2022 Monitoring Report

Olympic Forest Collaborative

RESILIENT FORESTRY

Prepared by:
Miles LeFevre
miles@resilientforestry.com

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Introduction

Monitoring Program History

The Olympic Forest Collaborative (OFC) was initiated in 2013-2014 by US Representative Derek Kilmer as a key element of an effort to increase the total timber volume harvested from the Olympic National Forest (ONF), stabilize and support the local timber-focused economy, and improve forest and watershed health across the Olympic Peninsula. OFC was organized as a functioning entity by 2015, and has since been continually working with the ONF to plan and implement restoration thinning projects yielding both merchantable timber and improved ecological conditions.

As projects proceeded to implementation, the need was recognized to collect post-treatment data to monitor for effectiveness in creating desired forest conditions. Over time, OFC has come to value quantitative treatment monitoring as the best way to verify that project implementation matches planned treatments, understand project outcomes, identify required adaptations for future work, and communicate project results to a broader audience. Between 2019 and 2022, pre- and/or post-treatment monitoring plots were installed across six OFC project areas. In 2021 OFC published the OFC Monitoring Plan which formalized OFC's treatment monitoring program.

The OFC is seeking funding to continue the monitoring program. The data is available upon request for DNR, the ONF, other agencies, academic institutions, and other researchers. Please advise if DNR would like access to the raw data. The OFC plans to post reports on the website.

Monitoring Program Objectives

The overarching goal of OFC's monitoring program is to quantify the outcomes of forest management actions, track how well forest conditions are approaching the desired forest conditions, and to inform best management practices in future ONF timber harvest projects.

A secondary goal of OFC's monitoring work is to supply the ONF with data characterizing the changes to forest stands brought about by thinning treatments. While the Forest Service does monitor at a regional level for late successional forests, habitat of certain species, and watershed conditions, the ONF does not have a stand-level treatment monitoring program. OFC hopes that pre- and post-treatment data collected by OFC and made available to the

public will provide insights into the ecological impacts and benefits of forest thinning on the ONF and build trust between the ONF and interested members of the public.

Monitoring Report Objectives

The primary objectives of this report are to quantify the methods, analysis, results, and recommendations from the monitoring work carried out as part of the OFC monitoring program thus far.

In this document we briefly describe the OFC restoration projects for which monitoring data has been collected, including the biophysical setting, recent history of management and monitoring, management objectives, and monitoring objectives. We then describe methods though which monitoring data was collected, processed, and analyzed. We present descriptive metrics for each project area, including plot- and stand-level summary metrics, species composition metrics, as well as metrics describing understory species diversity and cover, and volume and cover of downed wood and snags.

We conclude with a discussion of the implications of these results within the context of the OFC monitoring program goals. The overarching goal of OFC's monitoring is to quantify the outcomes of forest management actions, track how well forest conditions are approaching the desired forest conditions, and to inform best management practices in future ONF timber harvest projects.

Methods

Project Areas

H to Z

The H to Z project area is located just south of the Sol Duc River and north of Cooper Rand road, approximately one mile down Cooper Ranch road from the intersection of Highway 101. The land classification is Adaptive Management Area (AMA).

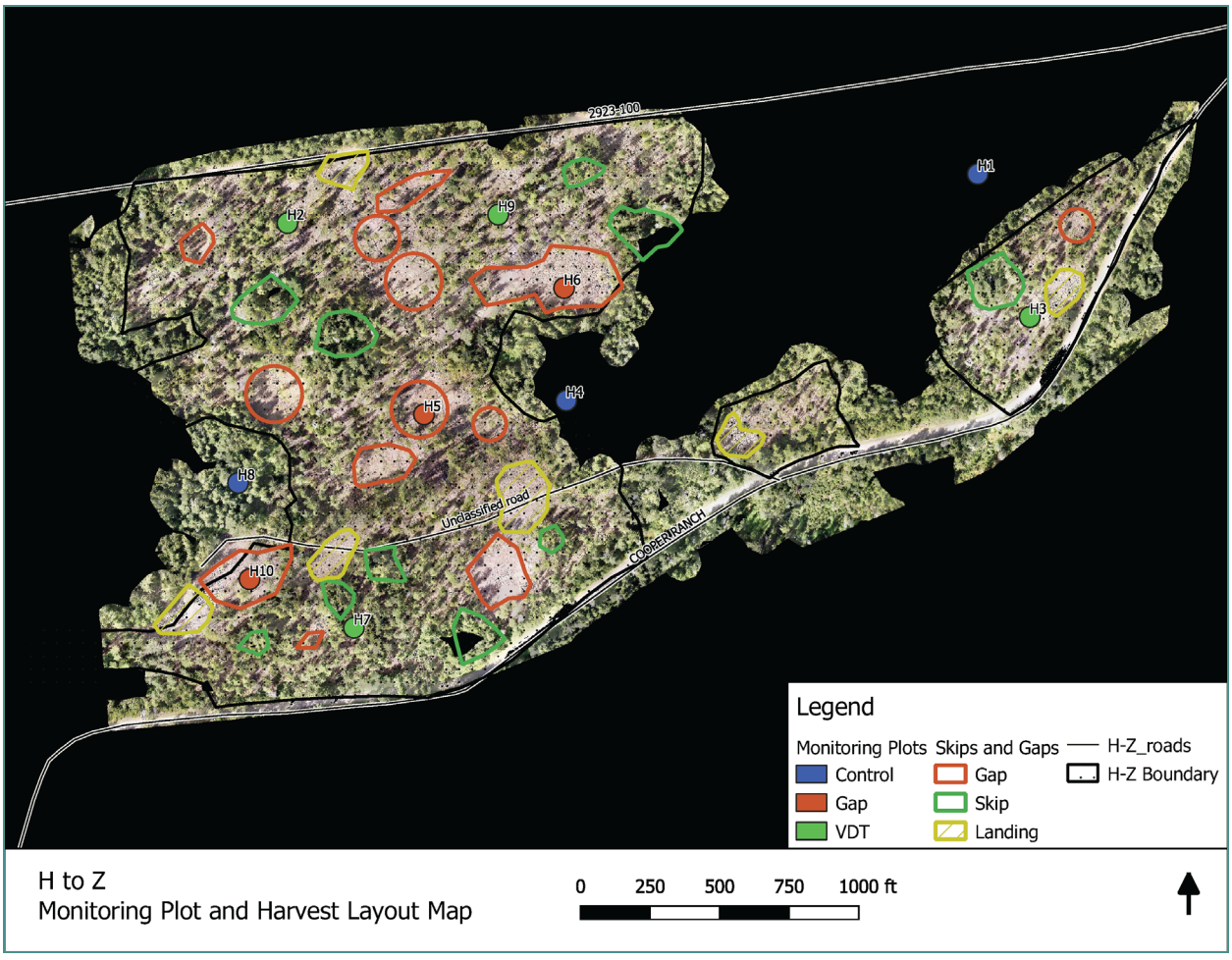

Figure 1 H to Z monitoring plot and harvest layout map

The H to Z project area elevation is 730 to 790 feet with annual precipitation ranging between 90 to 100 inches. Soils consist of alluvial gravels and sand deposited by the Sol Duc river and are classified as Nanich-Solduc cpx, 1-5% slopes. There is no perching agent (till or heavy

clays) in the project area, thus water percolates readily down through the profile and does not express itself at the surface. Soils are somewhat excessively drained with high bearing strength and resistance to compaction.

There are no streams, wetlands, seeps, or other riparian features within the project area. The northern boundary is approximately 575 to 1300 feet from the channel edge of the Sol Duc River. The project area has gentle topography (0% to 10% slopes) and is bisected by a short, east-west 50-degree slope. Roughly one third of the unit is on the southern upper bench, while the other two thirds are on the lower northern bench.

Figure 2 Post treatment site conditions as observed from plot 5.

Of the 116-acre unit, 76 acres were commercially thinned in 2016. Ten monitoring plots were installed in 2019. The treatment was a designation by description (DxP) variable density thinning with delineated skips between 0.2 and 2 acres. Major objective for this project were:

- Acceleration of the development of old forest characteristics.
- Demonstration of prescriptions more attentive and variable than standard first-entry projects on the ONF.
- Provision of revenue for stewardship projects.
- Increase of wind and drought tolerance by shifting species composition.
- Evaluation of the efficiency and efficacy of DxP prescriptions.

- Application of adaptive learning through monitoring.

The OFC's long-term desired future condition for the H to Z project area was to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics were a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to high (10-20% ground cover), and there would be at least 4 large snags per acre over 20 inches in diameter at breast height (DBH) and 15 feet tall. Species composition would be a relatively even mix of Douglas-fir, western hemlock, sitka spruce, red cedar, along with lesser amounts of broadleaf species such as big leaf maple, red alder, and black cottonwood.

Queets Corner

The Queets Corner project area is located in the western foothills of the Olympic Mountains in the Queets HUC-10 watershed and Salmon River sub-watershed. The unit is approximately eight miles northwest of Amanda Park, WA, accessed from the Forest Service Road 21 approximately 4.5 miles from the road origin at US Highway 101, and then following one mile of DNR forest roads. Queets Corner is in Late Seral Reserve (LSR) land use allocation and is categorically excluded from documentation in an environmental analysis or environmental impact statement under 36 CFR 220.6(e)(12) of the National Environmental Policy Act (NEPA).

Queets Corner occupies a ridge descending from northeast to southwest. The majority of the stand is a southeast-facing slope, though substantial portions of the stand face west and north (working round the ridge). Elevation is approximately 725 feet above mean sea level. The majority of the project area is southeast facing, with portions of the project being southwest and northwest facing on the western and northern sides of the ridge. According to the Queets 2015 EA, soils in the majority of Queets Corner (formerly unit C6) are durable to ground-based logging. The bottomland area in the southeastern most part Unit 2 is sensitive.

