State Trust Lands Implementation Monitoring Report:

Pilot Project Comparing Different Methods for Monitoring the Large, Structurally Unique Trees and Snags Component of the Multispecies Conservation Strategy

This document is meant to fulfill the Washington State Department of Natural Resources' (DNR's) ongoing commitment to report on the implementation of the State Trust Lands Habitat Conservation Plan (HCP). The intended audience includes the Services (including the U.S. Fish and Wildlife Service and National Marine Services), the public, and DNR staff.

Executive Summary

DNR frequently retains snags and large, structurally unique trees as part of its implementation of the multispecies conservation strategy in the State Trust Lands Habitat Conservation Plan. This project was designed to assess the suitability and effectiveness of using remotely sensed data to evaluate leave tree quantity and proximity, compare leave tree proximity and quantity results from different data sources, summarize leave tree characteristics including blowdown and species diversity, and determine DNR's level of compliance in meeting the minimum leave tree quantity requirements. Leave tree proximity and quantity results from four remotely sensed data sources were compared with each other and with field data. Key findings include:

- Differing results among the data sources highlight the need to use remotely sensed data cautiously.
- Blowdown frequency of leave trees 2 to 4 years post-harvest completion averaged 16% across the field-sampled timber sale units.
- Species diversity of retained leave trees reflected species present in cruise data for the majority of field-sampled units.

- Of the units sampled with 3D Stereo NAIP[1] deviating from proximity requirements, 92% had explanatory documentation as to why, and 8% lacked such documentation.
- Leave tree quantities exceeded the minimum amount required when averaged across all field sampled units.

Overall results indicate field staff are taking a balanced approach with their leave tree strategies, by accounting for ecological and operational safety considerations.

Introduction

The multispecies conservation strategy (MCS) described in The State Trust Lands Habitat Conservation Plan (HCP, Washington State Department of Natural Resources 1997, pp. IV 145-182), which applies to all westside HCP planning units, directs DNR to provide habitat for numerous species of concern[2]. The uncommon habitats component of the MCS prescribes conservation objectives for large, structurally unique trees and snags (hereinafter collectively referred to as "leave trees") because these are important habitat elements for numerous species and are scarce in managed forests. The placement and retention of leave trees on DNR lands is implemented on all Variable Retention Harvests (VRH) within the six westside planning units, making it one of the most commonly implemented components of the HCP (Washington State Department of Natural Resources 2017). Consequently, leave trees have significant impacts on silvicultural operations, staff time expenditures during VRH layout, harvest systems, forest regeneration, and protection and preservation of various habitat elements.

DNR's procedure for the "Management of Forest Stand Cohorts (Westside)" stipulates leave tree spacing and retention quantities (PR 14-006-090, Washington State Department of Natural Resources 2009) based on direction in the HCP's MCS and other legal commitments. The document refers to leave trees as "legacy cohorts" and provides management specifications that allow DNR to comply (if implemented appropriately) with the HCP conservation objectives for the large, structurally unique trees and snags components of the MCS. Generalized[3] requirements of the procedure include:

[1] NAIP stands for the National Agriculture Imagery Program, which makes digital ortho photography available to governmental agencies and the public. In Washington, NAIP imagery is typically flown every other year with the most recent flights in Washington having occurred in summer of 2019 as of the writing of this report.
[2] Species of concern include federally listed, state listed, federal candidate, and state candidate animal species.
[3] PR-14-006-090 defines specific classes of legacy cohorts, their dimensions, and how many must be left per acre. Additionally, substitution of suitable live trees is permitted when snags are not available.

- *Proximity* – at least one clump per five acres (i.e., no voids exceeding five acres), and a distance between leave trees/clumps of no more than 400 feet (i.e., spacing of no more than 400 feet between leave trees/leave tree clumps)
- *Quantity* – retain an average density of eight leave trees per acre; acre-by-acre densities may vary as long as proximity criteria are followed

PR 14-006-090 permits flexibility by further specifying that "the density of clumps will not be less than one clump per five acres unless done to meet a specific ecological objective." Examples where a VRH may deviate from the proximity requirements are when leave trees are concentrated around "Type 5 streams"[4], balds, or cliffs to preserve the feature's integrity and protect it from logging equipment and future silvicultural treatments. Other common factors that supersede the procedure requirements are the safety of forest workers and the public. All green tree and snag retention is subject to the safety standards of the Department of Labor and Industries (L&I, Chapter 296-54 WAC); subsequently, both PR 14-006-090 and the HCP allow modifications for safety reasons. DNR's task TK 14-006-090 provides "direction to field foresters concerning safety in designating and working around retention trees" (TK 14-006-090, Washington State Department of Natural Resources 2006), and detailed guidance may be found in the 2005 Labor & Industries publication "Guidelines for Selecting Reserve Trees."

Implementation monitoring reports from 2004 and 2008, using field tallying of leave trees on VRH timber sale units after harvests, indicated that 29 out of 35 (83%) and 37 out of 41 (90%) of the timber sale units reviewed were compliant with minimum leave tree quantity requirements (Washington State Department of Natural Resources 2005 and 2009), respectively. The reports also monitored other factors, including the prevalence of snags, species diversity, and the representation of trees in the largest diameter class. Proximity monitoring was conducted in the 2008 report (referred to as leave tree distribution in the report) by visually assessing GPS-derived leave tree locations in GIS. Under this methodology, 98% of timber sale units were compliant.

While one of the most common HCP strategy components implemented on state uplands (over 90 percent of westside timber sales), leave trees have not been objectively monitored since 2008. Field tallying of leave trees requires extensive staff time and consequently has only been conducted on a subsample of closed-out timber sale units during fiscal years when adequate monitoring resources were available. While included in the 2008 report, the proximity component of PR 14-006-090 has not been objectively monitored over a large number of timber sale units.

[4] Type 5 Streams are all natural waters not classified as Type 1, 2, 3, or 4; including streams with or without well-defined channels, areas of perennial or intermittent seepage, ponds, natural sinks and drainage ways having short periods of spring or storm runoff.

Since 2013, DNR has used remotely sensed data (i.e., light detection and ranging (LIDAR) and photogrammetrically derived digital surface models (hereinafter referred to as PHODAR-derived data), to provide forest information at a higher spatial resolution and lower cost than that derived from traditional plot-based inventory data (Washington State Department of Natural Resources 2017). More recently, DNR has used unmanned aircraft systems (UAS) to collect two- and three-dimensional geographic data to inform silvicultural treatments and monitor changes over time on state uplands. Assessing leave tree proximity and quantity with remotely sensed data is both timely, given the 10-year gap in monitoring this HCP component, and worth exploring for potential cost savings over field-based monitoring.

Objectives

The objectives of this project were to:

1. Assess the suitability and effectiveness of using remotely sensed data to evaluate leave tree quantity and proximity on post-harvest VRH timber sale units in western WA HCP units.
2. Compare leave tree quantity and proximity results from different data sources, including both field-collected and remotely sensed data.
3. Summarize species diversity, leave tree characteristics, and blown down leave tree (referred to as "blowdown") frequency (2 to 4 years post-harvest completion).
4. Determine DNR's level of compliance in terms of meeting minimum leave tree quantity requirements.

Methods

The population of interest for this project included all VRH timber sale units in westside HCP planning units identified as "closed" in NaturE (DNRs financial tracking system) during fiscal year 2015 (n= 273 timber sale units). Fiscal year 2015 was selected as the time period since the most recent NAIP imagery available at the initiation of this project was 2015 NAIP. The four remotely sensed data (RSD) sources that were assessed and the methods used for acquisition of field data are described below:

Data Sources

3D Stereo NAIP RSD

Imagery collected in 2015 in support of the USDA National Aerial Imagery Program (NAIP) was viewed in stereo using BAE Socet Set GXP[5] for all 273 timber sale units.

