Scoping and Recommendations for Extensive Riparian Monitoring Implementation Pilot Project

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Andrew Cooke[1], L. Monika Moskal[2,3]
[1]Research Scientist -- Natural Resource Spatial Informatics Group, PFC, UW
[2]Associate Professor & Associate Director – School of Environmental and Forest Sciences (SEFS), University of Washington (UW)
[3]Director -- Precision Forestry Cooperative (PFC), UW lmmoskal@uw.edu

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Introduction and Purpose

From 2015 to 2017, the Precision Forestry Cooperative at the University of Washington School of Environmental and Forest Sciences undertook the Extensive Riparian Vegetation Monitoring – Remote Sensing Pilot Study [1] to investigate the effectiveness of using remote sensing methods as the basis for monitoring the status and trends of riparian stands on private lands in Washington State. This Pilot Study took place in the Mashel Watershed in the Cascade Mountains of Pierce County.

The Pilot Study demonstrated the viability of remote sensing as a component of extensive vegetation monitoring

The applicability of statistical models for estimating riparian metrics have not been validated for stand types that are different from those in the Mashel. Because there are significant differences in the species composition and physical structure of different types of forest in the State, it is likely that the Mashel models may not be as accurate in other forest types. Therefore, the Mashel models may need to be calibrated or different models may need to be developed for different types of forest as part of a statewide monitoring effort in order to maximize accuracy.

The next phase of the Extensive Riparian Vegetation Monitoring Project would focus on developing robust models that would be necessary to monitor riparian stands statewide.

The purpose of this scoping report is to provide recommendations on where the next phase of the project could take place, and on how to efficiently plan the fieldwork and modeling efforts based on what was learned in the Mashel Pilot Study. Results of the Pilot Study and any future phases of this project will be used to help design a statewide monitoring program for riparian forests.

Specific Questions Addressed

There are four deliverables for this project. These are each addressed in the "Deliverable" sections below:

1. Assess where lidar data is available to perform future analysis
2. Identify sites, where lidar is present, that capture the range of ecological conditions needed for statewide monitoring; the different forest types in the state and there locations
3. Identify sites, where lidar is present and with forest types of interest, where temporal analysis could take place; sites with multiple lidar acquisitions from different time periods
4. Examine changes to the list of metrics and field data collection protocol that should be made based on what was learned in the Mashel Pilot Study

Summary

Location, Cost, and Timing

- Two areas have been identified that have available lidar data and forest types that are very different from the Mashel: one on the northern Pacific coast, and one in northeast Washington.
- The cost of installing and measuring field plots and developing models is approximately $300,000 to $500,000 per study area ($400,000 to $600,000 if new technologies are examined),

and is dependent on the number of plots and the complexity of the field data collection protocol (based on metrics and methods selected).

- Approximately two years are required for the fieldwork and model development for each study area. If work is done at multiple study areas concurrently, there can be time savings and minor cost savings.
- The Mashel study area from the Pilot Study and two other study areas would cover the majority of lands in the state where forest practices rules apply, and should provide a good understanding of the variability of models needed for statewide monitoring.
- It may be necessary or desirable to add more study areas in the future, but that is not yet known. Each additional area costs $300,000 to $500,000 ($400,000 to $600,000 if new technologies are examined) and takes around two years.
- The age and availability of lidar data, as well as differences in forest type, suggest that the study area in northeast Washington should be studied first, especially if funding is limited.
- Future work should include a comparison of sole lidar or Structure from Motion (SfM) models to GNN [2] models fusing the various domains of remote sensing to gather better understanding of how long term monitoring can be achieved when high spatial detail data like lidar might lack in frequency. Although that will increase the costs of the research, it will give a deeper understanding on how to proceed with a statewide monitoring program.

Lidar Caveats

- The lidar data in northeast Washington will be too old to use after 2021, and no future lidar acquisitions are currently planned in eastern Washington. This suggests that work should happen there quickly.

Metrics and Field Protocol

- Large Woody Debris and Species metrics should be removed from future project phases. Lidar and other remote sensing approaches are not the correct tools to estimate these metrics.
- A Leaf Area Index (LAI) metric should be added to the next project phase. There is potential for lidar to estimate LAI, and it has utility for understanding stream shading.

Long Term Data Availability

- Models developed in the Mashel Pilot Study and any future study areas are dependent on the future accusation of new lidar data and imagery in order to be used for monitoring the status and trends of riparian forests.
- There are new technologies such as Structure from Motion (SfM) and existing technologies such as terrestrial lidar that were not available during the Pilot Study. These technologies could not be included in the Pilot Study, but may provide additional data that is useful for monitoring riparian vegetation.
- Remote Sensing technology is rapidly evolving. Any long term monitoring program will need to be able to adapt to the changing availability of sensors and data or commit to acquiring necessary data over the length of the monitoring effort.

Deliverable 1: Identify Lidar Availability and Forest Types

Lidar Availability

The availability of lidar data will be the primary limiting factor on where the next phase of the Extensive Riparian Vegetation Monitoring Project can take place. Lidar is expensive ($) and time consuming to collect and process, and its utility for this project is time-sensitive because it is being used to model growing, managed, and changing forests.

Background

Lidar acquisitions in Washington State began sometime around the mid-1990s. Early acquisitions were funded by individual agencies for internal purposes, e.g. private timber companies for stand inventory and harvest planning, or through collaborative efforts like the Puget Sound Lidar Consortium (PSLC) [3]. The earliest publically distributed lidar data is from 2002.

In response to the fatal Hazel landslide in Oso, WA (March 2014), the Washington State Legislature passed SB 5088 / HB 1182 (2015), which mandated that the Washington Geological Survey (DNR Geology):

> (a) Coordinate with state and local government agencies to compile existing data, including geological hazard maps and geotechnical reports, tending to inform geological hazard planning decisions;
>
> (b) Acquire and process new data or update deficient data using the best practicable technology, including lidar;
>
> (c) Create and maintain an efficient, publicly available database of lidar and geological hazard maps and geotechnical reports collected under (a) and (b) of this subsection; [4]

Since that time, the DNR has developed the Lidar Portal [5] to consolidate and distribute data, and is functioning as a coordinator for interagency purchasing and acquisition of new lidar data. Through the DNR's efforts, new lidar has been acquired over large areas of the State between 2015 and 2018. As of this writing, there are no planned new acquisitions by DNR after 2018. At the end of 2018, publically available lidar will cover approximately 1/3rd of the State, with the majority of the coverage west of the Cascades (Figure 1). Many areas, especially river corridors and urban areas around the Puget Sound, have multiple lidar acquisitions.

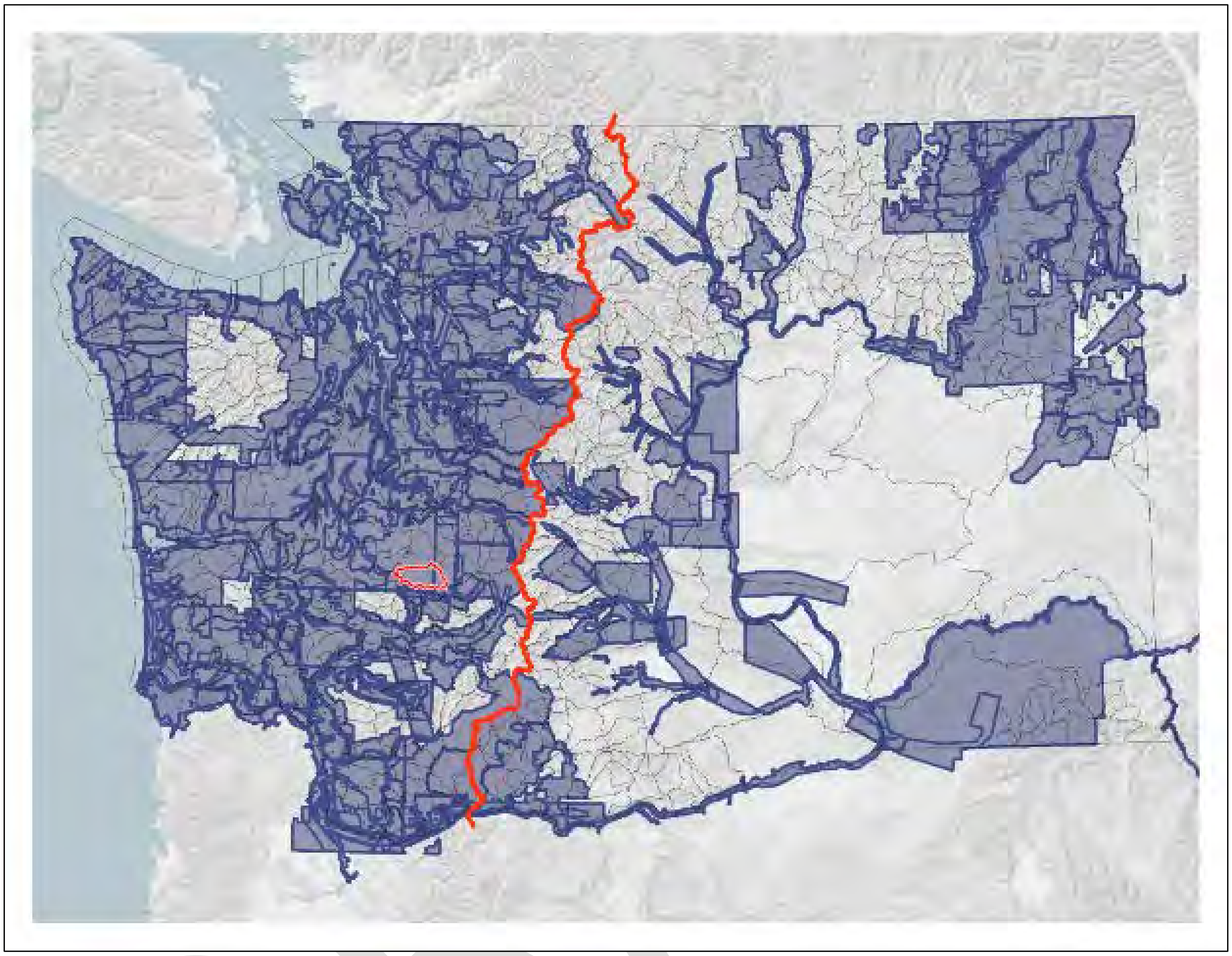

Figure 1: Available public lidar in Washington State. Collected between 2002 and 2018. The red line is the Cascade crest. The red polygon is the Mashel Watershed (the location of the Extensive Riparian Vegetation Monitoring – Remote Sensing Pilot Study).

Lidar Availability by Year

Moving forward with the Extensive Riparian Vegetation Monitoring Project, the primary consideration should be to minimize the time between lidar acquisition and field data collection. All recent acquisitions should meet quality standards in terms of point densities and data processing methods, so the driving factors should be using lidar in a forest type or types of interest, and making sure the lidar is as current as possible.

When a time delay exists between data acquisition and fieldwork, the changes in the riparian stand that occur during this time period are built into the statistical models, and will be an inherent component of using the models to estimate riparian forest metrics. Whether or not a delay *significantly* alters model predictions is not clear, but reducing delays will minimize the impact.

Additionally, new growth in clear cuts and young stands can be dramatic over short time periods. Because the lidar is used to stratify the landscape before field crews measure the plots, areas that appear as clear-cuts or short, open, young stands in the lidar will likely have significant growth when time delays exist between lidar acquisition and fieldwork. This could cause an under-sampling of young stands as growth moves plots from one strata to another, and different rates of growth for different species and areas make this movement unpredictable.

It is recommended that lidar data older than three to five years should not be used for Riparian Extensive Vegetation Monitoring work at this time. For example, if fieldwork were to take place in 2020, lidar acquired before 2015 should not be used.

Lidar acquisition and post-processing by the vendors takes a great deal of time, and lidar data is required to pre-stratify the landscape to locate field plots. Therefore, it is not possible to do fieldwork the same year as the lidar is acquired. Ideally, fieldwork would take place the following summer. If, for example, fieldwork were to take place in 2020, it would be ideal to use lidar collected in 2019, but because there are no publicly sponsored acquisitions currently planned for 2019, the best scenario is to use 2018 lidar.

Given the known Lidar schedule, Figure 2 shows the locations of lidar data that is being acquired in 2018, including the Pacific coast and Strait of Juan de Fuca, the western Hood Canal and southern Olympic Mountains, the Cedar River Watershed, and the Blue Mountains in the southeast. Considering *only lidar availability*, and barring new data acquisitions in 2019 or beyond, these are the locations that should be prioritized for the next phase of the Riparian Extensive Vegetation Monitoring Project.