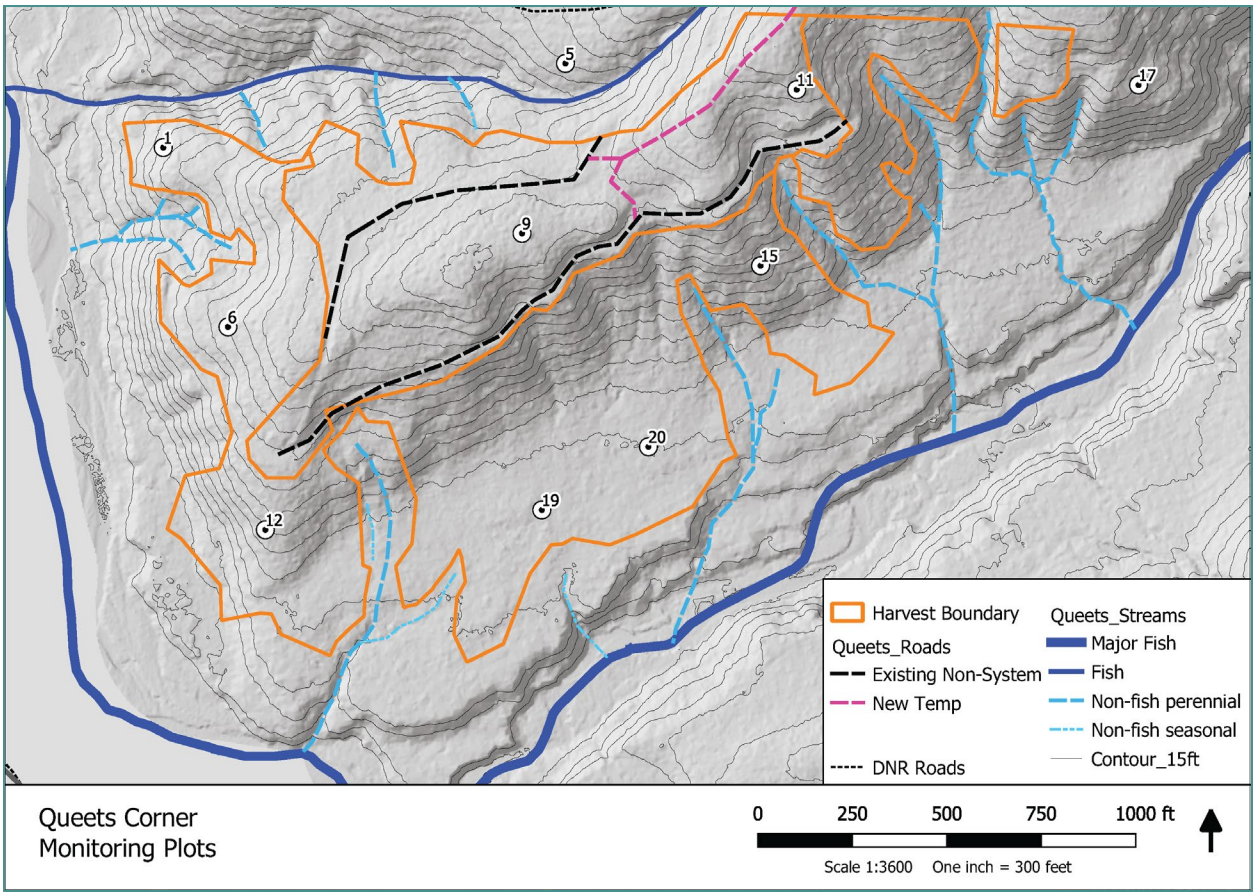

Figure 3 Queets Corner monitoring plots

There are a total of 24,349 feet of stream within the project area. 10,591 feet of stream were classified as fish bearing, while the remaining 13,758 was classified as non-fish perennial or seasonal. Several seeps were identified at Queets Corner. All seeps were hydrologically connected to streams and were incorporated into the steam buffers.

Of the 74-acre project area, 46 acres were selected for treatment. In 2019 10 pre-treatment monitoring plots were installed. In 2021 the treatment area was commercially thinned. All pre-treatment monitoring plots were re-measured immediately following the commercial thinning. The treatment was a DxP variable density thinning with delineated skips and openings. Invasive weed treatments, deadwood creation, and road decommissioning were additional elements of this treatment.

Figure 4 Queets Corner post-treatment site conditions as observed from plot 9

The OFC's long-term desired future condition for Queets Corner was to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics included a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to high (10-20% ground cover), and there would be at least 4 large snags per acre over 20 inches DBH and 15 feet tall. Stands would be dominated by western hemlock and Sitka spruce, but also have a diverse mix of western red cedar, red alder, and silver fir.

WWB

The WWB project area is located in the eastern foothills of the Olympic Mountains. The WWB project area is approximately 10 miles northeast of Skokomish, Washington and is accessed from W Skokomish Valley Rd. The project area is immediately adjacent to road NF-2340. The WWB project area falls within the Lower North Fork Skokomish River watershed. The land classification is LSR and Riparian Reserve.

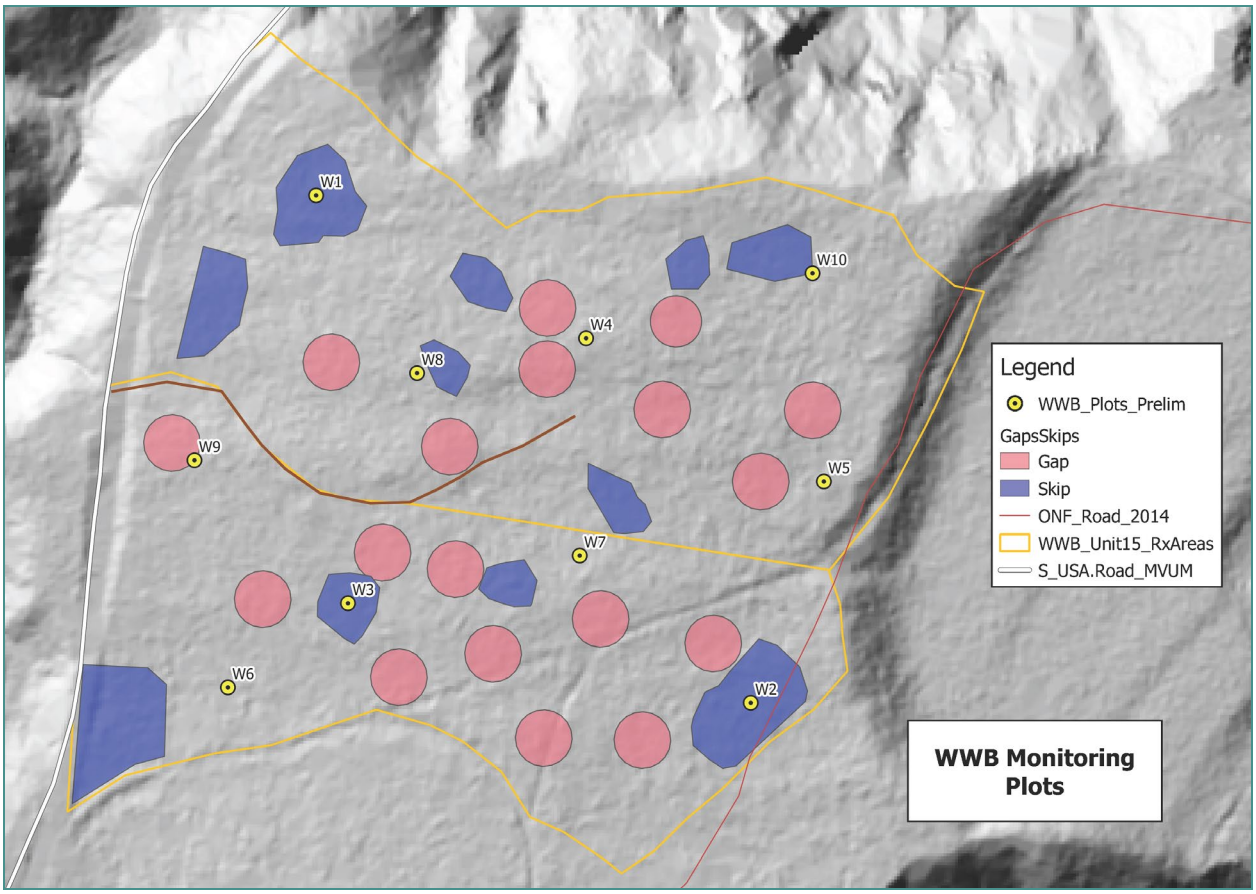

Figure 5 WWB monitoring plot locations

Topography of the WWB project is moderate with an average slope of 11% and a dominant east-facing aspect. Average elevation within the project area is 696 feet above sea level. Soils in the WWB project area generally have a shallow water table due to a compacted till layer at a depth of 2 to 5 feet. The primary concern in these stands is the potential for soil compaction and puddling by ground based operations during wet conditions. No streams are present in the WWB project area.

Figure 6 WWB post-treatment conditions observed from plot 2

The WWB project was commercially thinned in 2018. In 2020 ten post-treatment monitoring plots were installed throughout the project area. No pre-treatment monitoring took place in the WWB project area. The treatment was a Designation by Description (DxD) thinning from below with multiple density targets throughout the unit. Skips, gaps, and clumps were important elements of the treatment design.

The OFC's long-term desired future condition was to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics included a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and shade tolerant trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to high (10-20% ground cover), and there would be at least 4 large snags per acre (over 20 inches DBH and 15 feet tall).

Humptulips

The Humptulips project area is located in the Pacific Ranger District of the ONF. The Humptulips project area is located in the western foothills of the Olympic Mountains in Township 16 N, Range 13 W, Section 2 in Grays Harbor County, Washington. The unit is

approximately 17 miles south of Quinault, WA, accessed from Donkey Creek Road / Forest Service Road 22 at approximately 7.8 miles from the road origin at US Highway 101 and from FS 2204000. The project is in the Humptulips HUC-10 watershed and Lower West Fork Humptulips River subwatershed (HUC 12). Most units drain to Donkey Creek. The project includes three Sale Units based on access. Humptulips is in LSR land use allocation.

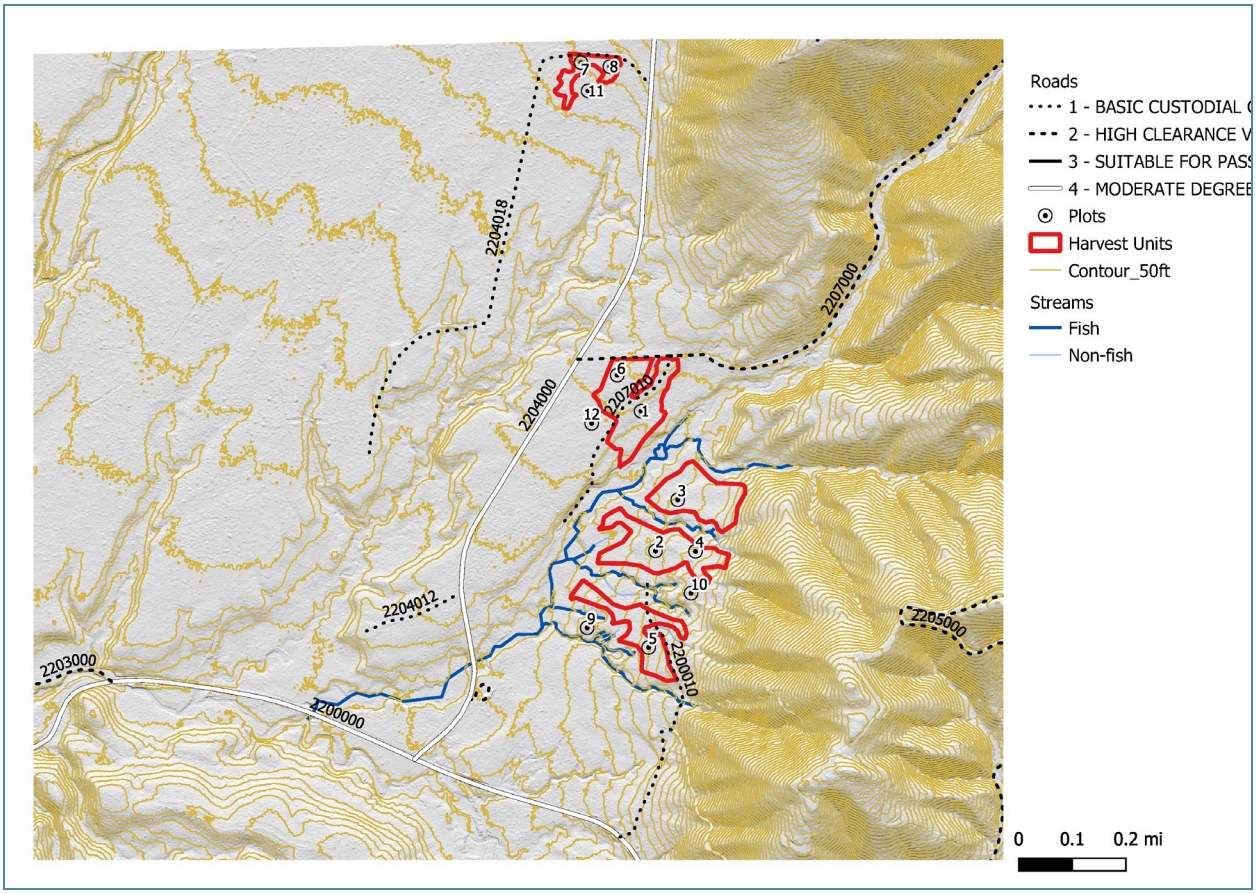

Figure 7 Humptulips monitoring plot locations

Humptulips sale units are all located on mostly flat terrain along the West Fork Humptulips River drainage. Unit 76's eastern edge abuts a steep hillside, and the harvest area includes slopes up to 35%. Generally, slopes are 10% or less and slope to the west. Unit 130 straddles a short bench with slopes up to 30% that runs northeast to southwest. Unit 155 is flat. Elevation is approximately 600 feet above mean sea level. The USDA Soil Survey for this area describes the dominant components of each soil type as "poorly suited" to timber harvest equipment operability, due primarily to low soil strength. There are 13,131 feet of stream within the project area, 10,995 feet of which were classified as fish-bearing and the remaining 2,136 feet classified as non-fish perennial or seasonal. There is 1.0 acre of wetland and seeps within the project area. At Humptulips, all seeps were hydrologically connected to streams.