[5] Socet Set GXP is digital mapping software used for photogrammetry and geospatial analysis. BAE Systems.

When viewed in 3D, the resolution of the NAIP imagery is 14 inches. For each timber sale unit, a professional photogrammetrist in DNR's Engineering Division manually digitized all standing leave trees ≥ 30 feet in height[6] as well as discernable blowdown into separate point feature classes (standing and blowdown); these data were then verified and analyzed in GIS by monitoring staff. Units where monitoring staff identified leave trees that were initially missed were reexamined by the photogrammetrist and, if applicable, corrected. Out of the 273, seven (2.6%) did not meet monitoring staff quality control standards and were excluded from analysis; thus the sample for the RSD 3D Stereo NAIP was 266 timber sale units (n = 266).

From previous work 3D-stereo-derived leave tree quantities were estimated to be within 10-20% of those obtained with field based methods and the leave tree locations are normally within 5-10 feet relative (relative to other tree position in the same timber sale unit) positional accuracy. Approximately 280 hours were spent digitizing leave trees, or roughly 61 minutes per timber sale unit at a rate of approximately 1.6 minutes per acre or four leave trees per minute. The work time estimates include all steps involved in setting up the workstation with the hard drive containing the NAIP imagery for the timber sale unit of interest, digitizing the trees, correcting omissions, and updating the leave tree GIS geodatabase.

<u>NAIP PHODAR RSD</u>

BAE Socet GXP software[7] was used to produce non-normalized 3D point clouds from the 2015 NAIP imagery similar to those produced with LIDAR data. The TreeSeg[8] program within Fusion[9] was used to produce a tree approximate object (TAO) with a minimum height of 25 feet. The 25-foot height threshold was chosen instead of the minimum 30 foot "snag recruits" and "snag" height requirements specified in PR 14-006-090 because raw PHODAR point clouds typically under-sample tree heights, often not capturing the terminal leader of conifer trees. The output from Fusion consisted of feature classes for both canopy polygons and corresponding tree points (representing the maximum height for the canopy polygon). The six timber sale units subsampled for the NAIP PHODAR analysis were the same as those sampled for the UAS PHODAR

[6] PR 14-006-090 stipulates height requirements of ≥ 30 feet for snag recruits and snags. While minimum tree diameters are also stipulated in the procedure, diameter is not discernable from RSD and was not used as a criteria in the remote analysis of leave trees in this project.

[7] Socet GXP is geospatial software used to identify, analyze, and extract ground features from satellite and aerial imagery. BAE Systems.

[8] "The TreeSeg program applies a watershed segmentation algorithm to a canopy height model to produce "basins" that correspond to dominate clumps of tree foliage and branches. In some cases, the segments represent individual trees, but it is common for segments to encompass several tree crowns. The resulting segments also represent dominant and co-dominant trees better that mid-story and under-story/suppressed trees." USDA 2016.

[9] Fusion was developed by the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

analysis described below (n=6). Processing (i.e., the creation of the tree points and polygons) time varies by unit size and number of leave trees, but in general takes under eight minutes per timber sale unit.

UAS PHODAR RSD

UAS imagery was collected from a subsample of six timber sale units (n = 6) using a DJI Matrice 100 outfitted with dual batteries and a DJI Zenmuse x3 camera (Figure 1). Universal Ground Control Station (UGCS) was used as the flight planning software, which permitted terrain following to provide consistent ground sampling resolution across timber sale units with varied terrain (Figure 2). Flight parameters were consistent across all timber sale units and included: flight speed = 16.7 feet per second, ground resolution = 2.05 inches per pixel, and forward and side overlap = 90%. Agisoft PhotoScan Professional was used for the creation of orthomosaics, digital elevation models, and 3D point clouds from the raw images for each timer sale unit. The 3D point clouds were processed in Fusion using the same methodology as the NAIP PHODAR analysis.

Figure 1. Raw photo taken by the DJI Zenmuse x3 of a unit sampled for the pilot project (left). These raw images are stitched together in Agisoft PhotoScan Professional to produce an orthomosaic with an approximate resolution of two inches per pixel. DJI Matrice 100 ready for take-off (right).

Initially, all 23 units where field data was collected were to be flown with a UAS for comparison. However, staffing constraints and the winter season limited the sample to six timber sale units. Processing in Fusion generally takes under 10 minutes per unit; however, the processing workflow in PhotoScan to create the 3D point cloud can take from one to two days to complete, depending on the number of images to process and computer hardware used.

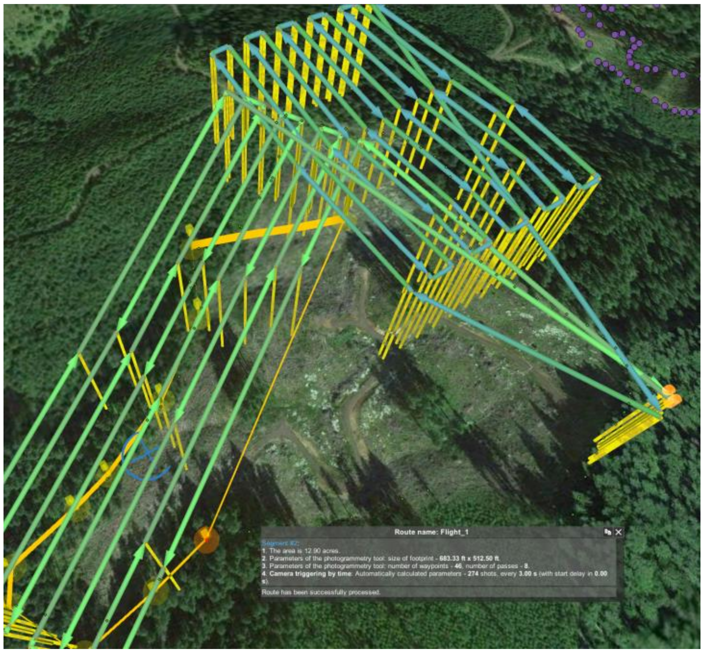

Figure 2. Screen capture of Universal Ground Control Station (UGCS) showing flight segments and flight lines for one of the UAS sampled units.

LIDAR RSD

DNR's corporate GIS layer called "Estimated Dominant Tree Points" represents TAOs with a point feature. This layer is derived from LIDAR data. Predictions of tree height are typically better from LIDAR than from PHODAR; therefore, LIDAR-derived tree points ≥ 30 feet were retained for each timber sale unit and used in the analysis, as opposed to the 25-foot thresholds for the PHODAR-derived tree points. Only timber sale units in the sample that had post-harvest tree points in the "Estimated Dominant Tree Points" layer were included in the subsample (n = 38).

Field Data

iPad tablets linked to Bad Elf Surveyor GPS receivers were used in the field to create leave tree points and leave tree clump polygons in Collector[10]. Field testing of the Bad Elf receiver by staff in DNR's Information Technology Division determined its location accuracy to be 18 feet under canopy, which is equivalent or better than the accuracy obtained with other GPS units commonly used by DNR staff. Two separate survey forms were created using Survey123[11], one for individual leave trees and one for leave tree clumps (Figure 3). The location accuracy threshold in Collector was set to 12 feet; this only permitted point and polygon feature collection when location accuracy was ≤ 12 feet. Once standing within two to six feet of a leave tree or snag field, staff collected a point for all standing trees with a diameter at breast height (DBH) ≥ 9.6 inches and all snags ≥ 14.6 inches DBH with a height ≥ 30 feet. When safe to do so, points for

[10] Collector for ArcGIS is an Esri mobile data collection application that allows users to capture and edit data.
[11] Survey 123 for ArcGIS is an Esri mobile data application that allows users to create survey forms and collect data.

blowdown were collected at the center of the depression previously occupied by the root wad. Once a point was collected, a survey form was launched where leave tree status (blowdown or standing), standing type (live, broken-top, or snag), and species were recorded. The perimeters of leave tree clumps were traversed to create polygons in Collector. Once a polygon was created, a survey form was launched that allowed all species within the clump to be tallied by status and type similar to the survey form for individual leave trees. The leave tree points and clump polygons collected with the GPS unit were linked to the corresponding survey data to facilitate GIS analysis.