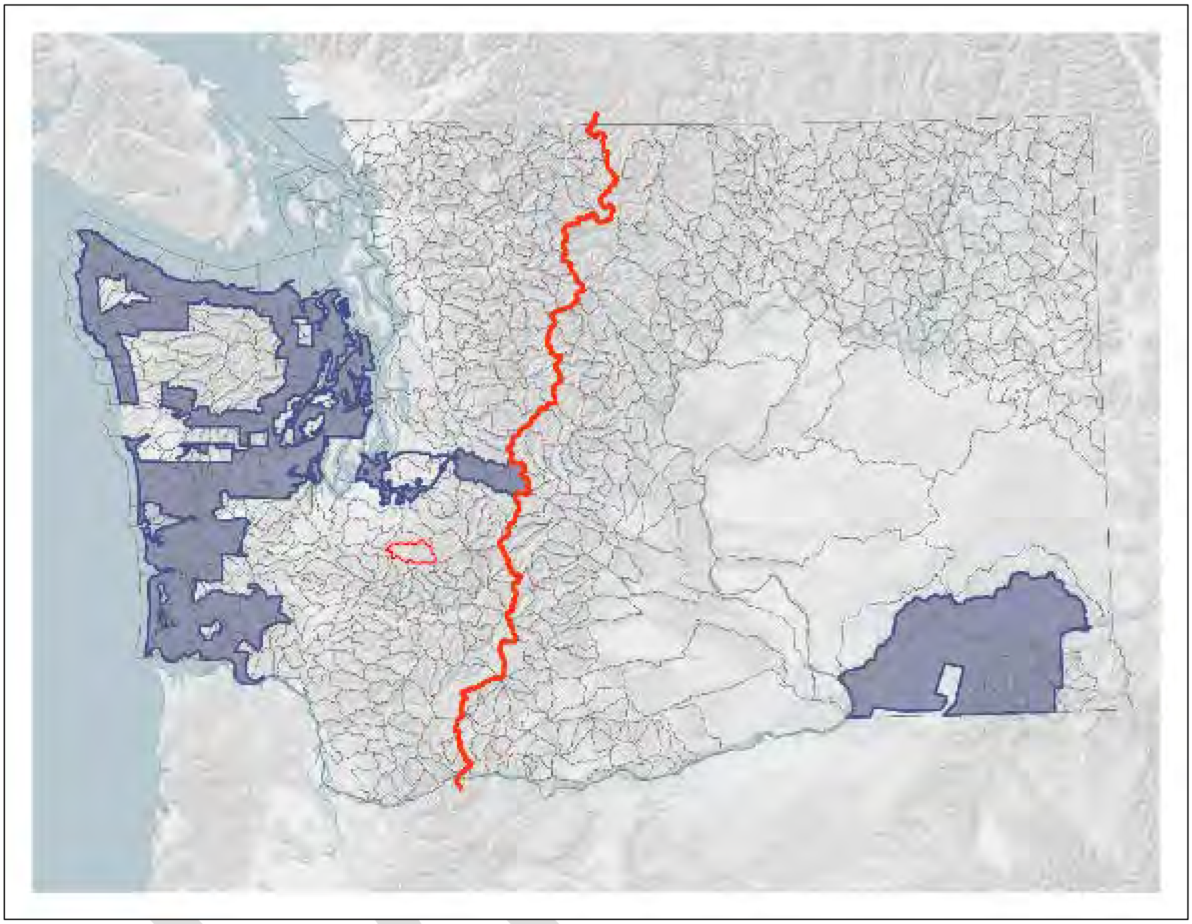

Figure 2: Lidar collected in 2018

If 2018 lidar is not suitable (e.g., it does not cover forest types of interest), Figure 3 shows the lidar acquired in 2017, covering the southern I-5 corridor, and Walla Walla in eastern Washington. In terms of timing, these locations should be prioritized next, but may not be of interest because they are heavily developed, non-forested, or too similar in forest type to the Mashel Watershed used for the Pilot Study. The ideal time for fieldwork to take place in these locations was this summer, the summer of 2018. Setting up and implementing another study area for the summer of 2018 was not feasible, meaning any work happening in these locations will have a time delay between lidar acquisition and fieldwork of at least two years. Changes in forest structure due to growth would not be accounted for in the models.

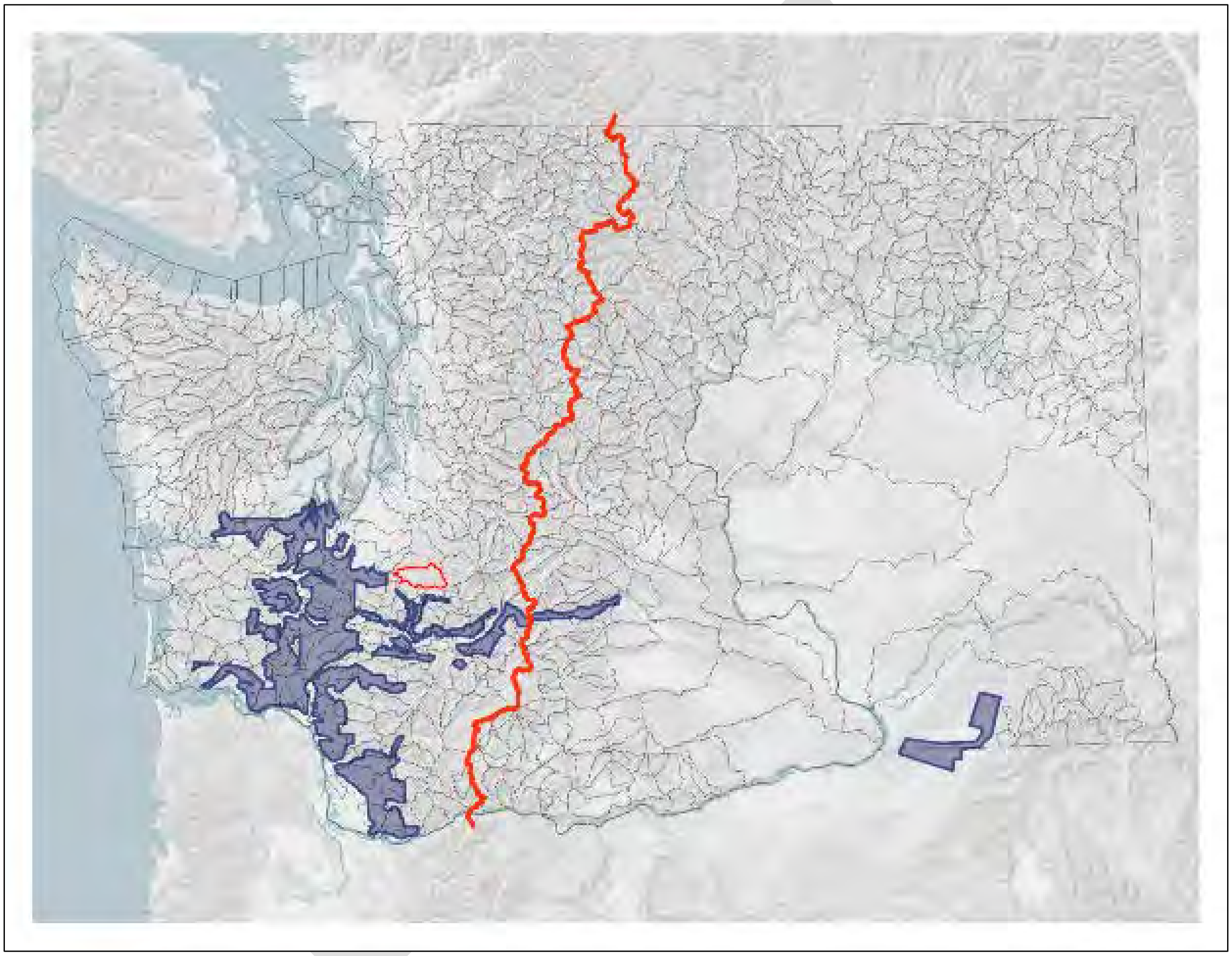

Figure 3: Lidar collected in 2017

Figure 4 shows lidar acquired in 2016, covering areas in the northern Puget Sound lowlands, King County, the southern Cascade crest, and the Colville National Forest in eastern Washington. If lidar from 2017 and 2018 cannot be used, these areas should be considered next. The Puget Sound lowlands are largely developed and agricultural land uses, while the southern Cascade crest is largely high elevation federal and tribal ownership. While neither of these is necessarily of interest (see Forest Types below), the Colville National Forest could be useful. The ideal time for fieldwork to take place in these locations was the summer of 2017, so any work happening in these locations would have a time delay between lidar acquisition and fieldwork of at least three years. Changes in forest structure due to growth would not be accounted for in the models.

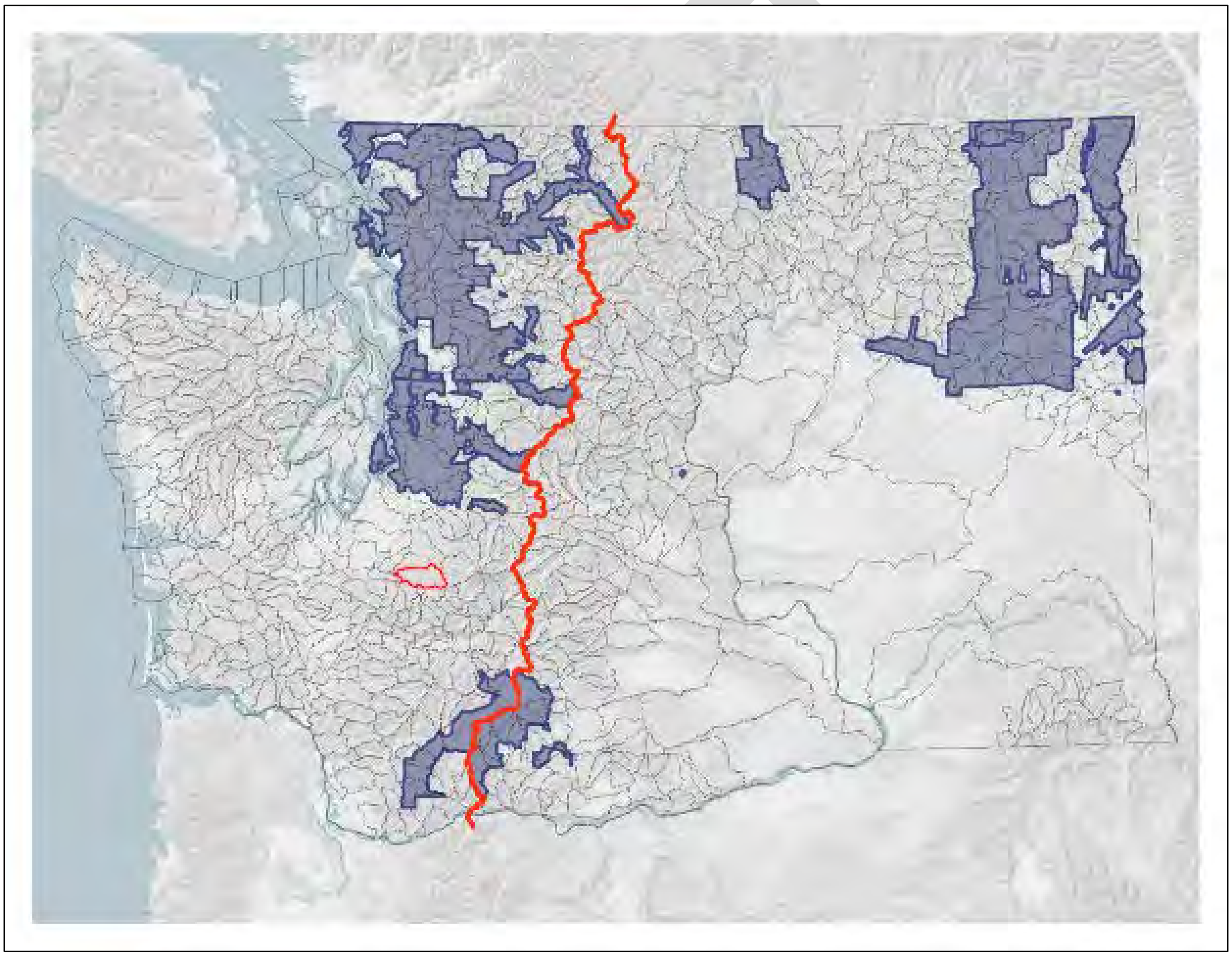

Figure 4: Lidar collected in 2016

Finally, Figure 5 shows lidar acquired in 2015, covering smaller areas across the State. Of particular interest, in terms of forest type, are the southern East Cascades in Klickitat County, and the Colville National Forest in the northeast. Assuming the fieldwork begins no later than 2020, this is the earliest lidar data that should be considered. If the start date for the next phase of this project moves to 2021 or beyond, these lidar data should not be used.