The porous soil resulted in a few disconnected stream segments that originated upslope of the harvest boundary, but dissipated within the harvest area with no downstream connection. These were designated non-fish streams.

Figure 8 Humptulips pre-treatment site conditions observed from plot 10

As of the writing of this report the Humptulips project has not yet been harvested. The treatment prescribed for the Humptulips project area is a variable density thinning, generally from below, to achieve spatial patterns, density, and species compositions that will move the units on a trajectory towards old-growth structure and functions. No-treatment skips and riparian reserves are also key aspects of this prescription. Cut trees were marked in 2022. In 2021, twelve pre-treatment monitoring plots were installed in the project area.

The OFC's long-term desired future condition were to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics included a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to high (10-20% ground cover), and there would be at least 4 large snags per acre (over 20 inches DBH and 15 feet tall). Stands will be dominated by western hemlock and Douglas-fir, but also have a diverse mix of western red cedar, Sitka spruce, red alder, and silver fir.

Big Stew

The Big Stew project area is located near the northeast end of Lake Cushman in the foothills of the east slope of the Olympic Mountains in Mason County, WA. Access to the units is on State Highway 119, about 10 miles northwest of the intersection with US Highway 101 at Hoodsport. The land use allocation for the Big Stew project area is AMA.

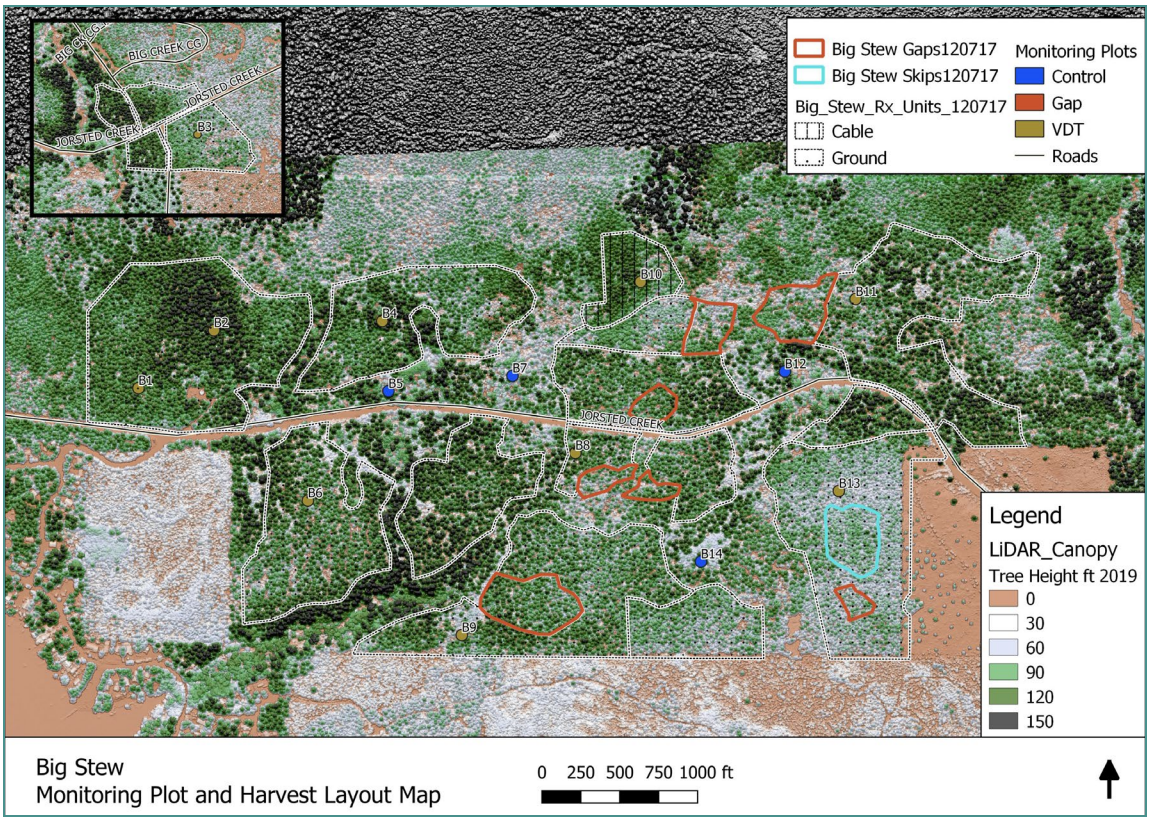

Figure 9 Big Stew monitoring plot locations

Elevation throughout the project area ranges from 950 feet above mean sea level at Big Creek, to over 1,250 feet at the northern boundary. The majority of the project area has flat to moderate terrain suitable for ground-based harvest systems. Units 2 and 3 are located on steep slopes with pitches in excess of 70%. The project area is located in the Middle Fork North Skokomish River HUC 12 watershed. All water drains to Lake Cushman, and then to Hood Canal via the Skokomish River. Big Creek is the main hydrologic feature in the treatment area, though several seasonal and perennial streams also occur in or near the treatment area. There are a total of 8,025 feet of streams within the project area, 890 of which are classified as fish bearing and the remaining 7,135 classified as seasonal non-fish and perennial non-fish.

As of the writing of this report, the Big Stew project area has not been harvested. In 2019, 14 pre-treatment monitoring plots were installed within the project area. The treatment prescribed for the Big stew project area is a combination of heavy thinning and variable density thinning. The retention of skips and creation of gaps are an important component of this prescription.

The OFC's long-term desired future conditions for this project were to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics included a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to high (10-20% ground cover), and there would be at least 4 large snags per acre (over 20 inches DBH and 15 feet tall). Stands will be dominated by larger Douglas-fir, but also have a diverse mix of western red cedar, western hemlock, big leaf maple, and red alder.

Orchard-Loner

The Orchard-Loner project area is located in the eastern foothills of the Olympic Mountains. The Orchard-Loner project is divided into multiple units across three locations – each with its own unit group designation: Orchard units, Loner, and D-units. The Orchard project area is mostly within Township 22N, Range 5W, Section 24; with a small area crossing into Township 22N, Range 5W, Section 13. Loner is entirely within Township 22N, Range 5W, Section 36. The D-units are entirely within Township 22N, Range 5W, Section 14. The entire Orchard-Loner project is within Mason County, Washington. Orchard-Loner is approximately 10 miles northeast of Skokomish, Washington and is accessed from W Skokomish Valley Rd. All of Loner and most of Orchard and a small part of the D-units fall within the Lower North Fork Skokomish River watershed, with a small portion of Orchard and most of the D-units falling within the Lower South Fork Skokomish River watershed. Orchard is a total of 73 acres, Loner is a total of 29.5 acres, and the D-units total 72.6 acres. The majority of the Orchard-Loner units are classified as AMA, with two units classified as LSR.

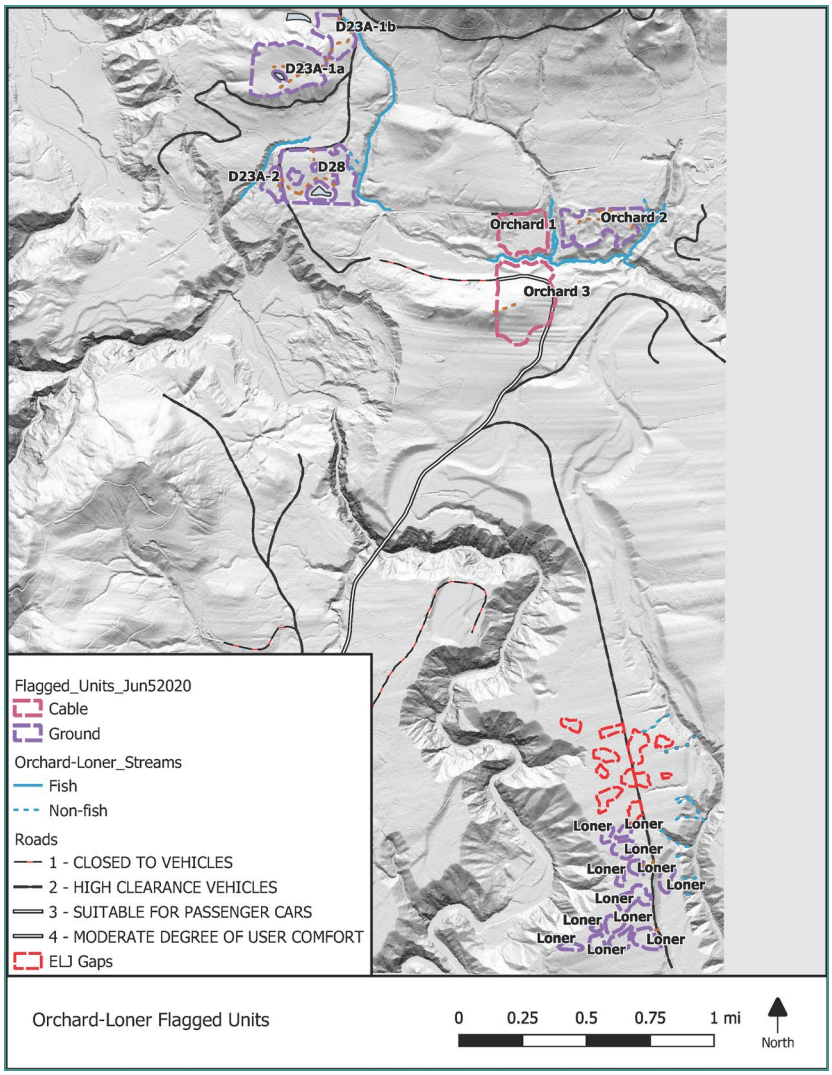

Figure 10 Orchard-Loner project area

The Orchard sale units are located on mixed terrain and slope along the north and south side of Frigid creek within the Lower North Fork and Lower South Fork Skokomish River watersheds. The southern half of Orchard-1 is mostly flat and abuts a short but steep hillside with slope exceeding 50% in some places. Elevation is about 650 feet above sea-level. Orchard-2 is variable throughout the unit. The terrain rolls up and down creating small hills with steep sides and flat areas in between. Elevation is about 650 feet above sea-level. Orchard-3 is centered around a flat hilltop with steep slopes extending in all directions. Elevation ranges from about 620 feet to 900 feet above sea-level. The Loner sale unit is located on a flat ridge with very steep slopes to the west and east, and an extension of the flat ridgetop to the north and south. Loner is about 650 feet above average sea-level. The slightly discernable aspect faces east. The D-units are mostly less than 25% slopes. All the D-

units exhibit a wide range of aspects with the majority of the units being generally south facing. The units are bounded by sleep slopes that descend to either a road or stream.