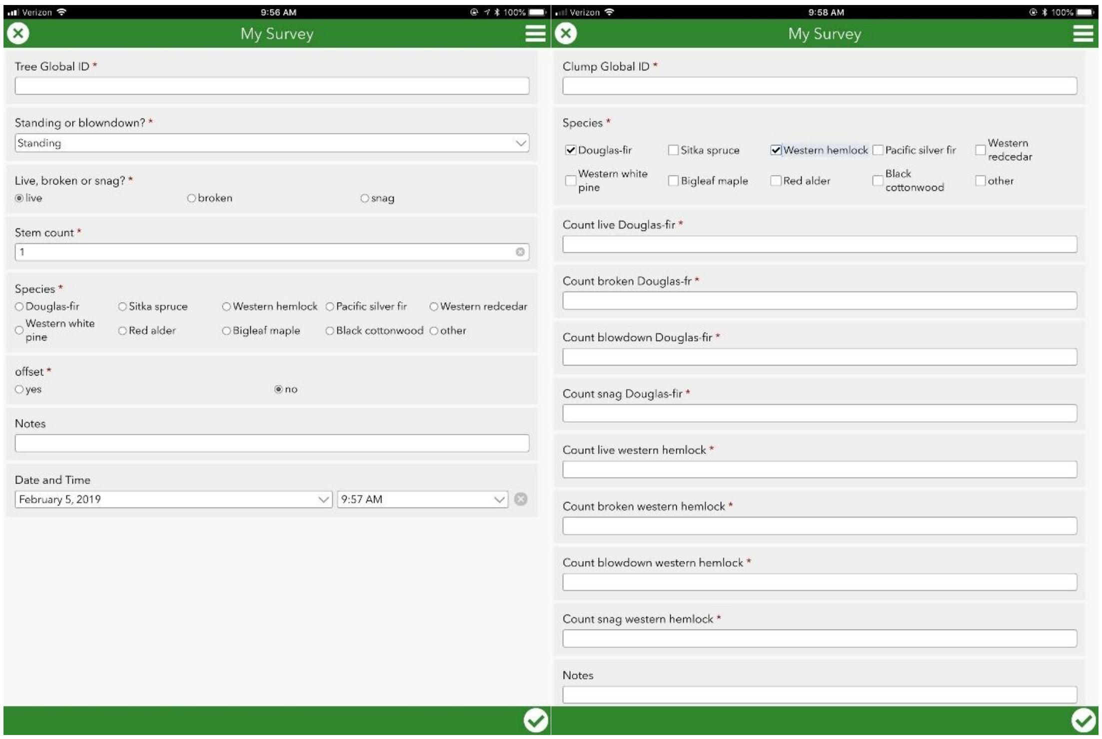

Figure 3. Survey123 forms used to collect field data for individual leave trees (left) and leave tree clumps (right).

Field staff were able to complete field sampling on 23 timber sale units (n = 23) during the 2017 field season. In two cases, a leave tree clump adjacent to a timber sale unit edge did not have tags on its periphery external to the unit, making it difficult to determine the extent of the clump. In these two cases, field staff used the timber sale unit polygon and their location visible in Collector to assist them in traversing the clump perimeter. It took approximately 120 hours (excluding travel time) to sample the 23 timber sale units in the field, which equates to five hours and 13 minutes per timber sale unit at a rate of approximately 7.4 minutes per acre, or approximately one leave tree per minute. The Survey123 forms, Collector maps, and Python[12] scripts (see below) developed for this project can be used for future leave tree monitoring efforts.

Timber Sale Unit Classification

Each timber sale unit was assigned a subjective classification for yarding method and leave tree spacing strategy. The three classifications for yarding method were: ground, cable/tower, and combination (both yarding methods employed). A combination of logging plan maps, 2015 NAIP imagery review for visible ground/cable yarding corridors, and a LIDAR-derived slope percent GIS layer (rise over run) were examined on a unit-by-unit basis to determine the appropriate yarding method classification. Constraints employed when utilizing slope percent were: areas ≤ 40% were assumed to be ground-based yarded and those areas > 40% were assumed to be cable/tower yarded. The 40% threshold was based on the suggested 35% threshold for ground-based yarding equipment in Western Washington referenced in Forest Practices Illustrated (Washington State Department of Natural Resources 2007), with a 5% margin added to account for operational flexibility and slope uncertainty. Leave tree strategy spacing classifications were: dispersed (where the majority of leave trees were distributed individually (not clumped) from each other), clumped (where the majority of leave trees were in clumps – multiple leave trees with crown overlap), and mixed (a combination of dispersed and clumped leave tree spacing strategies).

GIS Analysis

Python scripts were developed by Forest Informatics Staff to expedite the processing of leave tree data across all timber sale units sampled for the five data sources described above. Leave tree quantities were summed at the timber sale unit level. (3D Stereo NAIP RSD data and field derived data also summed blowdown.) The required minimum number of leave trees was determined by taking the acreage of a timber sale unit polygon and multiplying by eight. Units were flagged as not having met the minimum required quantity of leave trees if the calculated required quantity exceeded the summed quantity determined from field and/or remotely sensed data.

To explain why total unit leave tree quantities differ among the different data sources analyzed in this pilot project, periphery trees (for remotely sensed data, tree points that cannot definitely be determined internal or external to the timber sale unit boundary due to boundary digitization uncertainty) needed to be eliminated from the analysis, as these were identified as a common source of oversampling for the RSD sources. Therefore, from the six units that had UAS PHODAR, NAIP PHODAR, 3D Stereo NAIP, and field

[12] Python is a programming language that can be used with the ArcPy package to perform geographic analyses, statistical analyses, and summarize data.

sampling data, three units were chosen that had discernable leave tree clumps that did not contain periphery trees. Blowdown trees were removed from the sums of each clump for the field data, as RSD would not be able to pick up this blowdown. The field data sums for each clump were compared with those from the three other RSD sources. In total, only 15 clumps were deemed suitable for comparisons (n=15). LIDAR data was only available on one out of the three units and was not included in the analysis.

DNR field staff use a variety of GPS units when capturing and assessing leave tree locations in timber sale units, and the technology has improved in recent years with the addition of receivers compatible with the global navigation satellite system (GLONASS). Older Garmin 60CSx GPS units historically used by DNR staff had a range of location accuracies under different forest canopies and using different settings. A 2010 case study found the 60CSx unit's worst average location accuracy to be 35.1 feet across 67 surveyed points (Washington State Department of Natural Resources 2010). Therefore, an error threshold of 35 feet was added to the spacing requirement of 400 feet for GIS analysis (total buffer of 435 feet). For each unit, leave tree points and polygons were buffered by 217.5 feet (half of 435), the buffers were dissolved, and if gaps in the dissolved buffer dissected (i.e., split) a unit (Figure 4), it was flagged as not having met the proximity requirement of 400 feet.