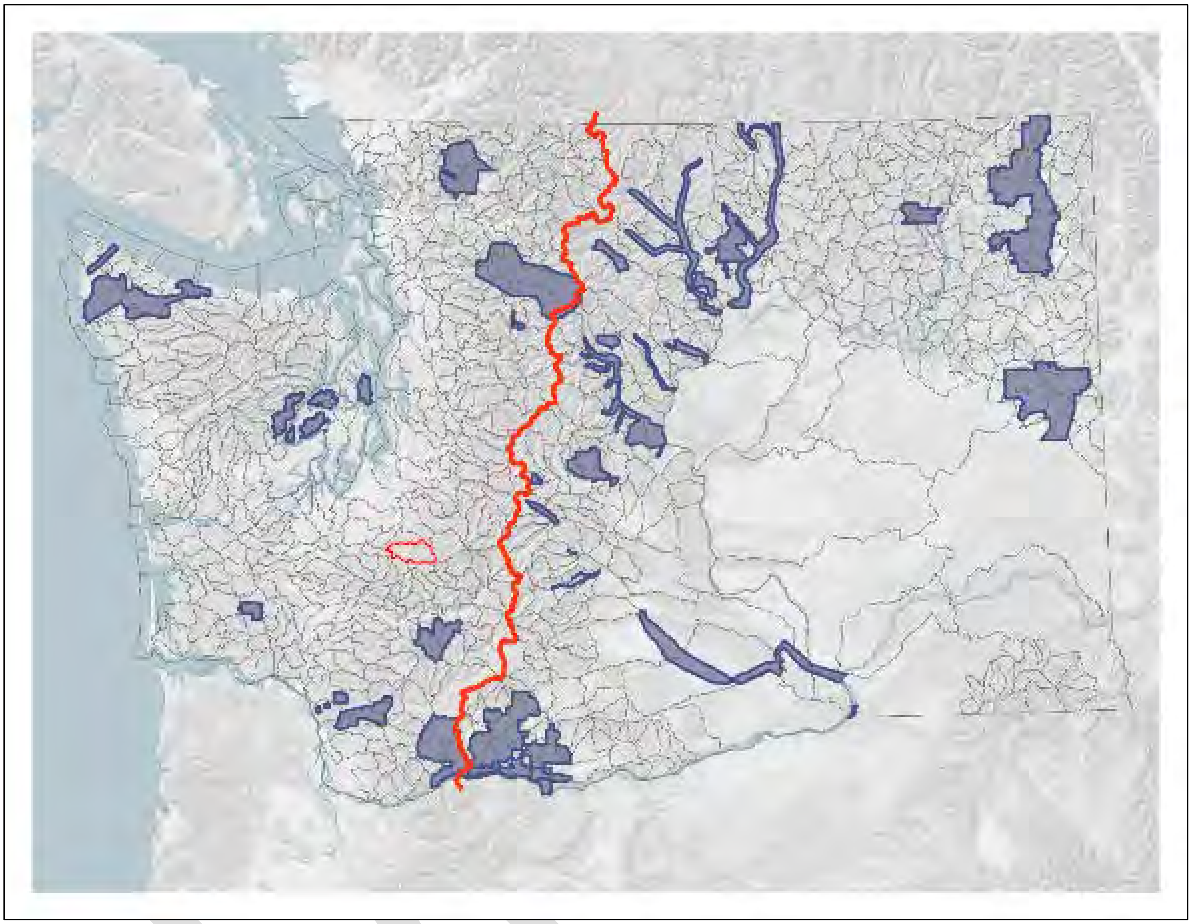

Figure 5: Lidar collected in 2015

Lidar Recommendations

If minimizing the time delay between lidar acquisition and field data collection is the top priority, the most current lidar should be prioritized. This means using 2018 lidar if no newer data is acquired, which suggests that the next phase of the project should occur along the Pacific coast or in the Blue Mountains.

Data earlier than 2015 should not be considered at this time. If the start date for the project moves beyond 2020, lidar datasets acquired more than five years before the fieldwork year should be removed from consideration (e.g., if the fieldwork takes place in 2021, lidar before 2016 should not be considered).

There are areas in the 2015 and 2016 lidar that are interesting in terms of forest type. If these areas are to be studied, the fieldwork should happen no later than 2020 or 2021 respectively.

Forest Types

Introduction

From a lidar-based modelling perspective, the number of models necessary to monitor riparian stands statewide will primarily be determined by the differences in structure of different types of forests, which are in turn determined by species composition and management history. It is therefore necessary to determine the magnitude of the differences between models developed in different forest types, and to look at the impacts on accuracy when models are applied outside of the forest type in which they were developed.

It is expected that the forest types that are the most different from one another would have the largest differences in their models, and their models would have the least accuracy in predicting each other.

Therefore, the goal should be to find forest types that are least similar to the Mashel Watershed, and see how additional models compare to the models that were developed in the Pilot Study.

Additional criteria for selecting locations for the next round of the project include prioritizing areas with private, municipal, and state ownerships (locations where forest practices rules apply) and prioritizing areas with management activity (locations with the largest impacts on riparian corridors). Areas with management activity will likely have a wider range of riparian forest conditions, which is useful for model building.

Approach

Vegetation is generally described using systems like the EPA Ecoregions [6] and USDA Forest Service Ecological Subregions of the United States [7]. These systems have a scale issue where one level (Level III or Sections) is too general, and the next level (Level IV or Subsections) is too specific to describe classes of forest for modeling purposes.

The Franklin and Dyrness [8] generalized vegetation map of Oregon and Washington (Figure 6) is at a scale that fits nicely between the Ecoregion scales, but also has several drawbacks. It is not spatially accurate enough to locate potential study areas for the next phase of the project; and it is a map of climax vegetation, not of what is out on the landscape, especially in areas with active commercial forest management activity.

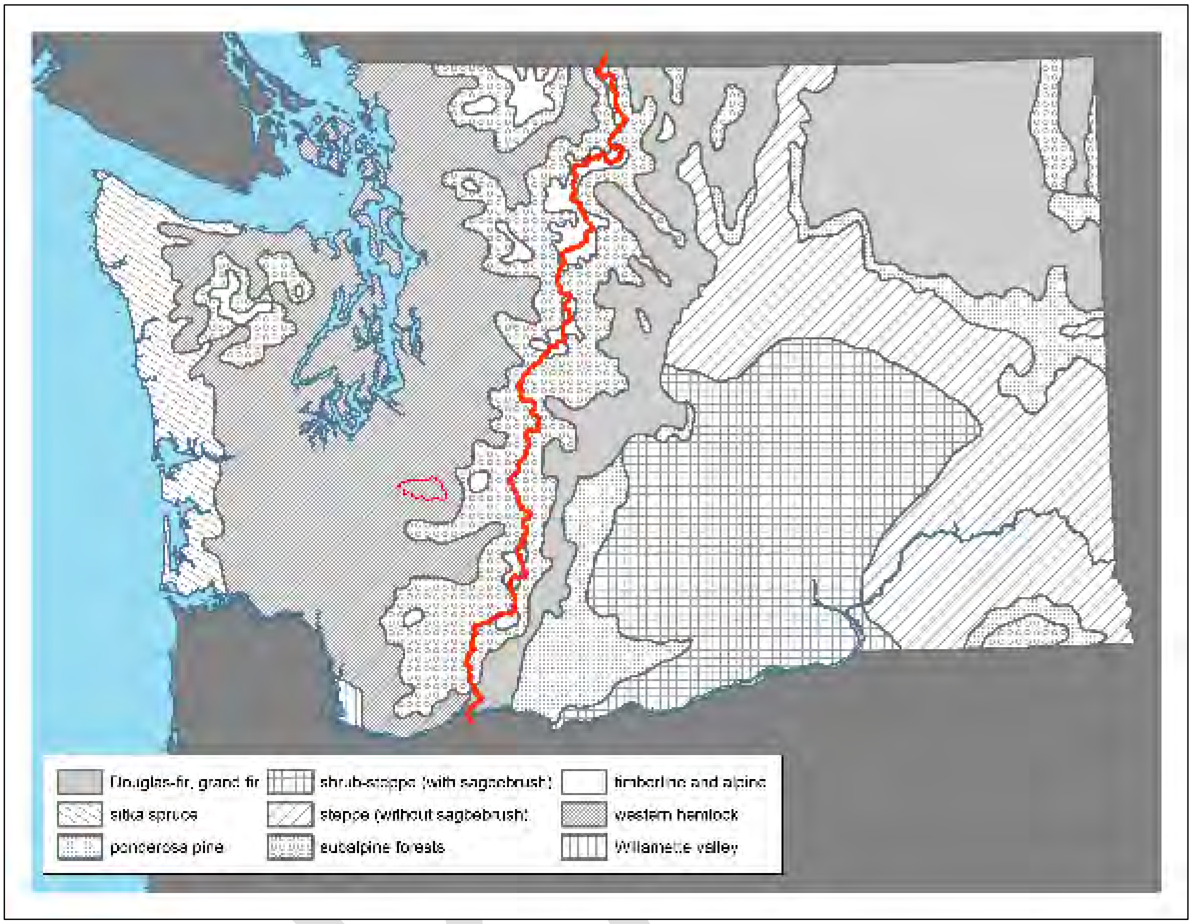

Figure 6: Generalized vegetation map of Oregon and Washington; Franklin and Dyrness 1973

However, this map can be used to identify locations that should be looked at in more detail. Three vegetation classes: ‘shrub-steppe’, ‘steppe’, and ‘timberline and alpine’, can be immediately removed from further consideration because there is no forest present. The ‘western hemlock’ vegetation class was captured by the Mashel Watershed and can also be removed from further consideration.

The ‘subalpine forests’ vegetation class can be removed because it occurs almost exclusively on federal lands (Figure 7) where the forest practices rules do not apply. Although subalpine forests are different from the forest type in the Mashel Watershed, they should be considered lower priority for the next round of the project because a very small percentage of FFR riparian stands are subalpine forest.

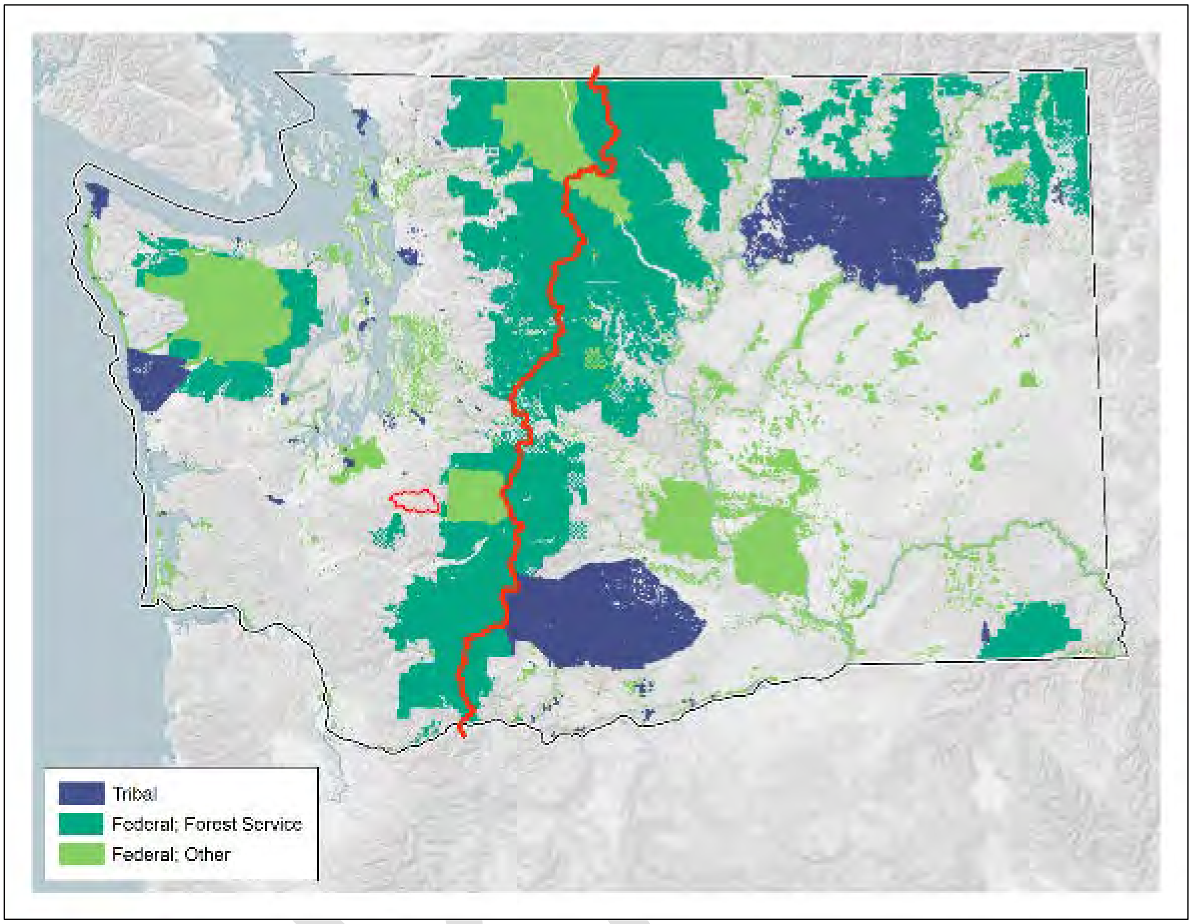

Figure 7: Federal and Tribal lands in Washington, from a parcel database developed for the 2012 Washington Forest Biomass Supply Assessment [9]. Subalpine forests occur in the high Olympic Mountains, along the Cascade crest, and in the Blue Mountains, all of which are primarily Federal ownership.