Soils in the Orchard-Loner project area are described as Moderately deep, well drained soils, Moderately deep, moderately well drained soils, Very deep, well drained soils, or Deep, well drained soils. Wind throw potential ranges from Moderate-Low to Moderate. A total of 13,177 feet of streams were observed within the Orchard-Loner project areas, 5,577 of which were classified as fish-bearing and the remaining 7,600 of which were classified as non-fish perennial or seasonal. 2.85 acres were classified as wetlands or seeps.

Figure 11 Orchard-Loner pre-treatment site conditions

As of the writing of this report, the Orchard-Loner project area has not been harvested. In 2022 UAV lidar data was flown across all units. The treatment prescribed for the Orchard-Loner project area is a combination of variable density thinning and gap cuts to achieve spatial patterns, density, and species compositions that will set the Orchard-Loner units on a trajectory towards old-growth structures and functions. The variable density thinning operations will use a basal area (BA) retention target while the gap cuts will use a trees per acre (TPA) retention target. Canopy openings and no-treatment skips are also key aspects of this prescription.

The OFC's long-term desired future condition was to obtain habitat characteristics that are found in fully functioning late successional/old growth forest. Desired characteristics included a patchy, multilayered canopy with a high degree of crown closure and trees of several age classes. The overstory would include large diameter trees (exceeding 36 inches DBH) with broken tops and other indications of old and decaying wood in some individuals. The understory would include a variety of herbs and shrubs on the forest floor, and trees with a range of diameters and ages. Levels of coarse woody debris would range from moderate to

high (10-20% ground cover), and there would be at least 4 large snags per acre (over 20 inches DBH and 15 feet tall). Stands will be dominated by Douglas-fir and western hemlock, but also have a diverse mix of western red cedar, red alder, and western white pine

Field Data Collection

Field data collection efforts followed the 2021 OFC Monitoring Plan. Monitoring plots installed prior to 2021 used early versions of this protocol and data collected had minor variations compared to plots installed in 2021 or later.

Plot center locations were selected based on digital and field reconnaissance data when available. A minimum of 1 plot per 10 acres, and 5 plots per forest strata were selected through a process of random assignment followed by manual adjustments to avoid logistical issues such as boundaries, access, and non-forest patches.

Overstory trees equal to or greater than 8 inches DBH within a 37.2 foot (1/10 acre) radius of plot center were spatially located and inventoried for species, diameter, wildlife characteristics, and aliveness. A subset of trees was subsequently inventoried for height. A single site tree was cored and age was recorded. Small trees less than 8 inches DBH within the same plot area were tallied by species within 2-inch diameter bins.

Two 150-foot woody debris transects were installed originating from the plot center at 90-degrees from one another using a random azimuth for the orientation. Diameter and decay class for all woody debris greater than 2 inches in diameter were recorded.

Four 3-meter by 3-meter vegetation plots were established in cardinal directions 10-meters from the plot center. Within each plot, biomass was estimated following The Olympic Natural Resources Center Long-term Ecosystem Productivity BioCube workbook and protocol. Understory cover percent by species was also recorded for each plot.

UAV Lidar Data Collection

Data was acquired in one mission consisting of several flights. Flight length was constrained by battery life; each battery allowed for single coverage of approximately 50 ac. Lidar

collection flights was performed in sequence with imagery collection flights to allow for individual optimization of flight parameters for each data type.

Data was collected at a ground speed of 6.5 m/s at an altitude of 60 m AGL. Flight lines were arranged as a square crosshatch pattern, with 60 m flight line spacing and 135 m swath width yielding >50% sidelap. The complete sidelap and crosshatch pattern ensured that each point within the area of interest was viewed from at least four different angles.

We established 4-6 ground control points near the four corners and center of each acquisition area. Each control point featured a retroreflective three-dimensional target with center points that were clearly discernible in the lidar point cloud. Control points were georeferenced using real-time kinematic GNSS, where the rover unit was corrected by our local base station.

Mission control and planning was accomplished using Litchi (VC Technology Ltd). Raw files from the lidar sensor was input into Inertial Explorer (NovaTel) for GNSS/trajectory processing. After differential correction was completed and the flight trajectory was resolved, the data was processed into a final point cloud using ScanLook PC (LidarUSA). Ground control corrections and bore sight adjustments (as needed) was made at this time as well. Each of these steps included internal QC reporting and flags to ensure that accuracy was within specified tolerances.

The quality of the final point clouds was manually verified using Global Mapper (Blue Marble Geographics). Data was visually reviewed for coherence between flight lines, continuity, and calibration of intensity values. Any necessary QC corrections was made in Global Mapper where possible, or earlier in the workflow when required.

After QC was completed, Global Mapper and Quick Terrain Modeler was used to classify point clouds as ground or non-ground and create the final raster data products.

UAV Lidar Data Analysis

All las file processing took place in R Studio using the LidR package. Las files were retiled into 400m2 chunks. We then created digital terrain models (DTM) from these data using the Triangulated Irregular Network (TIN) algorithm; this algorithm was chosen because it is computationally simple and because there is an abundance of data points on which to interpolate. We then normalized the height values based on the DTM.

We rasterized the normalized height values at a resolution of 1m2 using the point-to-raster algorithm (p2r), again because of its computational simplicity and speed. Following this, we calculated a suite of height-related metrics (see list below) at 1m2 derived directly from the lidar data using an area-based approach, i.e. based on rasters as opposed to point clouds.

From the lidR package wiki (https://github.com/r-lidar/lidR/wiki/stdmetrics):

- zmax: maximum height
- zmean: mean height
- zsd: standard deviation of height distribution
- zskew: skewness of height distribution
- zkurt: kurtosis of height distribution
- zentropy: entropy of height distribution (see function entropy)
- pzabovezmean: percentage of returns above zmean
- pzabovex: percentage of returns above x.
- zqx: xth percentile (quantile) of height distribution
- zpcumx: cumulative percentage of return in the ith layer according to Wood et al. 2008 (see metrics named d1, d2, ...)

Results

Queets Corner

Pre-treatment Conditions

Table 1 Queets Corner pre-treatment summary metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
1	321	12.9	13.2	307	99	509	84
5	331	14.1	14.2	364	98	591	97
6	331	15.9	15.9	459	90	717	115
9	391	13.5	13.7	397	101	653	108
11	271	11.2	11.0	180	109	317	54
12	351	13.8	14.2	386	94	628	102
15	401	11.1	11.4	283	105	494	84
17	411	10.6	10.9	266	112	470	81
19	291	14.1	14.1	313	97	512	84
20	221	13.7	14.1	239	96	390	64
Average	332	13.1	13.3	319	100	528	88

No trees were observed in monitoring plots with diameters equal to or greater than 36.0 inches at breast height. There was an observed average of 12 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 6 of the 10 inventoried plots.

Queets Corner was observed to have a pre-treatment total species richness of 11 and an average plot-level richness of 3.3. The average Shannon Diversity index was 0.60. Average understory cover was 44.6%.

Snags were observed at a rate of 6 TPA and had a quadratic mean diameter (QMD) of 5.3 inches, comprising 4 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 5% and right skew distributed in decay classes 3-5. Total cover by downed dead wood was 18%. The project area had a percentage of stem volume in snags and logs averaging 13%.

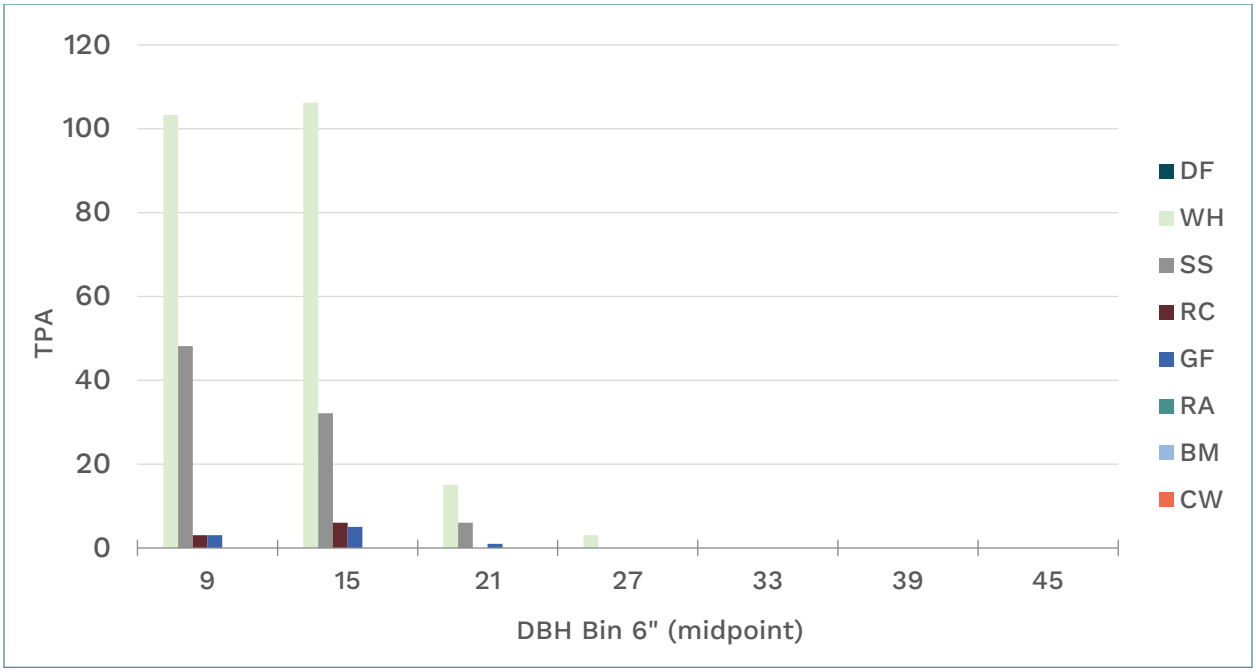

Figure 12 Queets Corner pre-treatment species by DBH

Post-treatment Conditions

Table 2 Queets Corner post-treatment summery metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
1	281	12.9	13.3	270	101	447	74
5	281	16.6	14.5	320	99	516	84
6	130	19.0	18.2	236	89	354	55
9	80	16.1	15.1	100	97	160	26
11	150	12.0	12.2	122	99	209	35
12	110	14.9	15.2	139	92	223	36
15	251	12.2	12.3	208	101	356	59
17	411	10.8	11.1	274	111	482	82
19	150	15.8	15.3	193	91	308	49
20	221	13.6	13.6	222	100	365	60
Average	207	14.4	14.1	208	98	342	56

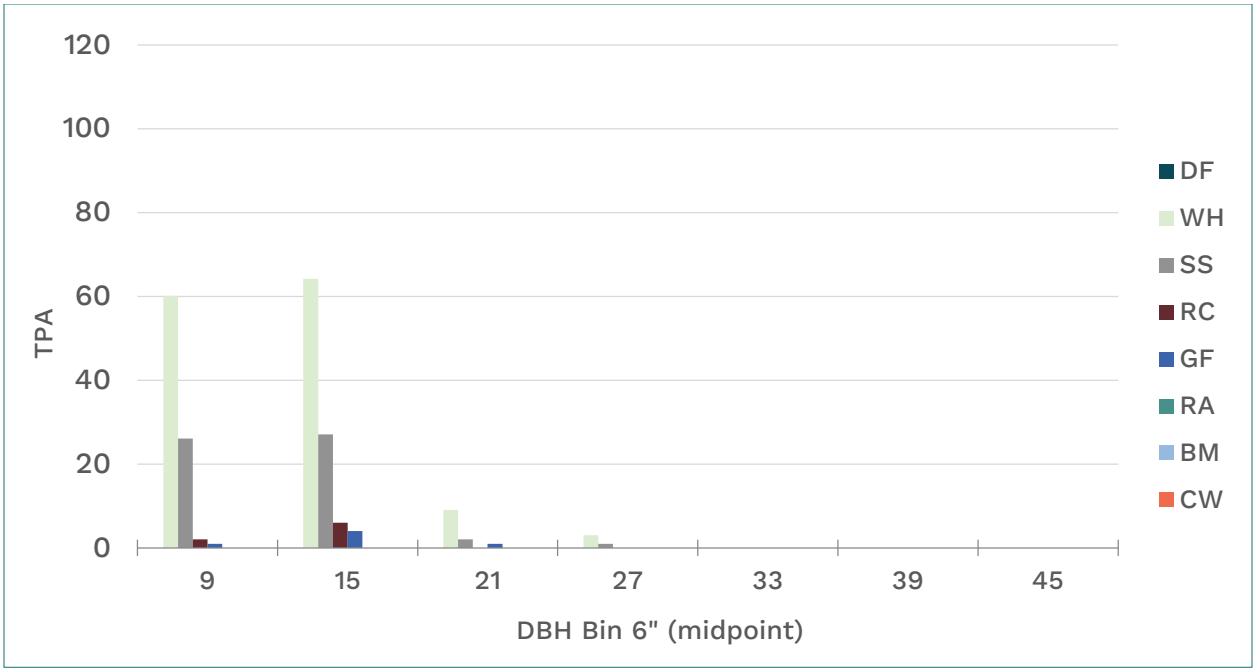

Figure 13 Queets Corner post-treatment species by DBH

No trees were observed in monitoring plots with diameters equal to or greater than 36.0 inches at breast height. There was an observed average of 26 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 7 of the 10 inventoried plots.