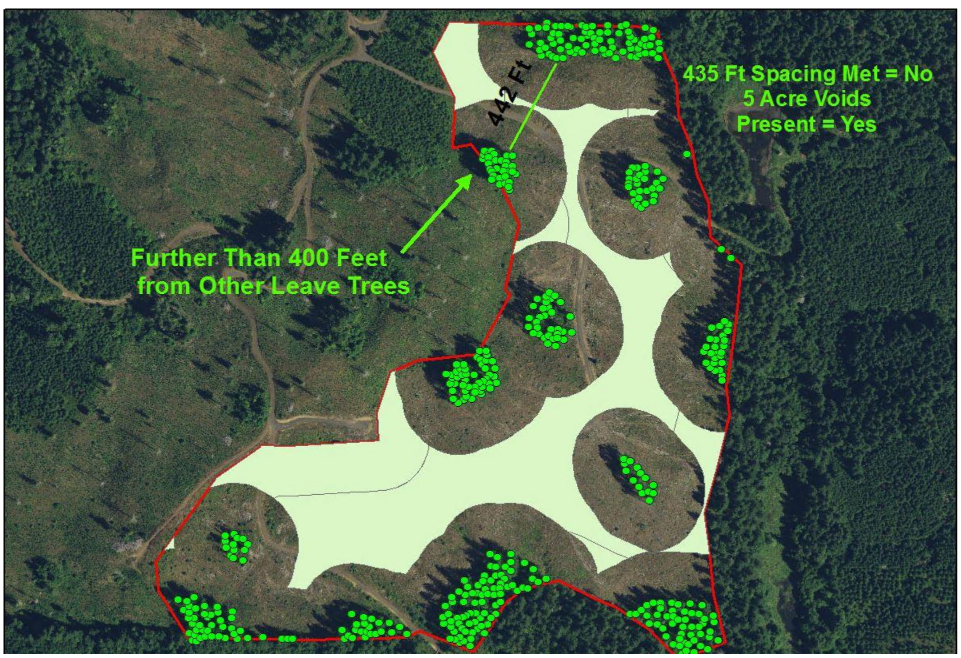

Figure 4. The 400-foot spacing requirement was assessed in GIS using a 217.5 foot buffer off of leave tree points and polygons. Areas outside of the buffers were dissolved and if the resulting polygon dissected a unit, it was flagged as not having met the spacing requirement. In this unit, the green line represent an area where the 400-foot spacing distance was exceeded (442 feet).

To assess the proximity requirement of at least one clump per five acres, all leave tree points were buffered by 263 feet (equivalent to the radius of a five-acre circle). Next, the resulting void polygons (areas lacking buffer overlap) were buffered by 262 feet (buffer off of the void or voids) and retained if no leave trees fell within them. Finally, the area of the void buffer was calculated and the unit was flagged as not having met the one clump per five acres proximity requirement if the area of any void within the unit exceeded five acres (Figure 5). A visual check of each unit was performed in GIS to ensure the results of both the spacing and five-acre void analyses were accurate. The measurement tool was used to confirm spacing length and void area. Units flagged for having voids greater than five acres, but where the void geometries were sinuous and/or linear, were unflagged, as it would be difficult to identify such an area in the field during leave tree layout. If a timber sale unit did not meet either the 400-foot spacing or the one clump per five acres requirements, it was flagged as not having met the proximity requirements.

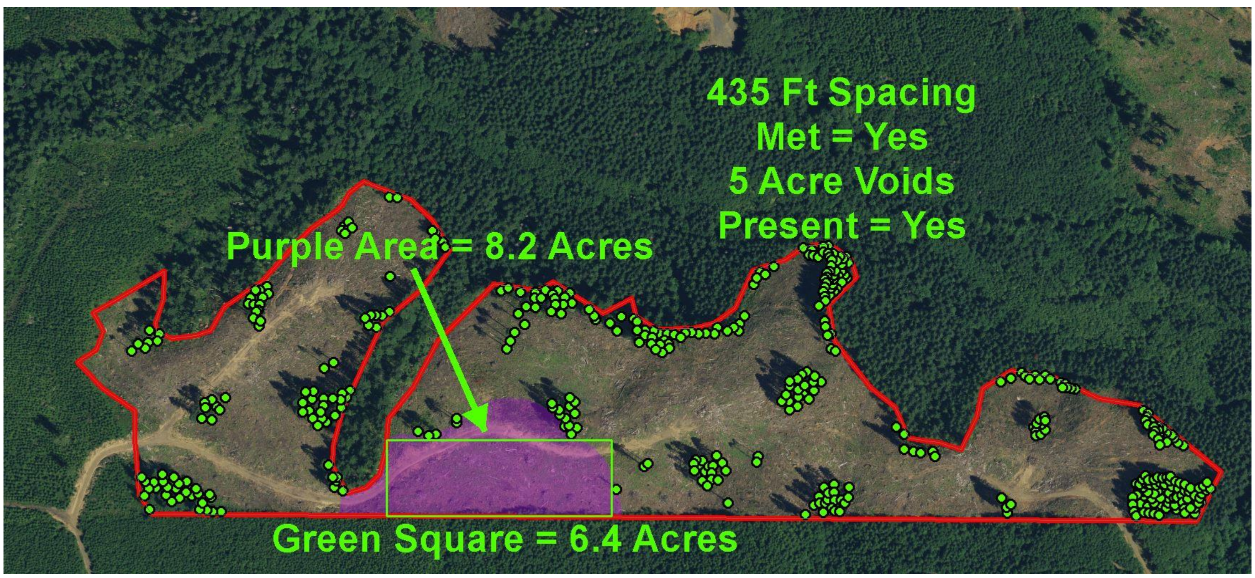

Figure 5. The purple-shaded area represents a void (8.2 acres) where there are no leave trees or leave tree clumps present. The green rectangle represents a visual check (utilizing the measurement tool) that monitoring staff used to determine if a void that resulted in the unit being flagged was valid (i.e., not sinuous and/or linear). In this case, the area of the rectangle was 6.4 acres and the unit was flagged as not having one clump per five acres.

Documentation

For units that did not meet the proximity and/or quantity requirements, a search was conducted on DNR's timber sales document center (TSDC[13]) as well as the silvicultural prescriptions to determine why the deviation occurred. Most explanations for deviations

[13] TSDC is an online repository of documentation, field notes, and compliance notes for DNR timber sales.

were included in the state environmental policy checklists (SEPA) and/or silvicultural prescriptions.

Limitations

The project is "pilot" in nature, as no preliminary work was performed prior to sampling efforts to determine if remotely sensed data sources could be used to monitor leave trees effectively. This project did not attempt to determine operational compliance in meeting the leave tree quantity (except for field-sampled data) and proximity requirements. The aforementioned safety and ecological considerations allow for deviations from the HCP's proximity requirements, and several factors described later affect the ability to obtain accurate quantities with remotely sensed data. Additionally, the following factors limit the accuracy of remotely sensed data as it relates to leave tree quantification and proximity analysis: difficulty and inability to detect blowdown leave trees, inability to detect suppressed and intermediate trees obscured by the main canopy, and inability to distinguish whether trees adjacent to the timber sale boundary are leave trees within the unit or non-leave trees external to the timber sale unit (periphery trees). Given the time lag between the completion of logging activities and field sampling (more than two years, in some cases), any unit was assumed to meet the quantity requirements for field sampling if the sum of leave trees was 90% or more of the required quantity. Lastly, the varying sample sizes and data collection dates across the data sources compared in this project impede statistically valid tests of significance.

Results

Proximity Comparisons of the Five Data Sources

Only two units could be compared across all five data sources for proximity results. Table 1 summarizes comparisons in terms of the outcome of the proximity analysis among the five data sources. The proximity outcomes from RSD differed from the field data on five of the 23 units (22%). For these five units where the proximity outcome for the field data was a "no" (proximity requirements not met), one or more RSD sources had an outcome of "yes" (RSD provided a false negative). GIS analysis showed that the differing outcomes resulted from RSD sources sampling periphery trees that field surveying found to be outside of the unit boundary (Figure 6).