The 'Willamette Valley' vegetation class can also be removed from further consideration because it covers a small area with primarily developed land uses.

This leaves three vegetation classes for further examination: 'Sitka spruce' on the Pacific coast, 'ponderosa pine' on the Eastside, and 'Douglas-fir/grand fir' on the Eastside.

Using a dataset called 'GNN Structure (Species-Size)' [2], which was developed by the Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) group at Oregon State University, it is possible to compare the distributions of tree species across Washington with high spatial accuracy. The GNN models use climate data, topographic data, and Landsat-derived vegetation data to predict the most similar USDA Forest Service inventory plot for every location on the landscape and assign that plot's species and structure information to that location. Because the inventory plots exist in managed and developed areas, this approach provide a more realistic representation of the forests in the State as they currently exist than the Franklin and Dyrness map.

By narrowing down the locations to watersheds in eastern Washington and along the Pacific coast that have at least 25% forest cover (forested) and are at least 50% non-Federal / non-Tribal ownership (where forest practices rules apply) [9], and grouping these watersheds into zones (Figure 8), it is possible to look at the species occurrence in each zone as described in the GNN models.

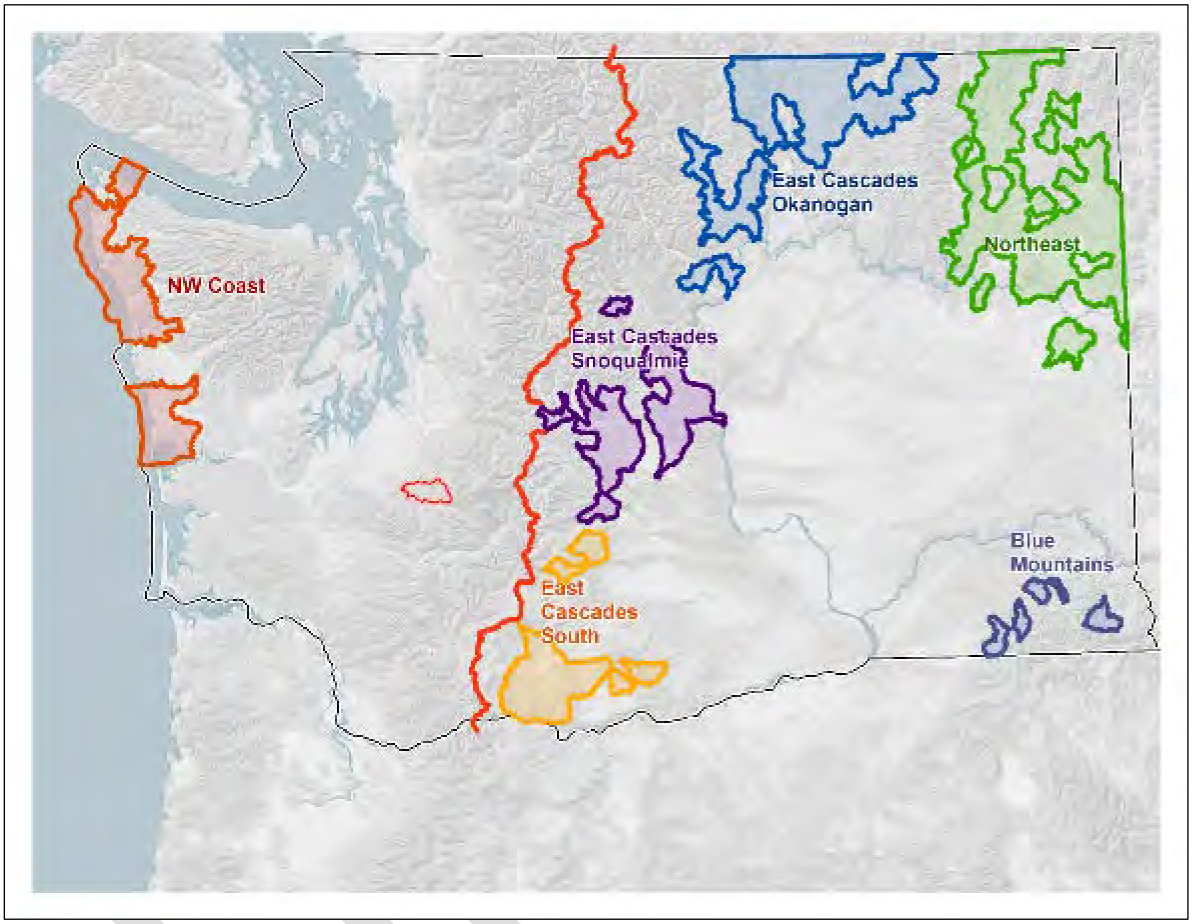

Figure 8: Forest Type Zones. Grouped watersheds with at least 25% forest cover and at least 50% non-Federal/non-Tribal ownership

Using the GNN data, the percentage of the basal area in each zone that is made up of each tree species was calculated, showing the relative ratios of species and how they mix in the different zones. Table 1 shows the basal area percentages of the top six species in each zone (plus the Mashel Watershed from the Pilot Study), and the total percentages of these six species for each zone. The top six species make up between 88% and 98% of the basal area in each zone. More detailed, zone-specific maps of species distributions are available in Appendix A: Dot Density Maps.

Table 1: GNN basal area percentages for each Forest Type Zone, and the Mashel Watershed

Mashel	
Douglas-fir	46%
western hemlock	25%
red alder	11%
Pacific silver fir	6%
western red cedar	5%
bigleaf maple	3%
	97%

NW Coast	
western hemlock	47%
Douglas-fir	18%
western red cedar	17%
Sitka spruce	8%
red alder	6%
lodgepole pine	2%
	98%

East Cascades Okanogan	
Douglas-fir	48%
ponderosa pine	14%
lodgepole pine	12%
western larch	10%
Engelmann spruce	8%
subalpine fir	4%
	96%

Northeast	
Douglas-fir	36%
ponderosa pine	19%
western red cedar	11%
western larch	10%
grand fir	8%
lodgepole pine	7%
	91%

East Cascades South	
Douglas-fir	42%
ponderosa pine	24%
Oregon white oak	11%
grand fir	10%
subalpine fir	3%
lodgepole pine	2%
	93%

East Cascades Snoqualmie	
Douglas-fir	38%
ponderosa pine	21%
grand fir	11%
subalpine fir	8%
lodgepole pine	7%
Pacific silver fir	3%
	88%

Blue Mountains	
grand fir	36%
Douglas-fir	30%
ponderosa pine	16%
western larch	6%
Engelmann spruce	6%
lodgepole pine	3%
	96%

Douglas-fir is a major component of all zones, accounting for 18% to 48% of the basal area in each zone.

Compared to the Mashel Watershed, the Northwest Coast zone has significantly more western hemlock and western red cedar, and also has Sitka spruce and lodgepole (shore) pine.

For the zones in eastern Washington, most species, especially dominant ones like ponderosa pine, do not occur at all in the Mashel. Grand fir, western larch, Engelmann spruce, and Oregon white oak are exclusively Eastside species, with others that are predominantly Eastside or high elevation species with sparse presence on the Westside. From a species composition standpoint, both the Eastside and the coast are different from the Mashel, but the Eastside is has larger differences.

To find areas that are the most different from the Mashel a Euclidian distance score was calculated for each watershed (WAU) in the State again using the GNN-derived basal area values. The absolute differences of the basal areas for each species in a watershed compared to the Mashel were calculated. These differences were summarized to a single distance (Figure 9), with larger distance values indicating greater differences in the species makeup of that watershed compared to the Mashel.

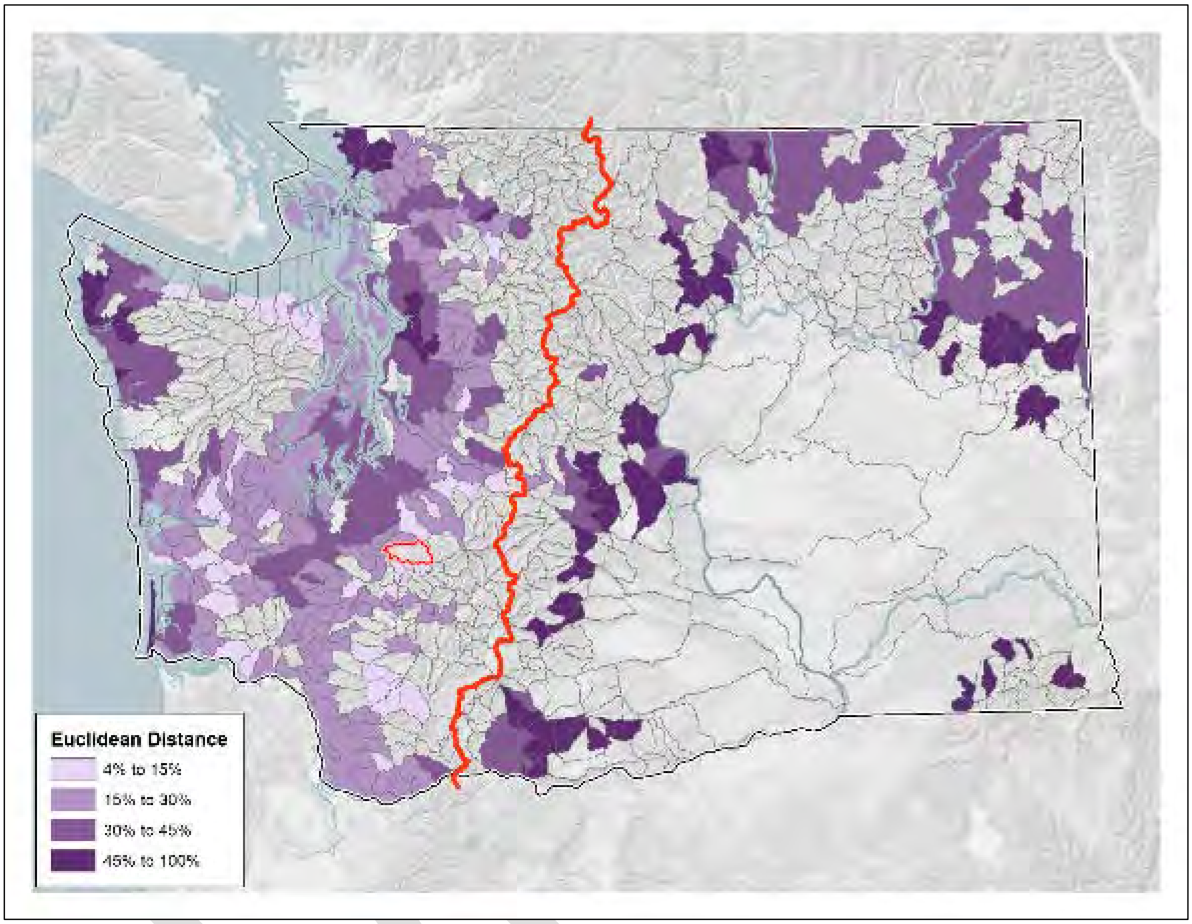

Figure 9: Basal area percentage difference from the Mashel Watershed. Calculated for watersheds with at least 25% forest cover and at least 50% non-Federal/non-Tribal ownership. Darker colors are more different

There are moderately high differences along the developed and agricultural areas of the I-5 corridor and Puget Sound lowlands, but again the greatest differences occur in eastern Washington and in the Northwest Coast Zone.

There are multiple Eastside areas that are very different from the Mashel in terms of forest species and structure. To prioritize which area on the Eastside should be considered first, zones can be ranked by the amount of management activity occurring on the landscape. Areas with management activity will likely have a wider range of riparian forest conditions, which is useful for model building. An estimate of management activity comes from the 2016 Washington State Timber Harvest Reports [10]. These reports summarize harvest volumes by owner type by county. Since the Forest Types Zones do not directly align with counties, the county numbers were grouped as shown in Table 2.