Queets Corner was observed to have a post-treatment total species richness of 16 and an average plot-level richness of 2.7. The average Shannon Diversity Index was 0.49. Average understory cover was 22.9%.

Snags were observed at a rate of 10 TPA and had a QMD of 6.3 inches, comprising 9 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 8% and was distributed in decay classes 1-5 with higher levels at 1 and 5. Total cover by downed dead wood was 23%. The project area had a percentage of stem volume in snags and logs averaging 28%.

Humptulips

Pre-treatment Conditions

Table 3 Humptulips pre-treatment summary metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
1	110	24.8	22.6	307	78	436	65
2	130	18.3	19.3	264	90	387	60
3	80	20.4	20.7	188	79	275	41
4	150	15.9	15.4	196	108	307	50
5	160	17.0	17.6	272	93	405	65
6	110	21.4	20.4	250	77	368	55
7	140	21.3	20.2	312	94	454	70
8	130	20.2	21.4	326	87	462	70
9	301	15.8	15.6	397	101	628	101
10	160	19.7	19.6	335	91	494	76
11	170	22.4	20.8	400	86	582	88
12	110	20.9	19.0	217	85	327	50
Average	146	19.8	19.4	289	89	427	66

No trees were observed in monitoring plots with diameters equal to or greater than 36.0 inches at breast height. There was an observed average of 15.8 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 9 of the 12 inventoried plots.

Humptulips was observed to have a pre-treatment total species richness of 20 and an average plot-level richness of 4.7. The average Shannon Diversity index was 0.89. Average understory cover was 61.0%.

Snags were observed at a rate of 13 TPA and had a QMD of 10.0 inches, comprising 12 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 4% and was left skewed in decay classes 4 and 5. Total cover by downed dead wood was 12%. The project area had a percentage of stem volume in snags and logs averaging 15%.

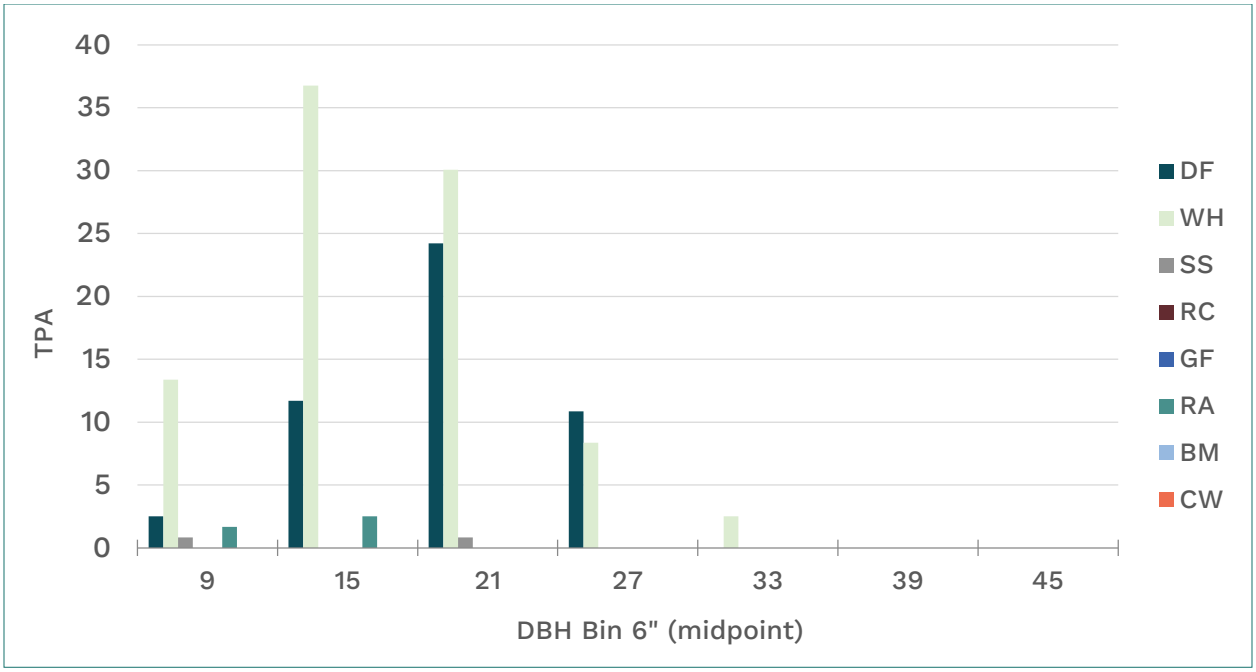

Figure 14 Humptulips pre-treatment species by DBH

Big Stew

Pre-treatment Conditions

Table 4 Big Stew pre-treatment summary metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
B1	140	19.9	19.5	290	77	425	66
B2	70	43.8	23.6	212	83	293	44
B3	200	13.0	13.6	203	90	331	55
B4	150	26.0	26.4	571	67	763	111
B5	120	25.6	25.8	437	67	579	86
B6	110	17.2	18.7	211	78	307	49
B7	90	23.6	21.6	230	57	324	50
B8	110	19.1	17.8	190	69	287	45
B9	160	17.0	15.4	208	82	322	53
B10	211	15.0	14.6	245	89	394	64

B11	100	13.5	14.6	116	71	183	30
B12	90	24.8	28.1	388	59	493	73
B13	200	14.3	12.9	181	83	304	51
B14	40	25.0	26.7	156	58	207	30
Average	128	21.3	19.9	260	74	372	58

There were an observed 4 TPA ≥ 36.0 inches DBH, which comprised 39 ft^2ac^{-1} BA. There was an observed average of 4.3 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 5 of the 14 inventoried plots.

Big Stew was observed to have a pre-treatment total species richness of 34 and an average plot-level richness of 6.7. The average Shannon Diversity index was 1.23. Average understory cover was 89.4%.

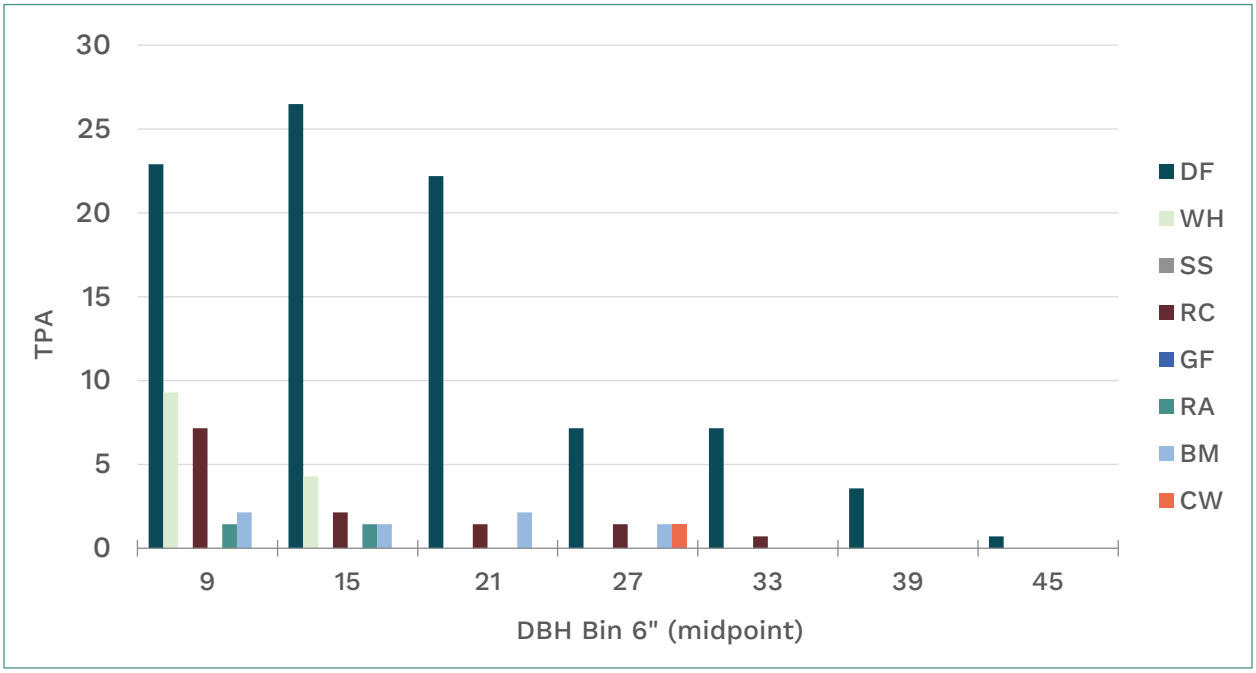

Figure 15 Big Stew pre-treatment species by DBH

Snags were observed at a rate of 6 TPA and had a QMD of 5.3 inches, comprising 4 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 3% and evenly distributed in decay classes 3-5. Total cover by downed dead wood was 8%. The project area had a percentage of stem volume in snags and logs averaging 17%.