Even when comparing proximity outcomes among RSD, the results sometimes differed. For example, the proximity outcomes from the LIDAR and 3D Stereo NAIP datasets had differing outcomes on three (8%) out of the 37 units available for comparison. For these units, the LIDAR proximity requirement was satisfied due to additional periphery trees that were not sampled in the 3D Stereo NAIP RSD.

Table 1. Summary of the outcomes for each unit as to whether or not both the 400 foot spacing and one clump per five acres proximity requirements were satisfied. The peach shading indicates where the proximity results from the remotely sensed data source(s) differ from the field data. A (-) indicates there was no data for comparison. Percent of units sampled meeting both proximity requirements for a specific data source are at the bottom of each column.

Unit Number	Leave Tree Strategy	Field	Stereo	LIDAR	NAIP	UAS
		Both Proximity Contraints Satisfied?				
1	Mixed	Yes	Yes	Yes	-	-
2	Dispersed	Yes	Yes	Yes	Yes	Yes
3	Mixed	Yes	Yes	Yes	-	-
4	Mixed	No	No	No	-	-
5	Mixed	Yes	Yes	-	Yes	Yes
6	Mixed	Yes	Yes	Yes	-	-
7	Clumped	No	-	-	No	No
8	Mixed	No	No	No	-	-
9	Mixed	No	Yes	Yes	Yes	Yes
10	Mixed	No	No	No	-	-
11	Mixed	No	No	Yes	-	-
12	Mixed	Yes	Yes	Yes	-	-
13	Mixed	No	No	-	Yes	No
14	Dispersed	Yes	Yes	-	-	-
15	Mixed	No	No	No	-	-
16	Clumped	No	No	-	No	No
17	Mixed	No	No	-	-	-
18	Mixed	No	Yes	-	-	-
19	Mixed	No	Yes	Yes	-	-
20	Mixed	Yes	Yes	Yes	-	-
21	Mixed	Yes	Yes	-	-	-
22	Mixed	Yes	Yes	Yes	-	-
23	Clumped	No	No	No	-	-
Percent Meeting Both		43%	59%	67%	67%	50%
	Distinguishes field sampling outcome					
	Indicates where RSD had a differing outcome from the field data					

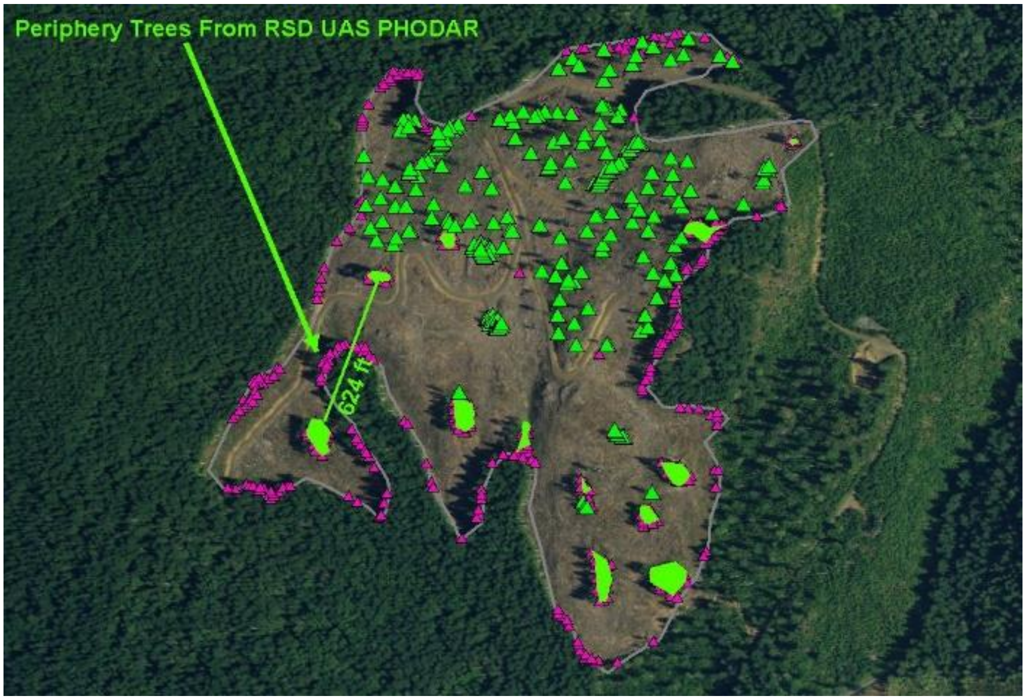

Figure 6. The leave tree polygons and points (green features) from field data indicate this unit does not meet both proximity requirements (does not meet the 400-foot spacing requirement and contains voids greater than five acres). However, the large number of pink points on the periphery of the unit derived from UAS PHODAR RSD indicate the unit does meet both proximity requirements.

Quantity Comparisons of the Five Data Sources

Table 2 summarizes comparisons among the five data sources in terms of meeting required leave tree quantities. The quantity requirement outcomes from RSD differed from the field data on 15 (65%) of the 23 units, with 25 total discrepancies. Sixteen of the 23 discrepancies occurred when field data indicated minimum leave tree quantity requirements were met (negative test result for not meeting quantity requirement), but RSD did not (RSD provided a false positive). Conversely, nine out of the 23 inconsistencies occurred when field data indicated quantity requirements were not met (positive test result for not meeting quantity requirement) but RSD indicated the units were meeting the requirement (RSD provided a false negative). Similar to the proximity results analysis, the differing outcomes for quantity requirements resulted from periphery trees being sampled in the RSD sources that were found to be outside of the unit boundary with field sampling (Figure 6 and 7). Another causal factor described in "Comparison of Clump Quantities" below was the apparent under-sampling of leave trees in clumps by LIDAR, 3D Stereo NAIP, and UAS RSD. NAIP PHODAR tended to drastically oversample leave trees and provided false negatives 67% of the time compared to field data.

Table 2. Summary of the outcomes for each unit as to whether or not the minimum quantity of eight leave trees per acre requirement was satisfied. The peach shading indicates where the quantity results from the RSD source(s) differ from the field data. A (-) indicates there was no data for comparison. The quantities of leave trees sampled for each data source are provided on the right side of the table for each unit. Percent of units sampled meeting the minimum quantity requirement for a specific data source are at the bottom of each column.

Unit Number	Field	Stereo	LIDAR	NAIP	UAS	Required	Field	Stereo	LIDAR	NAIP	UAS
	Required Minimum Quantity Satisfied					Quantity	Quantity of Leave Trees Sampled				
1	no	no	no	-	-	677	625	505	610	-	-
2	no	no	yes	yes	yes	245	224	236	286	902	414
3	yes	no	no	-	-	421	441	314	382	-	-
4	no	no	no	-	-	582	569	335	466	-	-
5	yes	no	-	yes	yes	393	427	331	-	2040	527
6*	no	no	no	-	-	83	29	39	66	-	-
7	no	-	-	yes	yes	354	337	-	-	939	388
8	yes	no	no	-	-	586	619	300	362	-	-
9	no	yes	no	yes	no	578	515	620	497	1904	493
10	yes	no	no	-	-	499	574	305	488	-	-
11	yes	no	yes	-	-	274	312	222	281	-	-
12	yes	yes	yes	-	-	113	169	113	133	-	-
13	no	no	-	yes	yes	336	318	141	-	1401	453
14	no	no	-	-	-	402	369	259	-	-	-
15	yes	no	no	-	-	433	464	244	367	-	-
16	yes	no	-	yes	no	336	349	176	-	1003	323
17	no	no	-	-	-	230	205	182	-	-	-
18	no	no	-	-	-	176	154	115	-	-	-
19	yes	no	yes	-	-	153	197	152	189	-	-
20	yes	yes	yes	-	-	89	192	130	166	-	-
21	yes	no	-	-	-	327	379	209	-	-	-
22	yes	no	yes	-	-	260	351	247	308	-	-
23	yes	no	yes	-	-	206	283	164	376	-	-
% Meeting Min. Quantity	57%	14%	47%	100%	67%						
(green)	Distinguishes field sampling outcome. *See discussion for explanation of circumstances.										
(peach)	Indicates where RSD had a differing outcome from the field data										