Table 2: Counties in each Forest Type Zone

Forest Type Zone	Counties
Northeast	Pend Oreille, Spokane, Stevens
Blue Mountains	Asotin, Columbia, Garfield, Walla Walla
East Cascades South	Klickitat, Yakima
East Cascades Snoqualmie	Chelan, Kittitas
East Cascades Okanogan	Ferry, Okanogan

By summing the harvest volumes for non-Federal / non-Tribal owners for these county groups, approximate timber harvest volumes for each zone can be calculated (Table 3).

Table 3: 2016 DNR Timber Harvest Report volumes by zone, including private, state, and other public lands, and excluding federal and tribal lands

Forest Type Zone	2016 MBF Non-Federal/Tribal
Northeast	193,433
East Cascades All	153,017 (Okanogan 77,406)
Blue Mountains	1,785

More than half of the timber volume in eastern Washington comes from the Northeast Zone, and almost no volume is produced in the Blue Mountains. In the East Cascade Zones, half of the volume is produced in the Okanogan Zone. Prioritizing by the amount of management activity results in the Northeast Zone being most important to measure in the next round of the project.

Forest Type Recommendations

From a forest type perspective, eastern Washington should be prioritized in the next project phase because it is the most different from the Mashel Watershed in occurrence and mix of species.

Within eastern Washington, the Northeast zone should be prioritized because the largest amount of management on non-Federal / non-Tribal lands is happening there.

The Northwest Coast Zone is also distinctive, but has more in common with the Mashel Watershed than the Eastside. If it is possible to look at more than one watershed, this zone should be sampled second.

The East Cascades Okanogan Zone also has significant management activity while the East Cascades South Zone, has several unique species for eastern Washington. If, in the future, it is decided that more than one Eastside zone is needed or should be measured, these zones should be looked at more closely.

The Blue Mountains Zone is a distinct forest type, but is a small area, has a small amount of private land, and has a small amount of timber production, so it should be a low priority at this time.

Conclusion and Recommendations

Matching the lidar timing with the need to model different forest types is problematic for planning the next project phase. For example, if minimizing time lag between the lidar acquisition and fieldwork is the priority, then it is recommended that the fieldwork happen along the Pacific Coast using the 2018 data acquisition. However, if modeling the forest type with the greatest difference from the Mashel is the priority, then it is recommended that the work happen in eastern Washington. Based on the amount of timber production on private and state lands on the Eastside, a watershed in the Northeast Zone should be prioritized.

The best available lidar in the Northeast Zone is from 2016, meaning the work should happen there no later than 2021. There is also lidar available in the Northeast Zone and East Cascades South Zone from 2015.

If no new lidar is flown on the Eastside, it is important to try to collect field data in the Northeast Zone quickly. If this does not happen before 2021, building models on the Eastside will be dependent on a new, currently unplanned, lidar acquisition, whenever that might happen.

If multiple watersheds can be studied, it would make sense to prioritize work on the Eastside and the Coast.

The watersheds in both the Northeast Zone and the Northwest Coast Zone are, on average, about half the size of the Mashel Watershed. Additionally, watersheds in the Northeast Zone generally have less total stream length and narrower buffer widths than the Mashel, which results in less riparian forest in each watershed. It may be desirable to combine multiple watersheds in either zone to produce a study area of equivalent size to the one used in the Pilot Study. If done correctly, this could help ensure the appropriate variety of forest conditions and management practices in either zone.

Deliverable 2: Locations with Multiple Lidar Acquisitions

When choosing a location or locations for the next phase of the Riparian Extensive Vegetation Monitoring Project, there is potential to the look at the effect of the age of the lidar dataset on the accuracy of models. As stated above (Lidar Availability), the primary consideration when choosing a location should be to minimize the time between lidar acquisition and field data collection. There are, however, many locations around the State where lidar has been acquired multiple times (Figure 10). If it is possible, while meeting other site selection objectives, it would be ideal to select a location that has both current and previously acquired lidar.

There have been many lidar acquisitions in Washington, most of them collected more than five years ago. It is not currently known how accurately models developed using current lidar and field plots can predict current forest metrics using old lidar. If the accuracy is satisfactory, it opens up the possibility to estimate forest metrics over larger areas. Using current models on old lidar datasets may also provide some insight into forest conditions at the time the old lidar was acquired.

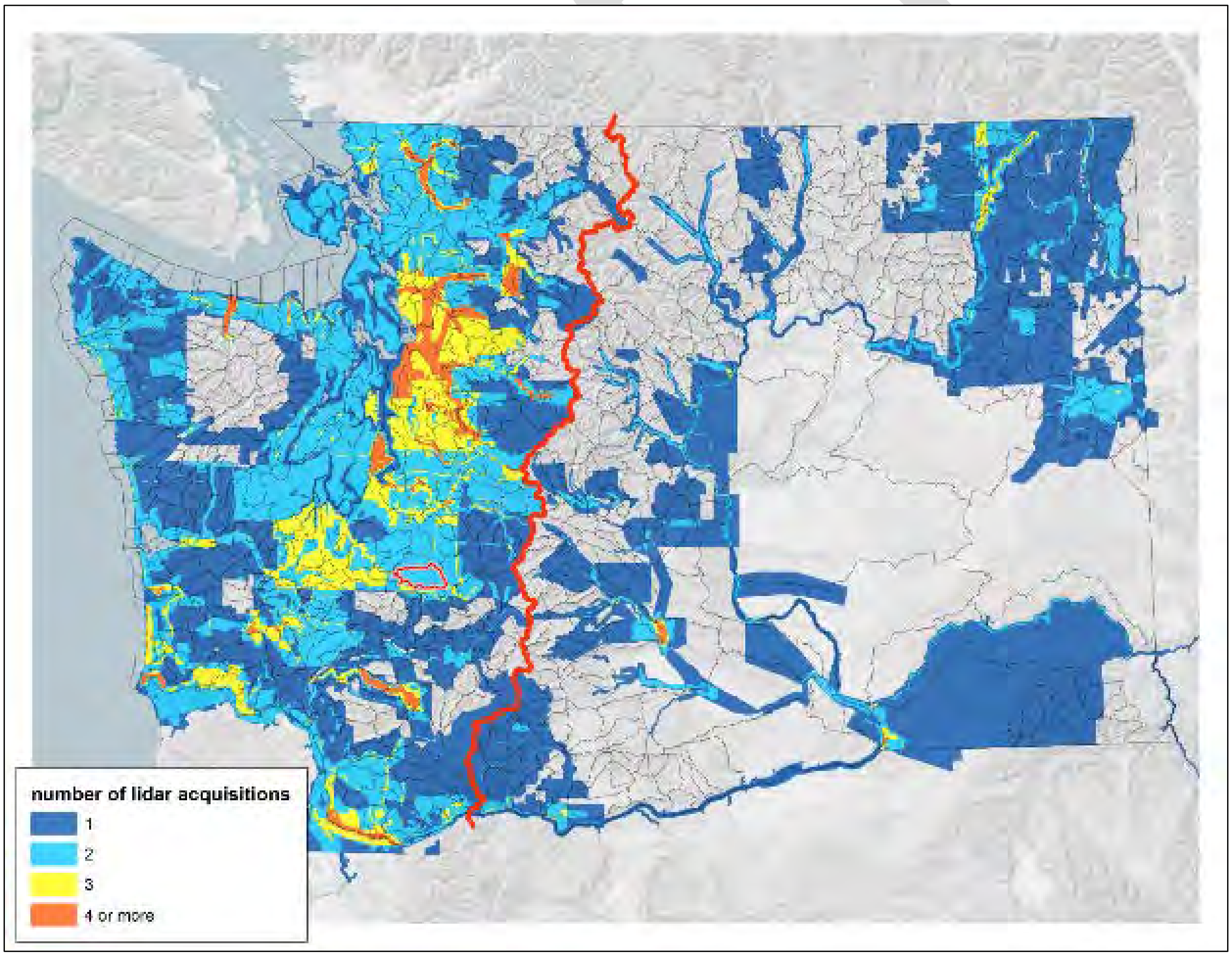

Figure 10: Areas with multiple, overlapping lidar acquisitions in Washington

Northeast Zone

Looking specifically at the Northeast Zone, which was identified in the previous section (Deliverable 1: Identify Lidar Availability and Forest Types) as a potential location, there are several areas of primarily non-Federal / non-Tribal ownership, one east of the Columbia River centered on Kettle Falls, and one along the Pend Oreille River north of Usk (Figure 11).

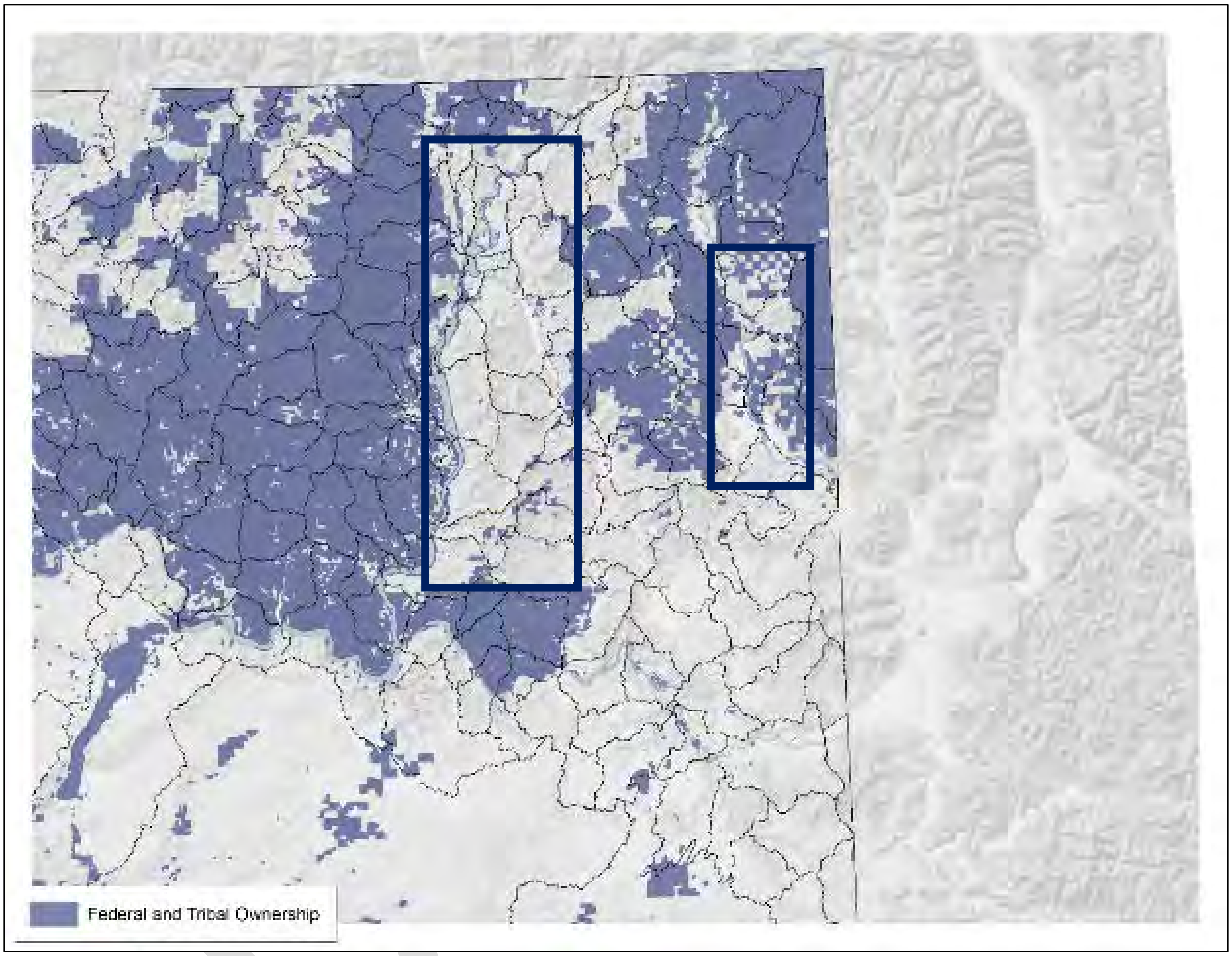

Figure 11: Watersheds in the Northeast Zone with minimal Federal and Tribal ownership

Within these areas, there are no watersheds that are completely covered by multiple lidar acquisitions (Figure 12). In most of the areas where older lidar datasets overlap with the 2016 (the most current) lidar, the older data is from 2014 or 2015. One or two years between lidar acquisitions is not adequate to study the effects of lidar age on model accuracy. There are areas along the Columbia River with data from 2007 and 2010, and several small areas represented by the pink boxes in Figure 12 with data from 2008. Therefore, any use of lidar from multiple dates would have to occur at the sub-watershed scale, or in a watershed that is primarily Federal / Tribal ownership. It may be possible to group two watersheds together to produce a larger area with multiple lidar acquisitions.