Orchard-Loner

Pre-treatment Conditions

Table 5 Orchard-Loner lidar data summary metrics. Values represent elevation (ft) above ground level across each unit

Unit	Min	1st Qu	Median	Mean	3rd Qu	Max
Loner	0	3.97	70.21	54.56	88.52	139.08
Orchard 1	0	76.74	103.67	93.51	121.85	180.93
Orchard 2	0	84.67	105.84	97.47	121.26	168.96
Orchard 3	0.001	74.653	94.596	86.751	109.237	164.304
D28	0	62.36	97.34	82.15	113.9	175.83
D23-1A	0.002	79.289	96.653	89.347	110.472	164.482
D23-1B	0	49.92	88.27	77.55	109.48	157.35
Loner	0	3.97	70.21	54.56	88.52	139.08

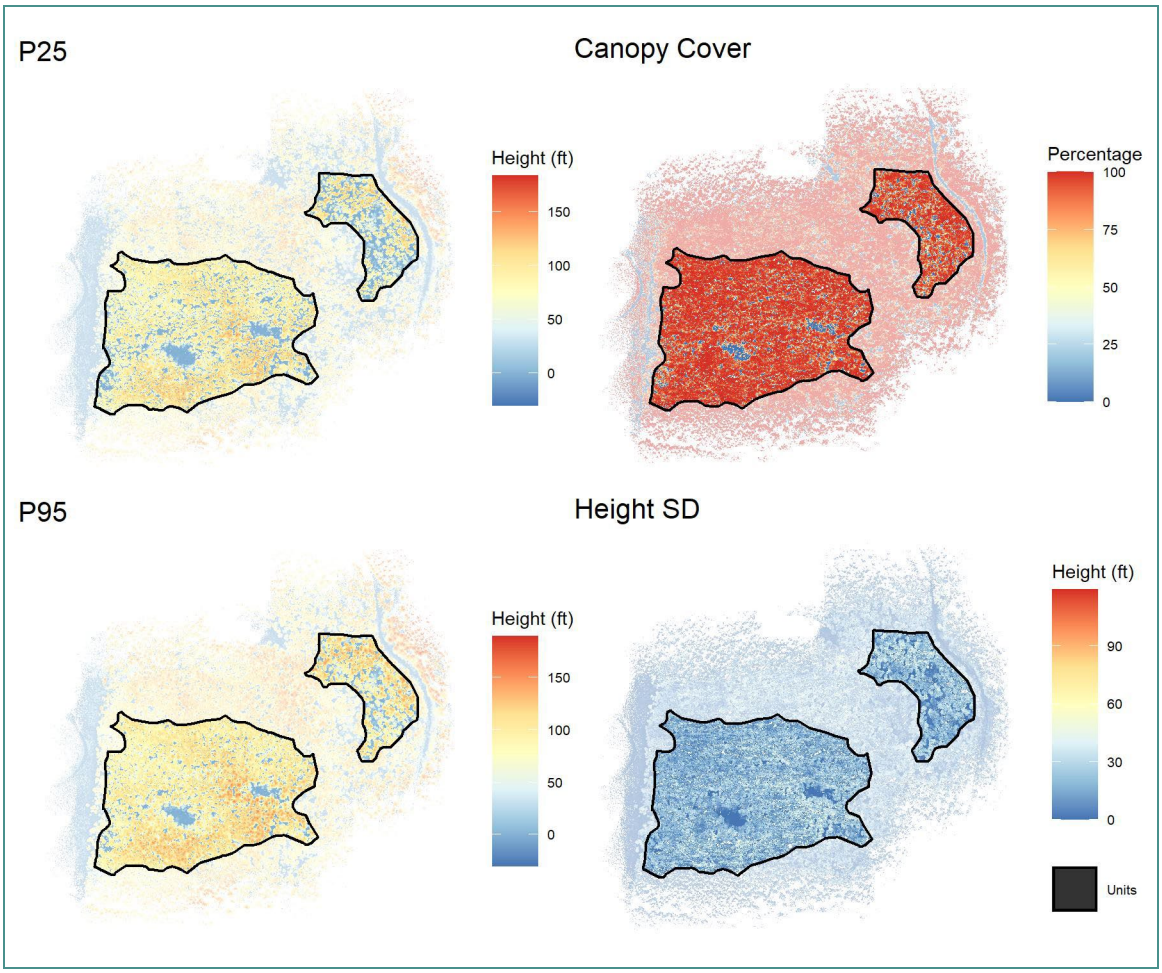

Figure 16 D23-1A and D23-1B lidar summary metrics

The D23-1A and D23-1B acquisition has two large, homogenous gaps with very short trees or possibly undercover only. These could be perhaps due to small, neighborhood scale disturbances such as pathogens or wind throw. In the NE unit, there are more heterogeneous gaps compared to the large homogenous gaps in the SW unit. The NE unit gaps have more vertical complexity as well. P95 is similar across the units but P25 is lower in the NE unit, implying differing stand structures between units.

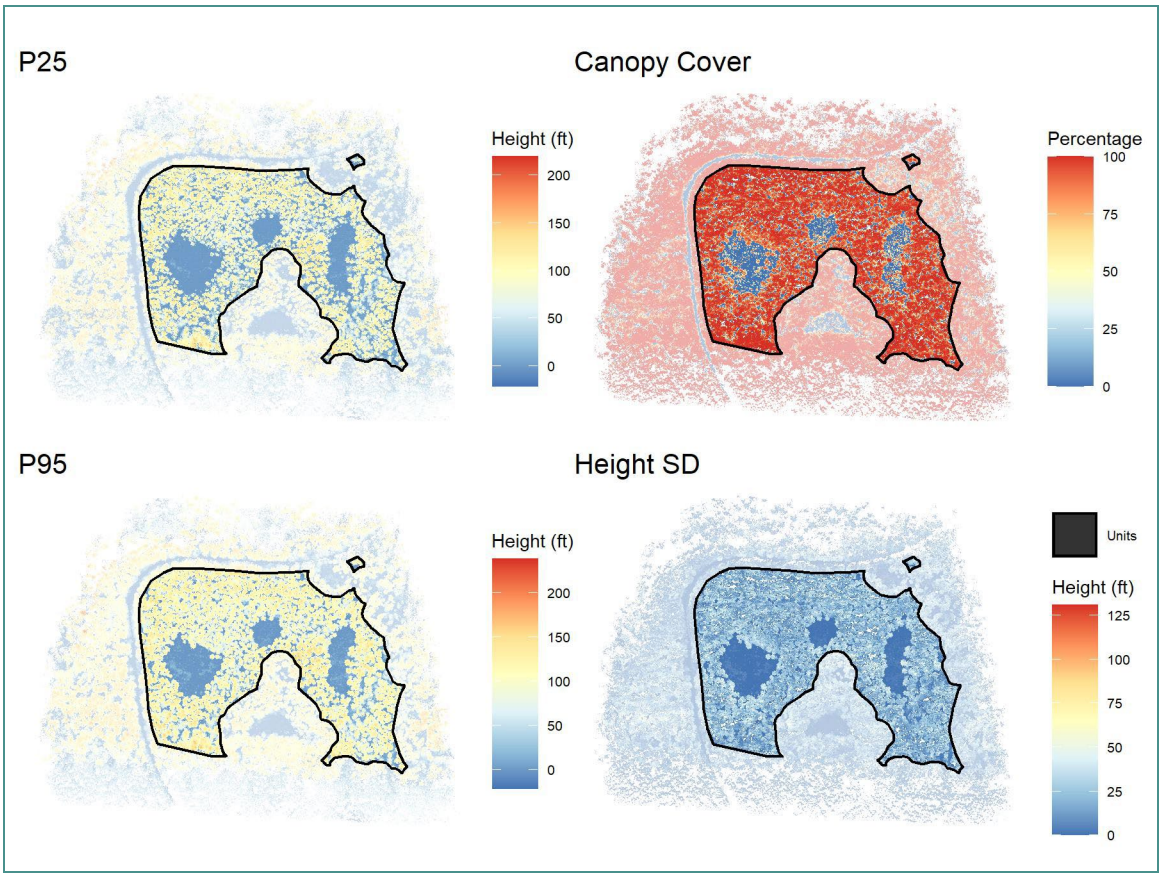

Figure 17 D28 lidar summary metrics

The D28 acquisition has three large, homogenous gaps with very short vegetation and no complexity. These gaps are larger than the gaps described in the prior acquisition. There is a linear relationship present between P25 and P95. Spacing between trees is even. The units are quite homogenous, either within the gaps or within the forested areas.

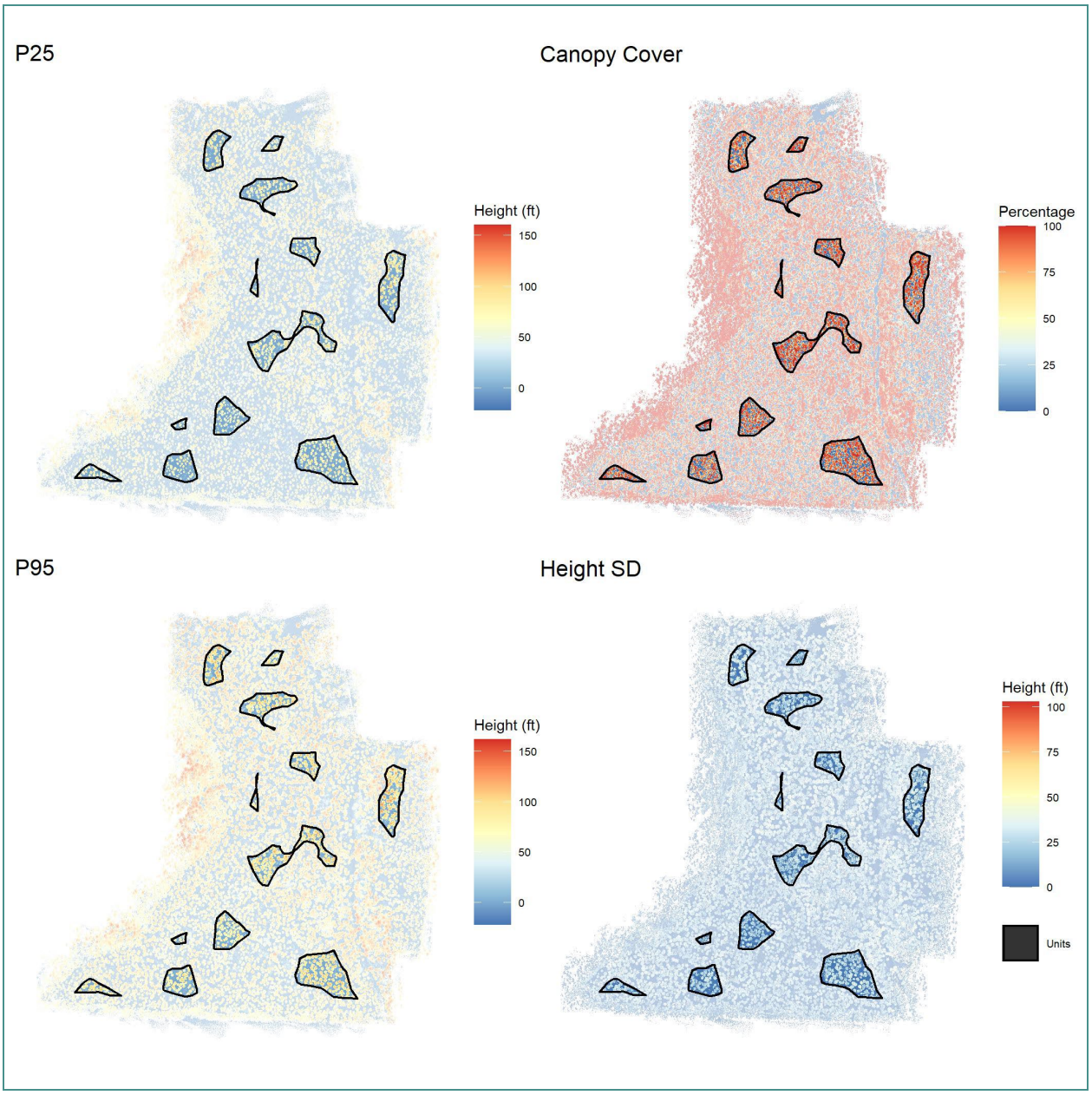

Figure 18 Loner units lidar summary metrics

The Loner acquisition appears to have many small clumps and gaps that are similarly spaced, which could potentially be considered individual clumps and gaps. Consequently, there is not continuous canopy coverage and there is also more variation in canopy height SD; in short, there is high horizontal and vertical structural complexity. The spacing of these clumps and gaps is uniform in some units while not uniform in others. P25, which can be considered height to live crown, and P95 are both smaller (shorter trees) in comparison to other acquisitions.