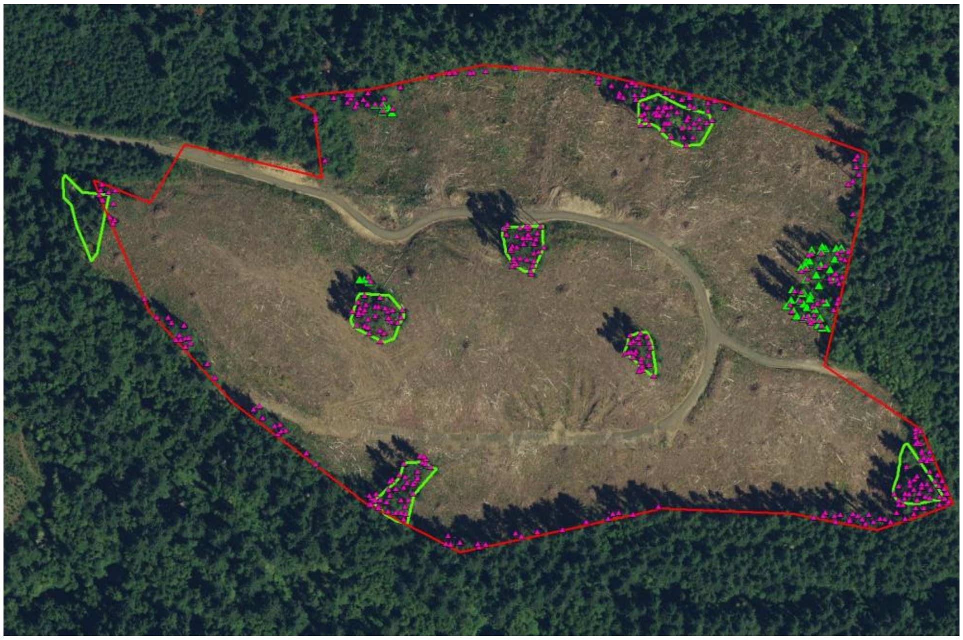

Figure 7. A comparison of UAS PHODAR leave tree points (pink triangles) with field sampled points and polygons (green features) shows the presence of periphery trees resulting in oversampling in RSD. In this 44.3-acre unit, the UAS PHODAR analysis indicated the unit met the minimum leave tree quantity requirement, while the field data indicated a deficit of 17 leave trees (unit had 95% of required minimum quantity). Proximity results (not met), however, were the same for both data sources. The leave tree clump outside of the boundary in the west portion of the unit was missed with RSD sources, but was identified with field sampling.

Quantity requirement outcomes also differ among RSD (Table 2). For example, LIDAR and 3D Stereo NAIP datasets had differing outcomes on 18 (49%) out of the 37 units available for comparison. The total quantities of leave trees sampled across these 37 units differed by 3,516 leave trees for LIDAR (12,051 total leave trees) and 3D Stereo NAIP (8,535 total leave trees). For this project, NAIP PHODAR RSD overestimated leave trees significantly when compared to all other data sources and was nearly four times (8,189) the number of leave trees sampled in the field (2,170) for the six units available for comparison. The oversampling of leave trees by NAIP PHODAR resulted in four instances of a false negative.

Comparison of Clump Quantities

Compared to field-sampled data, the 3D Stereo NAIP and UAS PHODAR RSD tended to underestimate the quantity of leave trees in clumps by an average of 9 and 7 leave trees per clump, respectively (Table 3). RSD NAIP PHODAR, however, oversampled trees in clumps by over two times those sampled in the field (219%, Table 3). When summed across all 15 clumps sampled the Stereo, NAIP, and UAS RSD sources sampled 71, 219, and 77% of the leave trees identified in the field within the clumps (Table 3).

Table 3. Summary of leave tree quantities on a clump-by-clump basis from three units sampled in the pilot project. The common names for species codes are provided at the bottom of the table. Differences in the number of leave trees captured from RSD sources as field sampled quantity minus RSD quantity are presented on the right side of the table.

Clump Number	Species Present From Field Data	Quantity of Leave Trees Sampled in Each Clump				Field Quantity Minus RSD Quantity		
		Field	Stereo	NAIP	UAS	Stereo	NAIP	UAS
1	MA,DF	14	28	128	39	-14	-114	-25
2	DF	29	17	95	27	12	-66	2
3	DF,WH	24	13	58	16	11	-34	8
4	DF,MA	45	21	128	44	24	-83	1
5	DF,MA	51	23	109	29	28	-58	22
6	DF,RC	67	18	111	25	49	-44	42
7	DF,RC,WH	18	44	60	24	-26	-42	-6
8	RC,DF,WH	34	33	38	15	1	-4	19
9	DF,RC,WH	18	16	32	11	2	-14	7
10	DF,WH,RC	39	34	61	25	5	-22	14
11	DF,WH,RC	17	17	46	14	0	-29	3
12	RC,DF,WH,MA	24	29	74	22	-5	-50	2
13	DF	43	19	44	31	24	-1	12
14	DF	32	23	38	24	9	-6	8
15	DF,RA	39	18	59	36	21	-20	3
Total		**494**	**353**	**1081**	**382**	**9**	**-39**	**7**
Total RSD Trees Sampled as a Percent of Total Field Trees Sampled For all Clumps			**71%**	**219%**	**77%**	**under sample**	**over sample**	**under sample**
						Average Over or Under Sampled Trees Across all Clumps of the Specified RSD Source Compared to Field Data		

DF = Douglas fir, MA = bigleaf maple, RA = red alder, RC = western redcedar, WH = western hemlock

Proximity

Out of the 23 field-sampled units, 13 (57%) did not meet the proximity requirements, and of these, three (23%) lacked explanatory documentation (Table 1). Eight (62%) of the 13 units not meeting proximity requirements were categorized as having combination or tower/cable-based yarding methods. The field-sampled units that met the proximity requirements employed either a dispersed or mixed leave tree strategy as opposed to a strictly clumped strategy.

Of the 266 units assessed with 3D Stereo NAIP RSD, 134 (50.4%) did not meet the proximity requirements, and of these, 11 (8%) lacked documentation describing why the unit deviated from the proximity requirements. Of the units not meeting proximity requirements, 85 (63%) were categorized as having combination or tower/cable-based yarding methods. None of the units deviating from the proximity requirement employed a dispersed leave tree strategy, but 75% of them did employ a mixed strategy of clumps and individually scattered leave trees.

Quantity

For the field sampled units, 10 out of 23 (43%, 39% excluding a special case unit described in the discussion) had leave tree quantities below the required level, with a range of 88 to 98% (excluding the special case unit) of the required level (Table 2). These 10 units all had documentation describing that either the minimum leave tree quantities were marked for retention or that eight leave trees per acre had been left for retention. Only four units fell below the 90% compliance threshold, with percent of required leave trees of 35% (nullifying circumstances provided in discussion), 88%, and (two units) 89%. Those units lacking the minimum required quantities had leave tree deficits (as percent of required minimum quantity) that ranged from 2 to 13% and averaged 8% (excluding the 35% unit that had a 65% deficit). Conversely, the 13 units that met the minimum quantities also exceeded the minimum with a range of 104 to 216%. The average of all 23 units was 109% (107%, excluding the 35% and 216% outlier units) of the minimum required quantity of leave trees.

