of the first HSC Type II installations established. The first, Humphrey Hill (#4201), was established in 1989 and the second, Clear Lake Hill (#4202,) was established in 1990.

HSC staff and representatives for Cascade Hardwood Group have discussed the methods for this study. Swaner Hardwood expressed willingness to go forward with the study, depending on further details to be determined. However, the forester managing these lands for Swaner Hardwood has expressed concerns about the feasibility and operational limitations for harvesting trees at Humphrey Hill. These were due to issues including low volume/acre, high costs, poor access, and problems with the neighbors.

The Clear Lake Hill site has fewer issues and constraints, but it is younger and has less volume, suggesting that it might be advisable to wait longer. Because of these issues, the study has not begun yet.

Cascade Hardwood Group has expressed continued interest in pursuing the lumber recovery study at their mill and it is still a priority for the HSC. Information on the recoverable volumes and grade yields of lumber from managed plantations of red alder is of great interest to land managers and mill owners.

Given the delays and the concerns about the initial sites selected, further consideration of study sites and the timeline for implementation is needed. In order to make comparisons among management approaches and treatments, and to make statistically valid conclusions, it will be important to study multiple sites for purposes of replication. This will be discussed further at the 2022 Annual Meeting.

Red Alder: A Natural Climate Solution for the Pacific Northwest?

HSC Director Glenn Ahrens co-authored a proposal for a study of biomass production and carbon sequestration rates for red alder vs. conifers. The proposal, titled "Red Alder: A Natural Climate Solution for the Pacific Northwest? – Phase 1" was accepted and is being funded by The Nature Conservancy (TNC) as part of their effort to explore "natural climate solutions". Natural climate solutions (NCS) are nature-based activities that either avoid carbon emissions, or promote carbon sequestration via improved management and restoration of lands and water.

The project is designed to explore key questions posed by The Nature Conservancy regarding the natural climate solution role red alder could play in western Washington. Specifically, this project will develop a framework to analyze whether expanded red alder silviculture is a viable NCS for working forests in the coastal areas of Washington, factoring in the biomass in the forests and the wood products mix. Aspects of this framework may include (i) the rate of carbon sequestration in red alder plantations, (ii) standing biomass in red alder stands over time, (iii) the longevity of wood products produced from red alder, and (iv) the production emissions associated with bringing the wood products to the market.

This study is a joint effort between HSC and the Center for Intensive Planted Forest Silviculture (CIPS) at OSU and the Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington. The study will utilize the HSC red alder growth and yield model along with similar models for Douglas-fir and western hemlock developed by CIPS. The growth models will be used to develop estimates of biomass production and carbon fixation for comparing performance of red alder vs. conifers on specific sites under managed forest conditions. CINTRFOR will address the life cycle analysis to estimate carbon sequestration consequences of harvesting and utilization of alder vs conifer wood products. The project was labeled "Phase 1" because there is the expectation that results of the study will stimulate further interest and funding to pursue increased management of red alder as a natural climate solution.

A key benefit of this project for HSC is that it will result in an updated working version of the red alder growth and yield model with help from Doug Mainwaring at CIPS. This version of the model will be produced by applying the growth and mortality equations developed by CIPS in a utility called "Red Alder CIPSANON" (written in R-code). This is a much-needed update that HSC can use to develop yield tables and other products of interest. The timeline for this project is July 2022 – April 2023. (Contact Glenn Ahrens if you would like to see the full proposal for this project.)

Outreach and Education

Lower Nehalem Watershed Council, Speaker Series

Andrew Bluhm presented a seminar on the "Role of Red Alder in the Oregon Coast Range" online to the Lower Nehalem Watershed council on March 10, 2022. The presentation introduced the characteristics of red alder and summarized the ecological role that red alder plays in the Oregon Coast Range. We looked at how red alder fits into the big picture of PNW ecosystems then examined red alder's effect on diversity, site productivity, community resiliency, and ecosystem function. Specific emphasis was placed on the function red alder has in riparian systems and it's influence on riparian communities.

Olympic Experimental Forest T3 Experiment "Kickoff"

Andrew Bluhm presented a seminar on the "Role of Red Alder in the Oregon Coast Range" as part of the T3 experiment stakeholders meeting at the Olympic natural Resources Center from October 7-8, 2021. This large-scale, long-term experiment is a collaboration of University of Washington and Washington State Department of Natural Resources.

Andrew outlined the red alder-redcedar polyculture stand-scale, upland silviculture prescription. He gave an overview of the prescription, objectives, implementation, and potential outcomes.

Direction for 2022

Issues:

Maintaining and measuring our matrix of field installations for the Red Alder Stand Management Study has demanded the majority of HSC's limited capacity. A key question going forward is how much longer to sustain the effort for field measurements. Consideration must be given to allocating our limited capacity among other tasks including growth and yield model updates, yield tables, lumber recovery studies, and genetic improvement.

HSC membership and the financial support that goes with it has declined. While there is continued interest in the ecology and management of red alder across the range of agencies and landowners, there appears to be less focus on managing alder plantations for timber production. There is a need for further effort to engage new cooperators, determine research priorities, and develop increased funding for work related to hardwood silviculture.

HSC's network of long term alder study sites has great value for pursuing a wide range of research questions of interest in the future. Understanding the response of alder to climate stress and potential shifts in site suitability are priority needs for land managers. It is still very important to understand growth and yield performance in response to site factors. While drought and heat issues may be causing some decline in alder production at lower latitudes and elevation, we might expect growth increases in higher latitudes and elevations.

Recommendations:

Continue data collection and data management from the HSC installations through the 2022-23 field season.

Work with CIPS on another update of the growth and yield model *Red Alder CIPSANON*, taking advantage of the joint effort with TNC and UW to characterize biomass production and carbon in red alder vs conifers.

Use *Red Alder CIPSANON* to update and flesh out yield tables for selected management scenarios for red alder plantations.

Pursue a long-term plan for the products from the Red Alder Stand Management Study and *Red Alder CIPSANON* in cooperation with CIPS.

Continue to pursue a lumber recovery study from managed red alder plantations, with further consideration of study sites and the timeline for implementation.

Survey hardwood-related issues and needs of HSC members and other interested entities. Work with all interested parties to develop priorities for hardwood-related research and development to inform decisions about the future of the HSC.

Consider holding a Red Alder Symposium in 2023 or 2024 to update the state of our knowledge and stimulate new collaborations.

HSC Financial Support 2022

Cooperator	Support
BC Ministry of Forests	$8,500
Bureau of Land Management	$8,500
Cascade hardwood LLC	------
Goodyear-Nelson Hardwood Lumber Company	$4,500
Hancock Natural Resource Group	$8,500
Oregon Department of Forestry	------
Port Angeles Hardwood	$8,500
Siuslaw National Forest	------
Washington Department of Natural Resources	$8,500
Washington Hardwood Commission	------
Subtotal	$47,000
Oregon State University	$16,511
Total	$63,511

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