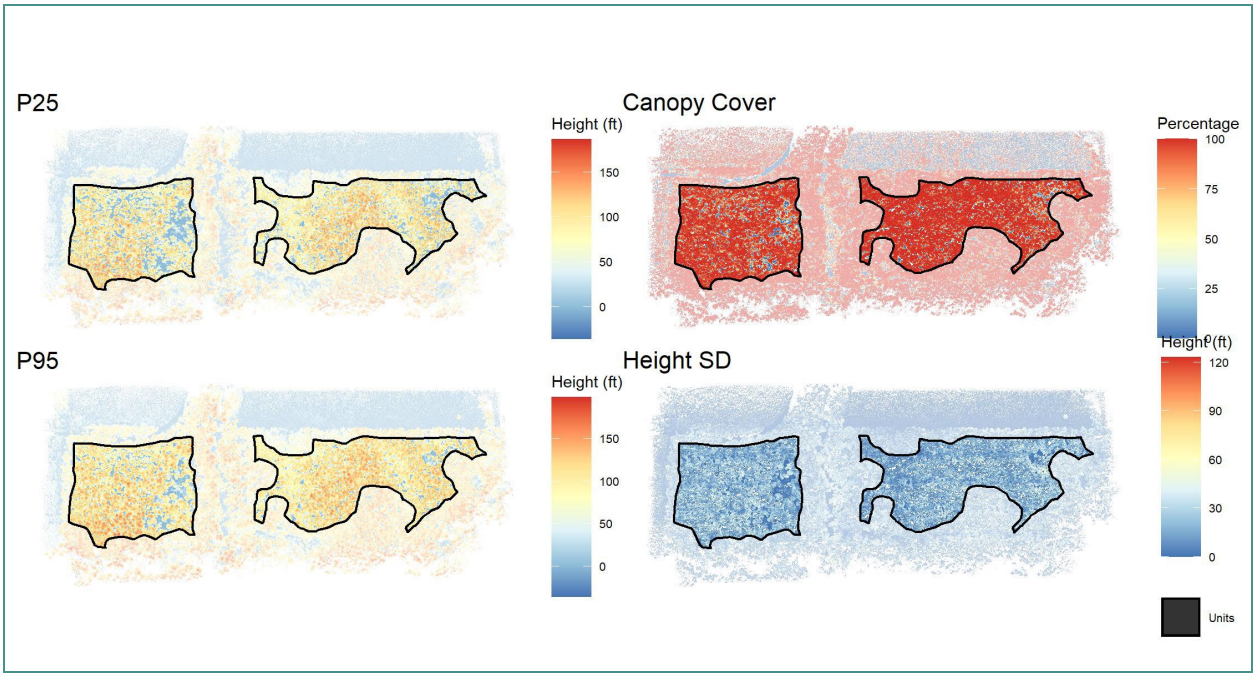

Figure 19 Orchard 1 and Orchard 2 lidar summary metrics

The Orchard 1 and Orchard 2 acquisition overall has much higher P25 and P95 (taller trees) than other acquisitions. The east sides of the two units both have clumps that have shorter, and therefore likely younger, trees. The western unit of the two has accompanying lower canopy cover while the eastern unit has the same height of trees but more closed canopy.

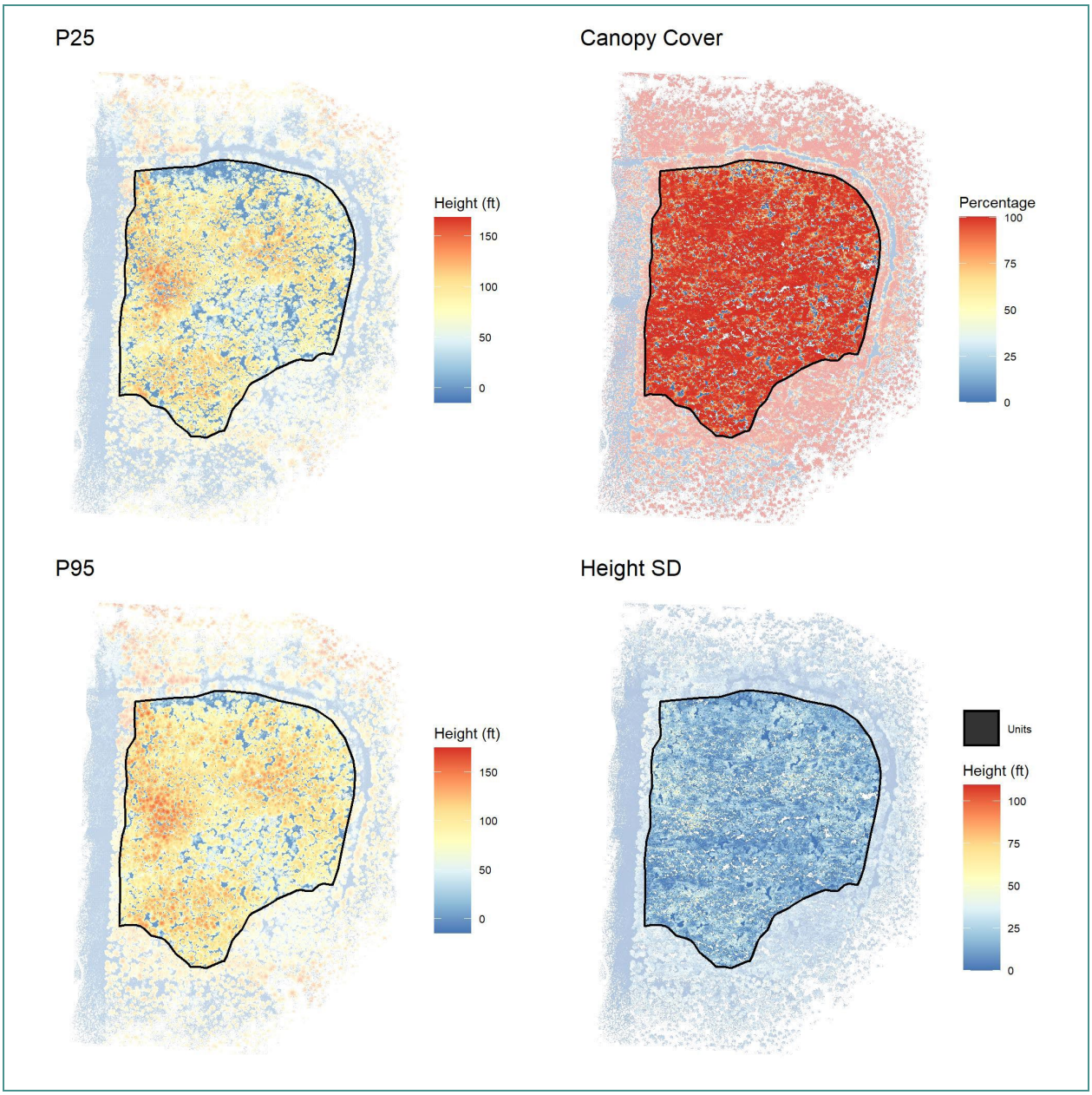

Figure 20 Orchard 3 lidar summary metrics

Orchard 3 has aggregated clumps of very tall trees. Within these clumps, there are still instances of a lack of canopy cover, creating spatial heterogeneity. In the lower central section of the unit, the clump/gap pattern is very defined compared to the rest of the unit.

H to Z

Post-treatment Conditions

Table 6 H to Z post-treatment summary metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
H1	60	22.3	20.3	135	72	198	30
H2	30	33.5	22.5	83	66	120	18
H3	30	21.3	21.5	76	71	110	16
H4	60	20.8	21.7	154	70	219	33
H5	0	0	0	0	0	0	0
H6	0	0	0	0	0	0	0
H7	50	27.0	24.5	164	69	226	33
H8	60	21.5	19.9	130	64	187	29
H9	90	24.3	23.1	262	62	360	55
H10	0	0	0	0	0	0	0
Average	38	17.1	15.3	100	68	142	26

There were an observed 1 TPA ≥ 36.0 inches DBH, which comprised 8 ft^2ac^{-1} BA. There was an observed average of 4 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 4 of the 10 inventoried plots.

H to Z was observed to have a post-treatment total species richness of 31 and an average plot-level richness of 5.9. The average Shannon Diversity index was 1.20. Average understory cover was 51.6%.

Snags were observed at a rate of 6 TPA and had a QMD of 9.2 inches, comprising 11 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 4% and was right skew distributed in decay classes 3 and 4. Total cover by downed dead wood was 30%. The project area had a percentage of stem volume in snags and logs averaging 35%.

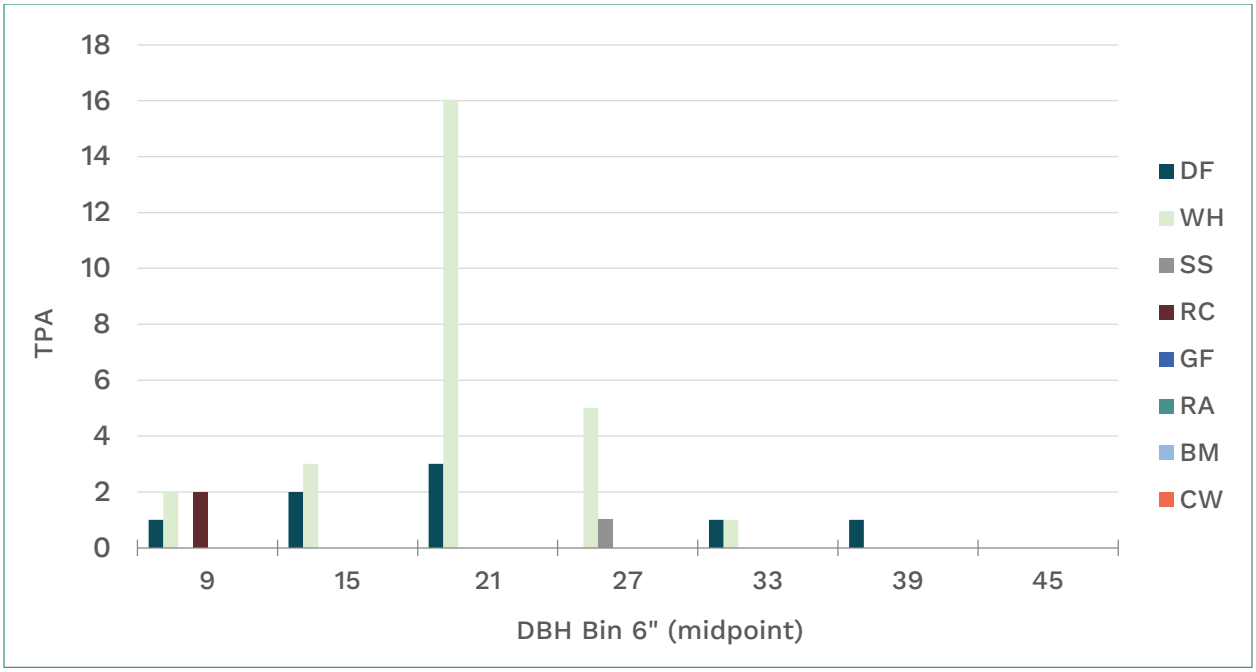

Figure 21 H to Z post-treatment species by DBH

WWB

Post-treatment Conditions

Table 7 WWB post-treatment summary metrics by plot

Plot	TPA	Avg Dbh	Qmd	BA	HDR	SDI	Curtis RD
W1	100	21.1	17.6	169	77	258	40
W2	80	13.8	14.9	97	96	152	25
W3	130	18.3	15.3	166	90	255	42
W4	100	17.3	17.1	160	85	245	39
W5	70	14.7	15.0	87	86	139	22
W6	90	17.3	17.5	151	97	223	36
W7	90	13.5	12.2	74	106	124	21
W8	70	12.3	12.6	61	93	103	17
W9	90	17.8	18.3	165	81	249	38

W10	130	14.6	14.6	152	89	244	40
Average	95	16.1	15.5	128	90	199	33

No trees were observed in monitoring plots with diameters equal to or greater than 36.0 inches at breast height. There was an observed average 8 TPA with wildlife characteristics (e.g. broken tops, forked tops, branch platforms) across all plots. Trees with wildlife characteristics were observed in 5 of the 10 inventoried plots.