The quantities of leave trees digitized from the 3D Stereo NAIP RSD were below those required on most units. Only 70 (26%) out of the 266 units were found to have the required quantities using this RSD collection method. Approximately 100 units (38%) had 90% or more of the required minimum quantity using 3D Stereo NAIP RSD. Even when accounting for a potential under-sampling error of 20% (increasing the quantity of leave trees digitized by 20%), only 121 (45%) of the units met the required quantities, with 147 (55%) having quantities within the 90% threshold.

Blowdown

Ten out of the 23 units field sampled had blowdown comprising over 10% of total leave trees at the time of sampling; the overall average for all units was 16%. All but one unit had blowdown, and the range was 0 to 75% of the total quantity of leave trees within the first 2 to 4 years post-harvest. As a percentage of the total quantity of leave trees retained per unit, the percent of blowdown per species averaged 7, 5, and 4% for Douglas fir, western hemlock, and western redcedar, respectively. The digitization of leave trees using 3D Stereo NAIP RSD did not detect blowdown on 139 (52%) of the units, and blowdown ranged from 0.1 to 55% where it was detected. The overall average of blowdown across all units where it was detected from the 3D Stereo NAIP RSD was 4%. Though nine out of 22 units available for comparison had equivalent blowdown quantities for field sampled and 3D Stereo NAIP RSD (tended to occur when blowdown quantities ranged from 0-36), the latter grossly underestimated blowdown by an average of 80% where values differed.

Leave Tree Characteristics From Field Data

The percent of standing live, standing snag, standing broken top, and blowdown leave trees varied across all units and overall averages as a percent of total leave trees across all units were 77, 5, 2, and 16%, respectively (Figure 8). Per-acre averages of snags (range 0 to 2 per acre) and live trees with broken tops (range 0 to 1 per acre) were relatively insignificant compared to live and blowdown leave trees.

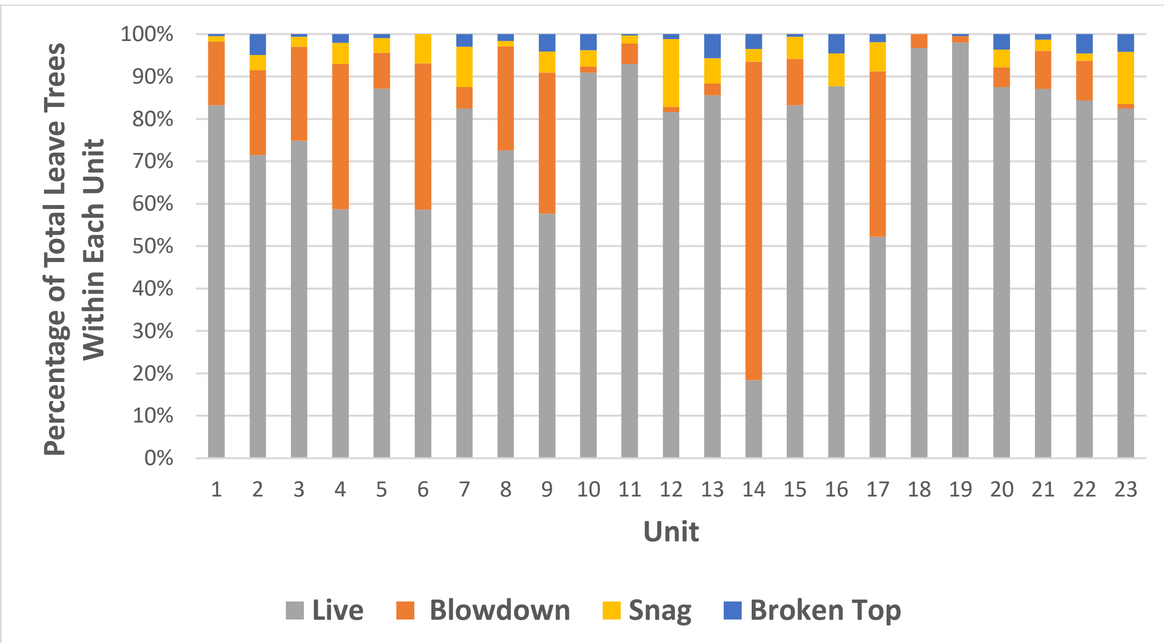

Figure 8. Percentage of total leave trees by type for each of the 23 units field sampled in the pilot project.

Averages across all units for species composition as percent of total leave trees were: Douglas fir 59%, western hemlock 16%, western redcedar 10%, true firs 6%, red alder 5%, other hardwoods 3%, and other conifers 1%. Other hardwoods included bigleaf maple, black cottonwood, cherry, Pacific madrone, and willow. Other conifers included lodgepole pine, Sitka spruce, and western white pine. The main species composition of leave trees varied across several units; however, Douglas fir was left for retention in all 23 units (Figure 9). When compared to the species sampled in cruise data prior to harvest, 20 of 23 units represented all species present as leave trees, including species that constituted a relatively small component of the stand.

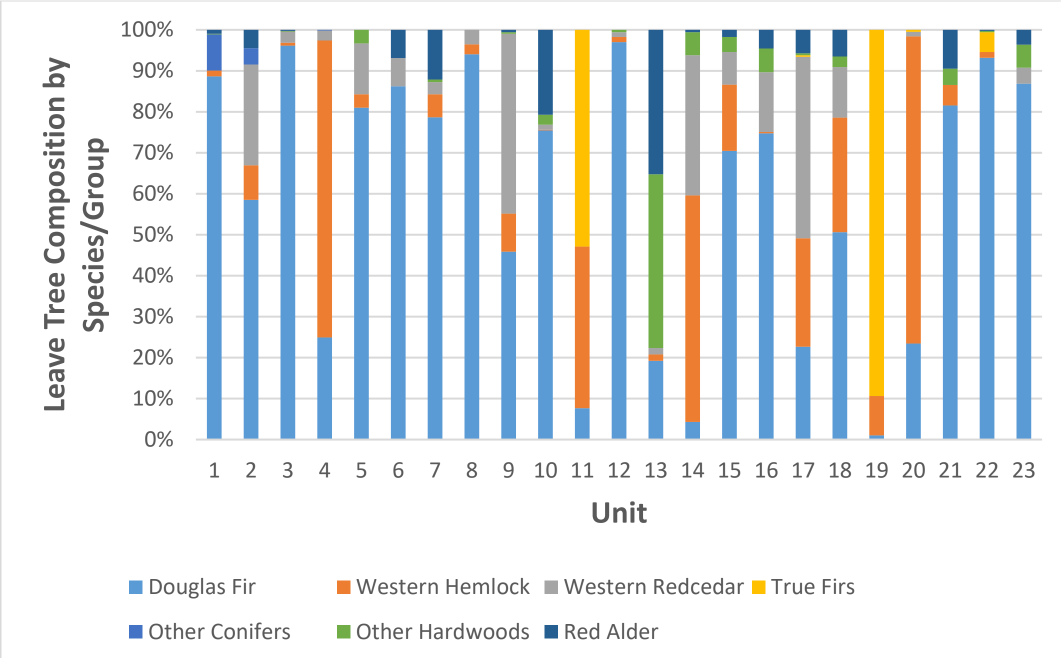

Figure 9. Leave tree species composition in each unit as a percentage of total leave trees for the unit. The other hardwoods included bigleaf maple, black cottonwood, cherry, Pacific madrone, and willow. Other conifers included lodgepole pine, Sitka spruce, and western white pine. True firs included noble fir and Pacific silver fir.