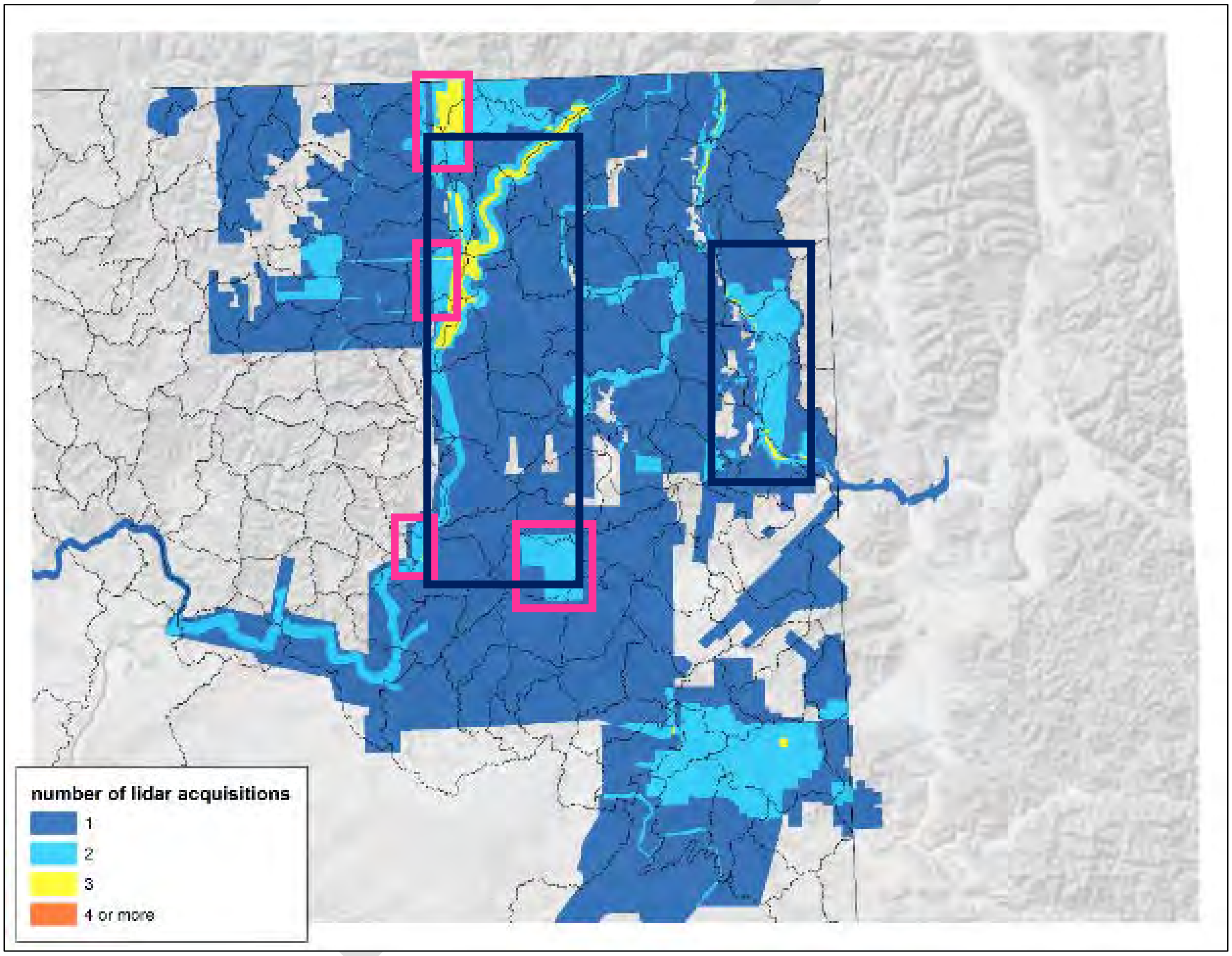

Figure 12: The number of lidar acquisitions in the Northeast Zone. The dark blue boxes represent areas with minimal Federal and Tribal ownership. Pink boxes represent areas where 2008 and 2016 lidar overlap.

Northwest Coast

The Northwest Coast Zone was also identified as a potential location for the next phase of the Riparian Extensive Vegetation Monitoring Project. Again, there are several areas of primarily non-Federal / non-Tribal ownership, one between Grays Harbor and the Quinault Reservation, and one north of the Quinault Reservation and west of Olympic National Park (Figure 13).

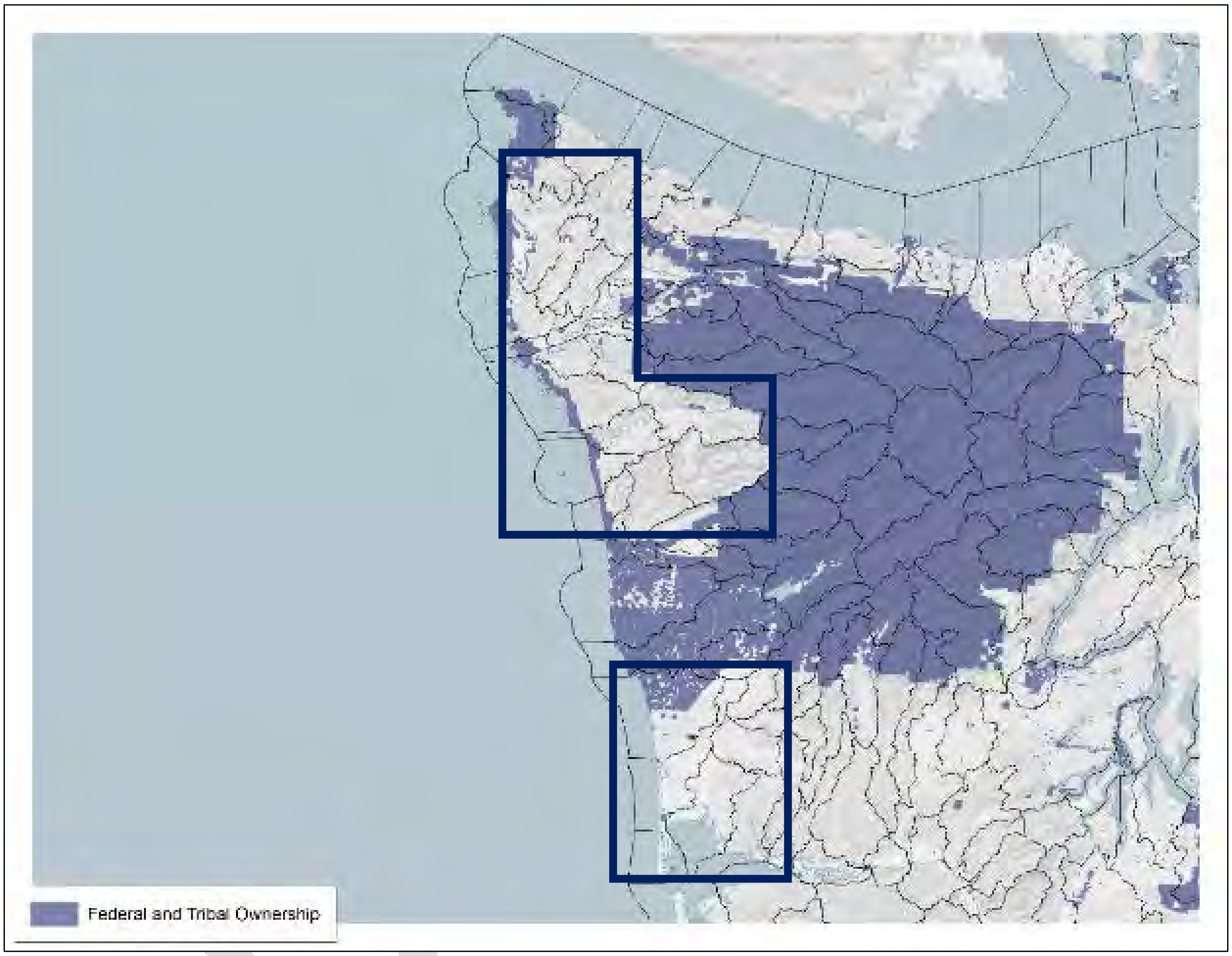

Figure 13: Watersheds in the Northwest Coast Zone with minimal Federal and Tribal ownership

Within these areas, there is a single watershed with complete coverage by two lidar acquisitions (Figure 14). This watershed has lidar from 2018 and 2015. There are several watersheds with the appearance of coverage by two acquisitions, but actually have two or more older acquisitions that each only partially cover the watershed. The older lidar datasets in these areas are from 2002, 2012, 2014, and 2015. The lidar from 2002 covers the town of Forks and part of the Quillayute River basin, but does not entirely cover any watershed. The other lidar datasets only have a time difference of three to six years. It will be challenging to find any watersheds along the coast with a long enough time difference between acquisitions, or where the areas of lidar overlap are significantly large.

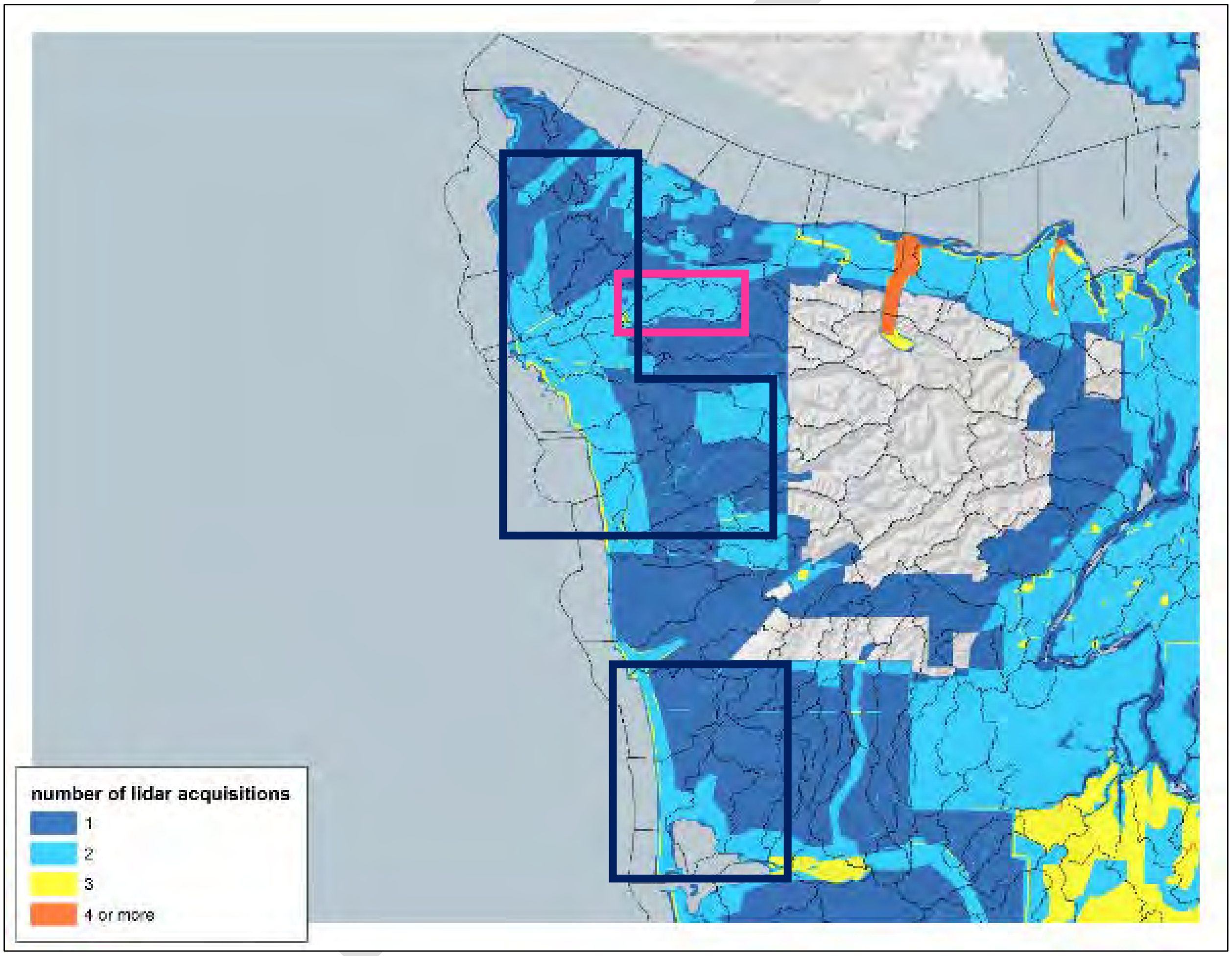

Figure 14: The number of lidar acquisitions in the Northwest Coast Zone. The dark blue boxes represent areas with minimal Federal and Tribal ownership. The pink box represents the single watershed with complete coverage by multiple acquisitions.