WWB was observed to have a post-treatment total species richness of 16 and an average plot-level richness of 4.6. The average Shannon Diversity index was 1.01. Average understory cover was 52.7%.

Snags were observed at a rate of 12 TPA and had a QMD of 6.7 inches, comprising 10 ft^2ac^{-1} BA. Percent cover for logs (≥ 4-inches) was 5% and was evenly distributed in decay classes 3-5. Total cover by downed dead wood was 15%. The project area had a percentage of stem volume in snags and logs averaging 26%.

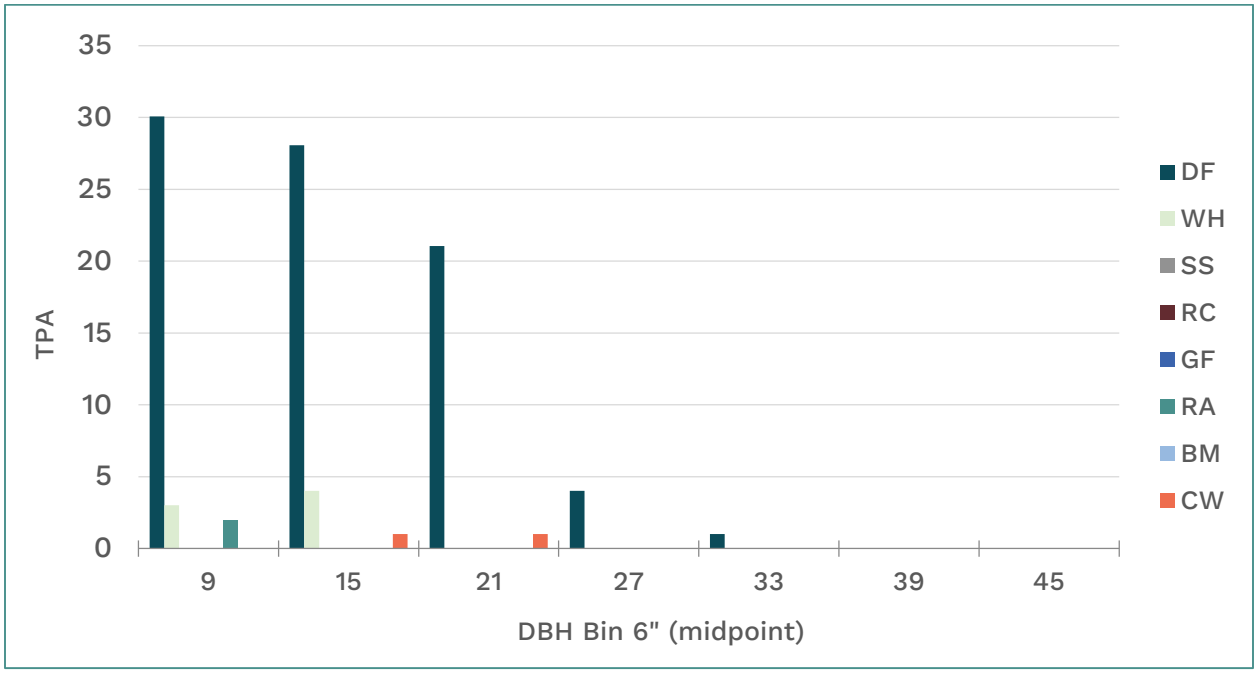

Figure 22 WWB post-treatment species by DBH

Discussion

Pre-treatment Conditions

Pre-treatment stand structural conditions were generally observed to be of single-story canopies with fairly homogenous canopy structural conditions. Queets Corner was found to be dominated by trees with diameters between 8 and 18 inches, and had a very minor component of trees with diameters 21 inches or larger. Canopy openings in Queets Corner were rare with minimum TPA values of 221 across all measured plots. Humptulips similarly had small ranges in average TPA across the project area, albeit with lower average density values. Humptulips was observed to have a broader range of diameters, but lacked distinct canopy layers. The Big Stew project area was found to have the broadest range of tree diameters and densities across the project area. The Orchard-Loner lidar data illustrated multiple large canopy opening which were known to be wet areas from field observations. These pre-treatment conditions are/were not meeting the OFC desired forest conditions of a patchy, multistoried overstory canopy.

Very few large trees exceeding 36 inches DBH were observed across all project areas and were absent from most. Of the projects for which pre-treatment monitoring data were collected, only the Big Stew project area was observed to have trees above 36 inches DBH. Trees with complex crown structures were relatively infrequent across plots and occurred at low frequencies within plots when present. These pre-treatment conditions are/were not meeting the OFC desired forest conditions of including large diameter trees exceeding 36 inches DBH, and trees with complex crown structures.

Understory species cover was moderate to high across pre-treatment conditions, however species diversity was observed to be relatively low. The Shannon Diversity Index was below 1.0 across the majority of project areas, and plot-level species richness under 5. The exception was the Big Stew project area, for which these values were 1.23 and 6.7 respectively. The Big Stew project area also had the highest average understory cover. These finding are likely related to the overall higher variation in overstory density in this project area.

Dead wood was present both as snags and downed wood across all project areas, but were generally of smaller diameters than is desired. Average snag TPA ranged between 6 and 18 across project areas, which is within the range of desirable conditions. However, snag QMD was often small ranging between 5 and 10. This is likely due to the dominance of competitive

mortality as an agent of snag recruitment across project sites. Percent cover of downed logs ranged between 3% and 5%. The majority of logs observed were of advanced decay, indicating that log recruitment has slowed. Logs and snags comprised less than 20% of all stem volume across all project sites. These pre-treatment conditions are/were not meeting the OFC desired forest conditions of containing frequent large snags and high cover of large diameter downed wood.

Post-treatment Conditions

Post-treatment stand conditions are similar to pre-treatment stands with regards to the distribution of tree sizes, but have more variable densities across the treatment areas. Queets Corner was found to be dominated by trees with diameters between 8 and 18 inches, and had a very minor component of trees with diameters 21 inches or larger. Canopy opening were found across the project area, with multiple plots occurring in areas with TPA values below 150. These plots were often within or on the edge of small opening or yarding corridors. The H to Z project area was found to have a broad range of tree diameters and densities across the project area. Diameters ranged from 8 to 39 inches, and TPA ranged from 0 to 90. Multiple plots were within openings and had no observed overstory trees. The WWB project area similarly had a broad range of tree sizes and densities, with DBH values ranging from 8 to 33 inches. Several plots were found to have TPA values below 100. These project areas appear to be on a trajectory to be meeting the OFC's desired forest conditions of a patchy, multistoried overstory canopy. The creation of more variable densities across these project areas though thinning has created patchier conditions. The creation of small openings is expected to facilitate the development of younger cohorts.

Large trees exceeding 36 inches DBH were rare across post-treatment project areas, similar to observations in pre-treatment project areas. Of the three project areas monitored for post-treatment conditions, only H to Z was found to have any trees exceeding 36 inches DBH. Trees with complex crown structures were relatively infrequent across plots, and occurred at low frequencies within plots when present. These finding are unsurprising based on our understanding of pre-treatment conditions in these project areas. Larger diameter trees appear to have been successfully retained where present. We expect both the abundance of large trees and trees with complex crown structures to continue to increase as these retained trees continue to develop.

Understory cover was moderate across post-treatment project areas. However, post-treatment species diversity was higher on average than pre-treatment project areas. The exception was the Queets Corner post-treatment Shannon diversity index, which was the lowest observed across all project areas. This is likely due to the fact that Queets Corner was measured immediately post treatment while WWB and H to Z were measured two and three years' post-treatment respectively. The reduction in understory cover and diversity observed in Queets Corner is likely due to the influence of recent operations, while WWB and H to Z had had sufficient time for recovery of the understory. Understory species diversity is expected to continue to increase for these project areas in subsequent re-measurements.

Similar to pre-treatment conditions, dead wood was present both as snags and downed wood across all project areas, but were generally of smaller diameters than is desired. Snag TPA ranged from 6 to 12 across project areas and had an average QMD of 7.5. As with the existence of large live trees, the lack of difference between snag QMD in pre-treatment and post-treatment monitoring project areas is likely due to pre-treatment conditions. Specifically, this is likely due to the lack of large diameter trees available to recruit as snags. That TPA of snags were found to be similar between pre-treatment and post-treatment project areas could indicate that rates of snag creation though mechanical intervention are not significantly altering average snag TPA within project areas. Percent cover of downed logs ranged between 4% and 8%. The majority of logs observed were of earlier stages of decay. Total percent cover of downed wood ranged between 15% and 30%. These findings indicate that treatments were successful in increasing cover by downed wood. Percentage of stem volume in snags and downed wood ranged between 26% and 35%, and was generally higher than in pre-treatment conditions. Although there was some recruitment of downed wood, these higher values are likely a reflection of the reduction in standing live volume throughout these project areas. These findings suggest that these project areas are on a trajectory to achieve OFC's desired forest conditions of including large diameter snags and abundant downed wood.

Effects of Treatment

As of the writing of this report, the Queets Corner project area is the only OFC restoration project for which pre-treatment and post-treatment monitoring data has been collected. In this section, we explore the changes in forest structure related to the desired future conditions of the Queets Corner project area.

As the Queets Corner treatment was a thinning prescription, one of the main outcomes was a reduction in density. Changes in the distribution of tree sizes appear to primarily be a reduction in TPA of smaller diameter stems, while maintaining the overall range of tree diameters within the project area. The range in plot-level TPA increased from 190 to 331. This is largely due to the variable distribution in thinning intensities, including the retention of skips and creation of openings.

While the TPA of large trees exceeding 36 inches DBH did not change as a result of treatment, the TPA of trees with complex crown structures increased from 7 to 12. The most frequent crown feature observed was forked tops, with only one tree being observed as developing a broken top since the pre-treatment measurement. It is unlikely that these trees developed fork tops in-between measurements. The most likely explanation is that the lower stand densities post-treatment facilitated clearer views of the canopies of trees, allowing technicians to observe forked tops that were previously missed in the pre-treatment inventory. Repeat post-treatment inventories will be valuable in determining if complex crown structures continue to increase over time.

There were reductions in both understory cover and understory diversity as a result of treatment. Cover showed a decrease of 50%, while the Shannon Diversity Index decreased from 0.6 to 0.5. As the post-treatment inventory took place immediately following the thinning treatment, the effects of recent forest operations were still a dominant factor for these metrics. Repeat post-treatment inventories will be valuable in determining if the reduction in overstory density and the creation of openings will affect understory cover and diversity.

There were minor increases in snag TPA (6 to 10) and snag QMD (5 to 6). The lack of difference between snag QMD in pre-treatment and post-treatment monitoring project areas is likely due to pre-treatment conditions. The minor change in snag TPA rates post-treatment may indicate that the level of snag creation during the thinning treatment were too low. However, additional mortality is expected to occur over time, so repeat post-treatment inventories will be valuable in determining long-term snag recruitment. Percent cover by logs increased from 5% to 8%, and average decay class of logs was reduced. Total cover by downed wood increased from 15% to 22%. These findings suggest that the treatment was effective in recruiting coarse wood. Additional downed wood recruitment is expected as a result of wind throw events. Repeat post-treatment inventories will be valuable in determining the long-term recruitment of downed wood.

Table of Figures