Discussion

Comparing the proximity outcomes of RSD with field-sampled data shows that results often differ between the data sources. Periphery trees sampled in the RSD often led to false negatives, with units being considered to have met the HCP proximity requirements when field data found they had not. Unfortunately, it is not possible to conclusively discern and dismiss periphery trees from the RSD during office reviews, as DNR staff will often leave trees on the unit perimeter for a variety of ecological and operational reasons. Therefore, RSD may be best used as an initial screening tool to check if units meet the proximity requirements, taking into account the presence of periphery trees in the data and their potential for providing false negatives. Initial office review of RSD could narrow the focus of a field sample and help monitoring staff identify which areas of a unit to focus their monitoring efforts.

Based on recent DNR silviculture pilot projects using UAS PHODAR, monitoring staff hypothesized that RSD sources would undersample leave tree quantities as compared to field data because PHODAR cannot detect suppressed and intermediate trees obscured by above canopy. In light of this, it was anticipated that RSD could be used as an initial screening tool for quantity requirements under the assumption that a unit meeting the minimum required leave tree quantity from RSD would also meet the minimum required quantity from field data. However, the results indicated there were many (9) instances where this was not true because RSD provided false negatives (RSD found the unit to have met the quantity requirements when field data indicated it had not). NAIP PHODAR grossly overestimated leave tree quantities and there were many instances where noise in the data produced leave tree points where there were none (Figure 10). NAIP PHODAR also tended to produce multiple leave tree points for the crown of the same tree (Figure 10). NAIP PHODAR data may possibly be refined by filtering out noise in the data and adjusting parameters in FUSION; however, this would increase the analysis time and may not provide consistent results across all units.

Figure 10. Example of noise in the NAIP PHODAR data resulting in the false assignment of leave tree points (left). The green triangles represent field-sampled leave tree points and the pink represent NAIP PHODAR leave tree points. On the right is an example of oversampling of a single leave tree by NAIP PHODAR data. The green triangles represent field-sampled leave tree points and the pink represent NAIP PHODAR leave tree points (right).

It would prove useful if RSD sources consistently under- or oversampled leave tree quantities to allow monitoring staff to develop a correction factor; however, the small number of units compared in this project did not show this to be true for any of the RSD except for NAIP PHODAR (Tables 2 and 3), which oversampled. The lack of consistency of leave tree sampling appears to be a combination of periphery trees causing oversampling and leave trees within clumps being undersampled by UAS PHODAR and 3D Stereo NAIP. Thus, whether leave trees are over/undersampled by RSD depends on the ratio of leave trees on the periphery to leave trees within clumps and ultimately will depend on how much perimeter versus clumps a unit contains as well as the accuracy of its boundary polygon (Figure 7). Figure 7 also illustrates how a clump falling outside of a unit boundary (west side of unit) in GIS may be completely missed with RSD. For these reasons, monitoring staff do not recommend relying solely on RSD to determine minimum leave tree quantity compliance.

Field data indicate that units often deviate from one or both of the proximity requirements; however, for the majority of these units, available timber sale documentation provided one or more justifications for the deviations. Justifications included but were not limited to the protection of remnant and legacy trees, balds, cliffs, snags, Type-5 streams, potentially unstable topography, wet areas, and operational safety constraints. However, the 23% and 8% of the field and 3D Stereo NAIP RSD deviating units lacking documentation indicate an area for improvement. Monitoring staff suggest that deviations from leave tree proximity requirements be clearly documented within the silvicultural prescriptions for each unit, instead of the generalized justifications typically found in the timber sale SEPA checklist for this project. Detailing explicit justifications in the silvicultural prescription for each timber sale unit will aid future monitoring efforts as well as review from outside stakeholders. Staff spend a lot of time and effort in strategically and optimally placing leave trees on DNR timber sale units, and it is worth investing the time to document these important considerations. The few units that employed a strict dispersed leave tree strategy always met the proximity requirements. Those units that did not meet the proximity requirements were often those that employed tower/cable-based yarding or a combination of ground and tower/cable-based yarding methods (~63%).

Results of field-sampled leave tree quantities indicate that the majority of units exceed the minimum levels required by the MCS, and the compliance rate was similar to that of the 2004 monitoring report (Washington Department of Natural Resources 2005). Following timber sale documentation and GIS review, monitoring staff determined the unit having 35% of the required quantity of required leave trees was incorrectly evaluated due to the way the unit was digitized as a thinning subunit and VRH subunit. In summary, the unit with the large deficit was adjacent to a commercial thinning unit, and both were assigned to the same timber sale unit for the purposes of leave tree quantity and proximity requirements because the adjacent thinning unit was a protection measure for a bald eagle nest. Taking into account both units and their associated acreage, the minimum leave tree quantities were achieved for that unit. Taking this information into account, only three units fell below the 90% compliance threshold with 88 (two units) and 89% of the required quantities.

Blowdown quantities from the small field and broader 3D Stereo NAIP RSD samples indicate that leave trees are contributing to down dead wood, and blowdown within the first 2 to 4 years post-harvest can be significant (greater than 10% of the total leave trees) in some cases. The 3D Stereo NAIP RSD tended to undersample blowdown when occurring at larger quantities; therefore, it is likely that actual blowdown frequency may be even higher across the 266 sampled units. Similar to past monitoring results, retained snag densities were low. However, retained snag scarcity may be due to a combination of low and variable preharvest snag densities as indicated by DNR inventory data (1.6 snags per acre ≥ 15 inches DBH and ≥ 30 feet in height, 95% confidence interval 1.2 to 1.9 snags per acre), as well as L&I constraints (in consultation with DNR contract administrators, snags may be removed by logging operations for safety reasons or must be adequately buffered). Future monitoring efforts could better ascertain snag availability and retention by conducting leave tree sampling prior to harvest. Lastly, similar to past monitoring results, DNR staff are attempting to retain a diversity of species as leave trees (Figure 9).

DNR does not have control over the exact timing of LIDAR and NAIP acquisitions, which limits flexibility in which units are available for remote monitoring (only units with post-harvest imagery and LIDAR) and when. The ability to capture UAS imagery (except for weather, daylight, and controlled airspace constraints) when desired is a major benefit of this remote data source and its leave tree proximity and clump quantity results compared to field data were better compared to other RSD sources. Taking oblique imagery around the periphery of units with a UAS could alleviate the oversampling bias for periphery trees, as a determination could be made as to whether the periphery tree is actually a leave tree. Unfortunately, this additional step coupled with the associated extra flight planning, flight time, and imagery processing could diminish or eliminate any time savings UAS PHODAR provides over field sampling. DNR's portfolio of UAS imagery is steadily growing (for example, staff are collecting UAS imagery to support young stand silvicultural decisions), and monitoring staff could save time by using UAS PHODAR from these units where appropriate. Future LIDAR acquisitions (Washington State Department of Natural Resources et al. 2019) are planned in westside HCP units and could also be used for future leave tree monitoring efforts as well.

Conclusions

Results from this pilot project and the small sample sizes available for comparison do not provide conclusive evidence of which RSD source is the best to use to monitor leave tree proximity and quantity requirements. Field sampling, while time-intensive, is still the most reliable method to determine operational compliance with leave tree spacing and quantity requirements. Accounting for potential biases in terms of under/oversampling, RSD sources could be used as an initial office review tool for leave tree proximity monitoring, but should not be used for definitive compliance determination without further testing and refinement. Future leave tree monitoring efforts conducted both in the field and remotely should use the tools, scripts, and sampling methodologies developed for this project to make data comparisons across monitoring projects feasible. Leave tree quantities from field sampling indicate a high level of operational compliance in meeting the minimum required quantities. Field data and associated timber sale documentation indicate DNR staff are taking a balanced approach in their leave tree strategies with ecological and operational safety considerations in mind.

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