Conclusion

No predominantly privately owned watersheds in the Northeast Zone are completely covered by multiple lidar acquisitions.

A single predominantly privately owned watershed in the Northwest Coast Zone has complete coverage in multiple acquisitions. The time difference between the lidar acquisitions in this watershed is only three years.

In areas with multiple lidar acquisitions, there are only a few small locations where the time difference between lidar acquisitions is greater than a few years. A short time difference is not useful in understanding the effect of lidar age on model accuracy.

Watersheds in both the Northeast Zone and the Northwest Coast Zone are, on average, about half the size of the Mashel Watershed. It may be desirable to combine multiple watersheds in either zone to produce a study area of equivalent size to the one used in the Pilot Study.

Deliverables 3 and 4: Riparian Metric and Field Protocol Recommendations

Introduction

For the Pilot Study [1] in the Mashel Watershed, RSAG was interested in measuring 13 metrics (Table 4). The pilot study produced two products:

1. A protocol for field plot sample design [11]that describes the plot size, layout, and sampling methodology used to collect the necessary field data, and
2. An assessment of using remote sensing for estimating the 13 metrics.

Table 4: Extensive Riparian Vegetation Monitoring – Remote Sensing Pilot Study; Model Results. Arrows indicate recommended actions for metrics in future phases of this project.

Metric	Status	LiDAR Model Type	R2	RMSE	Imagery Model Type	R2	RMSE
↓Species	not modeled	N/A	N/A	N/A	N/A	N/A	N/A
→Age	not modeled	N/A	N/A	N/A	N/A	N/A	N/A
↗Hydrology	completed; describe method; no accuracy assessment	DEM processing, flow accumulation, initiation point definition	N/A	N/A	N/A	N/A	N/A
↗Canopy % Cover	completed; describe method; no accuracy assessment	direct Lidar measurement	N/A	N/A	linear regression	0.56*	0.34
→Vegetation Class	completed; describe method; no accuracy assessment	probability based classification	N/A	N/A	NA	N/A	N/A
↑Height (ft)	completed	linear regression	0.86, 0.89	9.74, 11.12	N/A	N/A	N/A
→Crown Diameter (ft)	completed	linear regression	0.54	4.03	linear regression	0.5	8.19
→Stand Density	completed	linear regression	0.49	67.12	linear regression	0.45	105.14
↑Basal Area (sq. ft)	completed	linear regression	0.72	63.12	linear regression	0.27	116.15
↑DBH	completed	linear regression	0.7	2.77	N/A	N/A	N/A
→Snag Detection	completed	combined logistic regression / linear regression	0.47	2.53	N/A	N/A	NA
→Conifer/Deciduous Classification	completed	combined logistic regression / linear regression	0.67	2.8	linear regression	0.78	2.6
↓Large Woody Debris	completed	combined logistic regression / linear regression	0.24	5854.07	NA	NA	NA

* field data only suitable for imagery methods

↑	↗	→	↓
Retain	Retain without Accuracy Assessment	Improve with Additions to Field Protocol	Remove

Measuring field data was the largest cost in the Pilot Study. The cost was primarily driven by the time the crew spent getting to and from the plots, but secondarily by the time spent at each plot making the necessary field measurements. Time spent collect additional field measurements increases the cost associated with measuring each plot, while taking fewer measurements reduces time spent and cost.

Models for several metrics had moderate to high accuracy, however it was not possible to build models for all 13 metrics. Several metrics could not be modeled using lidar or imagery because these technologies do not collect the necessary information. Other metrics require plot data that could not be collected or was not collected because of the time or cost required to collect it. The remaining metrics were modeled, but the accuracy of some of the models was low enough to suggest that remote sensing is not the way to measure them.

Based on what was learned in the Riparian Extensive Vegetation Monitoring Pilot Study, not all 13 metrics should be attempted in the next phase. The models for several metrics may be improved with additional fieldwork, but with higher cost.

The following recommendations are based on the Pilot Study results.

Metrics to Retain

Lidar models for estimating height, basal area, and tree diameters (DBH) were effective and should be modeled again in the next phase of the project.

Metrics to Retain (Without Accuracy Assessment)

Hydrology

A hydrology (stream channel location) model was developed, but it was not possible to test its accuracy without significant additional study.

One of the recommendations of the Pilot Study was to further research the impacts of different stream channel delineation methods. Comparing the stream datasets produced using these different methods to true stream locations would enable an accuracy assessment of the hydrology model.

Collecting the true stream channel location data is an entirely different process than the plot measurement done for the vegetation. It is likely infeasible to collect the necessary stream location data as part of the Extensive Riparian Vegetation Monitoring Project.

Understanding the best way to develop stream channel datasets from lidar ground models could have larger implications on stream buffering, water type mapping, and end of fish points, among other things.

A hydrology model can be developed directly from the lidar and is useful whether or not an accuracy assessment is done. It does provide a more realistic picture of the stream network than the DNR Hydro GIS dataset, especially in upper stream reaches, even if its accuracy is unknown.

Canopy Cover Measurement

In the Pilot Study, canopy percent cover was estimated directly from the lidar, and the field crew did not measure it. Methods for estimating canopy percent cover from the ground do not measure the three-dimensional structure of the crown the same way that lidar does, making direct comparisons difficult. These methods can also be time consuming, causing fieldwork to be more expensive.

Lidar-based direct measurements of canopy percent cover are likely the best way to estimate this metric [12], [13]. It was decided for the Pilot Study that the time that could have been spent having the crew measure canopy cover was better spent measuring more plots, and so an accuracy assessment could not be performed. If CMER or RSAG are interested in comparing ground-based percent cover estimates with direct lidar measurements of canopy percent cover, the field protocol could be modified to include this measurement going forward, with an increase in cost for the fieldwork, or with potentially fewer plots measured.

Metrics That Could be Improved/Modeled with Revisions to the Field Protocol

Adding Stem Mapping to the Protocol

In the Pilot Study, it was hoped that individual tree crown segmentation, a method of processing lidar to locate individual tree crowns in the point cloud, might prove useful for building models to estimate several metrics: Crown Diameter, Conifer/Deciduous Classification, Stand Density, and Snag Detection.

It was determined during the segmentation development efforts that not knowing the locations of the individual trees on the plots made it impossible to perform the individual tree crown segmentation with enough accuracy to be useful. Therefore, the models for these metrics were developed without lidar data for individual trees, which may have impacted their overall accuracy. It is possible that stem mapping trees on the plots would allow individual tree segmentation efforts to be successful providing additional attributes to these models, improving their accuracy. The time required to stem map plots is not insignificant, which is the reason it was not done during the Pilot Study. The impacts on model accuracy of adding individual tree data cannot be known until it is attempted.

Adding Tree Coring to the Protocol

In the Pilot Study, there was no attempt to model stand age. A correlation exists between tree height, size, and age, so it is theoretically possible to make an age model using structural (height) information from lidar, but this is complicated when species are mixed, or when the same species occur in areas with different site index values. Modeling age was not attempted because of the time and cost necessary to core trees, and the issues involved in securing permission from landowners. If RSAG or CMER are interested in modeling age, tree coring could be added to the field protocol.

Adding Vegetation Class to the Protocol

Field measurements of vegetation class are highly subjective. Consistent measurements are required to develop an accuracy assessment of the vegetation class model from the Pilot Study. It may be possible to take the proposed vegetation class framework from the Pilot Study and develop a repeatable field methodology. If a repeatable field methodology can be developed, the field crews can measure vegetation class and an accuracy assessment can be performed.

Metrics to Remove

Neither the lidar nor the imagery approaches to estimate Large Woody Debris and Species were successful in the Pilot Study. This suggests that either the sensors are not capable of measuring the necessary information or that the currently available modeling approaches are not suitable to estimating these metrics using remote sensing. It is recommended that future phases of this project do not continue attempting to estimate these metrics. This would reduce cost as field crews could remove the large woody debris measurements from their protocol.

New Metrics to Add

There has been some success, by the Precision Forestry Cooperative, in modelling Leaf Area Index (LAI) using lidar and image derived point clouds. Because LAI may be useful for estimating stream shading, it may be desirable to add an LAI metric in future phases of this project. Field crews would need to collect the necessary data to develop ground-based LAI estimates, which could be done by collecting and processing hemispherical photos. The methods for this are presented in a Master's thesis by Travis Axe based on Mashel data [14]. The field data collection is minimal, but there is post-processing of the photographs that is required. A more robust method would be to use an LAI2100 (previous version of the instrument is known as LAI2000) instrument instead of the hemispherical photographs [15]. This is a common LAI ground trothing technique and the Precision Forestry Cooperative is experienced in using this equipment and has two of them available for a future project. However, the LAI2100 method requires specific light conditions and would have implications for field data, limiting data collections to those lighting conditions or necessitating revisiting plots when the conditions exist. This could have significant implication on the field data acquisition costs, as the crew(s) might have to visit each plot more than once. It is estimated that this could increase field costs by about 30%, but very little post-processing is needed as the equipment collects LAI measurements. The final approach to collecting LAI is by using a terrestrial laser scanning (TLS). The Precision Forestry Cooperative has published on these methods since 2009. The costs saved in the field due to being able to perform the scan under any lighting conditions are offset by the post collection processing of the TLS data that is needed. This would add substantial costs to data processing and analysis, but it is the experience of the Precision Forestry Cooperative (and other researchers), that the TLS measurements are the most accurate way to monitor LAI when compared to hemispherical photography or LAI2100.

Conclusions on recommendations on Field Protocol and Metrics Selection

We propose that the fall of 2018 is focused on multiple meetings with RSAG to finalize the metrics suitable for a long-term monitoring program that RSAG determines through focus sessions. The UW Precision Forestry Cooperative is willing to host these meetings, including a webinar/call-in option, or this can be accomplished by dedicating time in the regular monthly RSAG meetings. Upon RSAG decision of which metrics to prioritize the 2016 field protocol can be revised and updated with new metrics. The field methods revisions would be presented to RSAG during regular RSAG meetings and finalized in the spring of 2019. This would allow for field planning and a campaign to take place in the summer of 2019.

Other Technologies and Considerations

Lidar data is not regularly available spatially or temporally for Washington State, which will limit monitoring efforts. If the monitoring process is dependent on lidar, the gap in lidar availability could potentially be addressed by using other remote sensing technologies or approaches. Although we did not focus on other technologies in this scoping report, the final report from the 2017 Pilot Study discusses and shows an example of using another remote sensing technology, Structure from Motion (SfM), a photogrammetric range imaging technique for estimating three-dimensional structures from two-dimensional image sequences that may be coupled with local motion signals. It is studied in the fields of computer vision and visual perception. The technique works with two or more images and produces point clouds similar to lidar point clouds, which can be further processed to surface models. In our 2017 report, we demonstrate how this technique can be applied to estimate tree heights in the Mashel watershed, [14]. Research performed by the Precision Forestry Cooperative also shows how SfM can be applied to NAIP imagery to derive LAI. Any future projects should utilize the SfM NAIP data in their analyses, or at the least, include a comparison to lidar.

Additionally, data fusion is a common approach in remote sensing. Gradient Nearest Neighbor (GNN) [2] modeling and similar techniques [16] specifically at locations where lidar is unavailable, could apply the utility of data fusion as a means of filling spatial or temporal data gaps. The GNN modeling approach is being utilized as a large-scale mapping tool by combining remote sensing datasets to model various forest parameters for entire spatial domains. Additional examples of work by the Precision Forestry Cooperative combine sparsely sampled lidar and various satellite data to estimate forest inventory metrics ([17], [18]). A data fusion approach can be readily adapted to large area monitoring by combining lidar, and potentially SfM from NAIP, with frequent continuous satellite coverage like Landsat. Thus, future Riparian Extensive Vegetation Monitoring work should include a comparison of metrics from lidar or SfM models alone to GNN-style models fusing the various domains of remote sensing to get better understanding of how long term monitoring can be achieved when high spatial resolution data like lidar might lack in frequency.

Location Options

The following section describes three location alternatives for future project work, and data analysis options regardless of selected location. This information is also summarized in Figure 15, which breaks down the decision by location first and metrics second.

Alternative 1

One study site in Northeast Washington.

Cost: $400,000 to $600,000.

Time: Approximately 2 years.

Pros:

Eastern Washington is the most different from Mashel in terms of forest composition. Models developed here will best demonstrate the magnitude of the differences for various metrics. Lidar in Eastern Washington will be too old to be useful in 2021, so performing fieldwork here quickly, takes advantage of existing data while it is possible.

Cons:

Models developed in the Mashel and in Eastern Washington will not cover the full variability of forest types in the state. At some point, it will be necessary to develop additional models along the northern Pacific Coast.

Alternative 2

One study site along the northern Pacific Coast.

Cost: $400,000 to $600,000.

Time: Approximately 2 years.

Pros:

Provides information on model performance in a forest type different from the Mashel. The lidar here is newer, so there is more time to plan and implement field data collection before the lidar is too old. It may be possible to use existing UW facilities (the Olympic Natural Resources Center in Forks) reducing the cost of the fieldwork by a small amount.

Cons:

Models developed in the Mashel and along the northern Pacific Coast will not cover the full variability of forest types in the state. At some point, it will be necessary to develop additional models in Eastern Washington.

Alternative 3

Two study sites, one in Northeast Washington and one along the northern Pacific Coast.

Cost: $800,000 to $1,200,000.

Time: Approximately 2 years.

Pros:

Models developed in the Mashel and these two additional study areas will cover the majority of forestlands in Washington where forest practices rules apply. Models developed will demonstrate the magnitude of the differences for various metrics at a statewide scale. Studying two areas simultaneously allows models to be developed in two years rather than four or more years if areas are studied separately.

Cons:

Studying two additional areas at once will nearly double the cost of studying one additional area, however there might be some savings in the setup of both site field sampling as well as batch processing during the analysis phase.

Analysis Regardless of Option

Metrics

There are six metrics that performed well enough in the Mashel Pilot Study to be modeled in any future stages of the project, five from lidar (height, basal area, DBH, hydrology, and canopy percent cover) and one from imagery (conifer/deciduous classification). An additional five metrics (age, vegetation class, crown diameter, stand density, and snag detection) may be worth studying further, but may only be useful with modifications to the field protocol. There may be cost savings by removing these from further study. Two metrics (species and large woody debris) should be removed from further consideration based on the poor performance of the models. Based on successful work outside of the Pilot Study, it may be worth adding a new metric, Leaf Area Index, to future stages of the project.

New Technology

Availability of lidar data will limit ongoing monitoring efforts; moreover, remote sensing is a field that changes at a fairly rapid pace. Newer data and modeling approaches could help address the issue of limited lidar availability; they may also help provide for integrated monitoring methods that facilitate incorporating new technologies that are not currently known/available. Two approaches are suggested for investigation:

- Structure from Motion (a technique that builds lidar-like datasets from aerial imagery) has been used by the DNR to build several statewide coverages from NAIP imagery. Structure from Motion datasets will likely be more consistently available than lidar. Using Structure from Motion datasets to model relevant metrics should be examined in any future stages of the pilot project. The field sampling design as driven by Structure from Motion should also be compared to the field sampling design driven by lidar; this analysis can be retroactively performed in the Mashel watershed and/or performed at all future locations.

- There are other modeling approaches than direct estimates from remote sensing, like GNN, which uses climate data, topographic data, and Landsat-derived vegetation data to predict the most similar USDA Forest Service inventory plot for every location on the landscape and assign that plot's species and structure information to that location. It may be worthwhile to examine how well a GNN approach can estimate various metrics.

The implementation of these new technologies should be investigated regardless of alternative option chosen. There is an inherent cost to exploring these new technologies, especially the GNN modeling, which can be estimated at $100,000/year (one fulltime analyst). Furthermore, regardless of which alternative option is chosen, the new technologies should be investigated for the Mashel Watershed. The Mashel analysis should add very minimal costs to the project as no further field data collection is required.

Location

Alternative 1

1 Site in Northeastern WA

Cost: $400K-$600K; Time: ~2 years

Pros:

Demonstrate the magnitude of the modeled differences for various metrics

Cons:

Will not cover the full variability of forest types in the state. At some point, it will be necessary to develop additional models along the northern Pacific Coast.

Alternative 2

1 Site on the Northern Pacific Coast

Cost: $400K-$600K; Time: ~2 years

Pros:

Newer lidar allowing better temporal match with plot data, small cost savings in field data collection due to reduced field costs (accommodations at ONRC less expensive)

Cons:

Will not cover the full variability of forest types in the state. At some point, it will be necessary to develop additional models in Eastern Washington.

Alternative 3

2 Sites - 1 in Northeastern WA & 1 on the Northern Pacific Coast

Cost: $800K-$1.2mil; Time: ~2 years

Pros:

Models would cover the majority of forest types in WA state, thus, can demonstrate the magnitude of the modeled differences for various metrics at a state scale

Cons:

Studying two areas at once will nearly double the cost compared to studying only one area.

Metrics (includes new technologies)

1.1

11 Metrics & LAI

Most robust range of metrics but limited in spatial scope

1.2

6 Metrics & LAI

Lower range of metrics and limited spatial scope simpler analysis = lower end of the estimated costs, potential saving in field data collection estimated at $50K

2.1

11 Metrics & LAI

Most robust range of metrics temporally matched but limited in spatial scope

2.2

6 Metrics & LAI

Lower range of temporally matched metrics and limited spatial scope simpler analysis = lower end of the estimated costs, potential saving in field data collection estimated at $50K

3.1

11 metrics & LAI

Most robust range of metrics capturing majority of forest types in the state

3.2

6 metrics & LAI

Lower range of metrics capturing majority of forest types in the state but simpler analysis = lower end of the estimated costs, potential saving in field data collection estimated at $100K

Figure 15: Location and Analysis Alternatives

1

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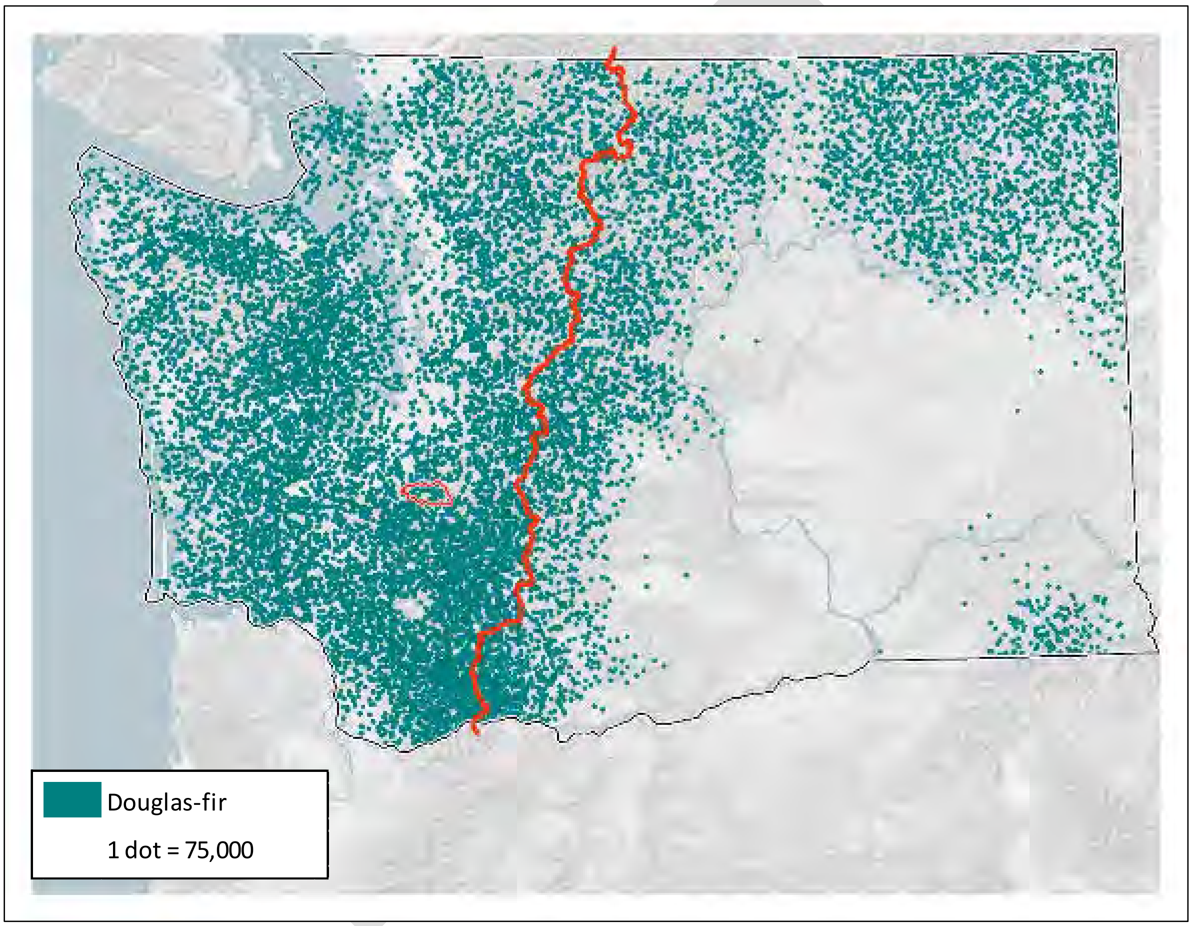
Appendix A: Dot Density Maps

The following series of maps show the distribution of the most common trees species in each forest zone, as measured by GNN basal area [2]. Each dot on the maps represents 75,000 square feet of basal area, while the different colors represent different species. The red vertical line in the center of the maps is the Cascade crest, and the red polygon in the lower left of the State is the Mashel Watershed used in the Pilot Study. The zones are defined in Figure 8 above.

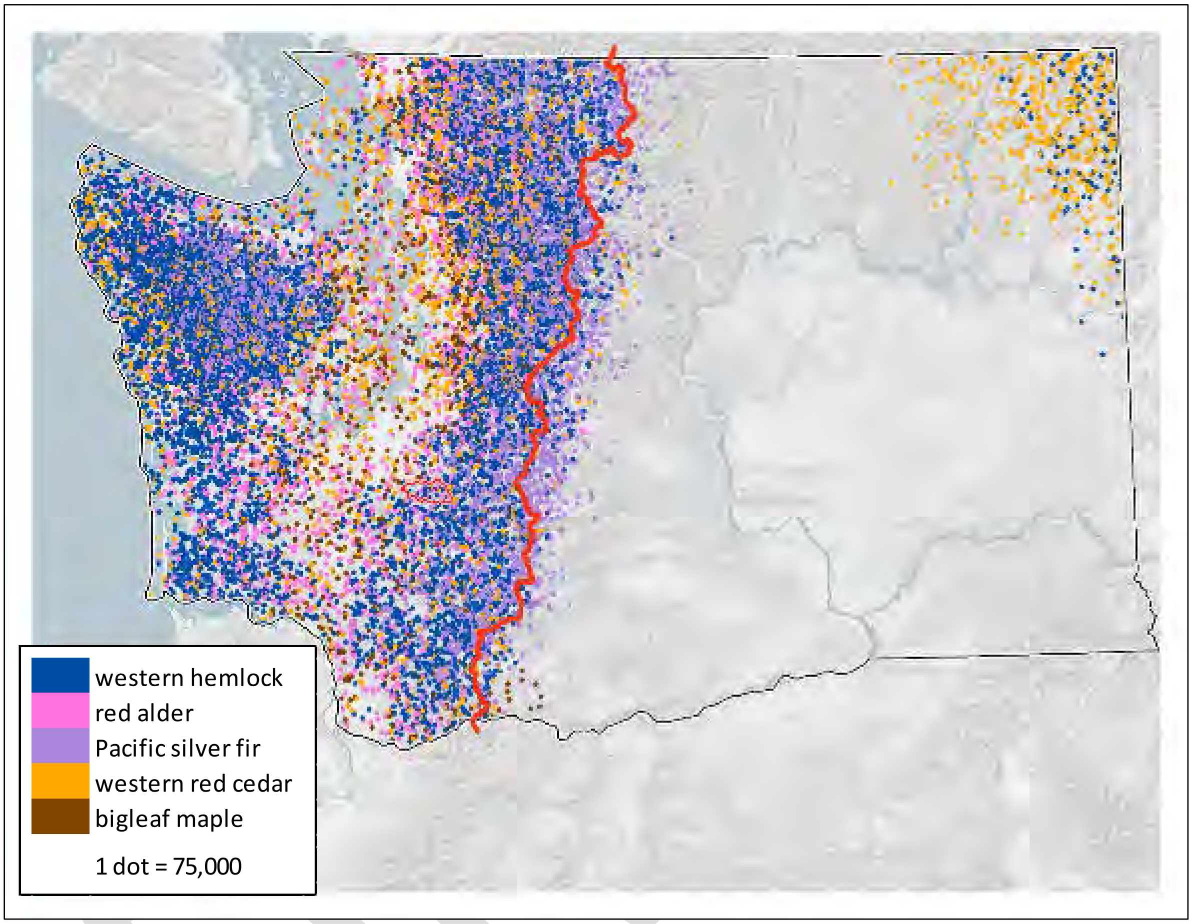
Because Douglas-fir is a dominant species across the State, it is removed from all of the maps, except the next one, to make the maps more readable.

Basal Area Distribution – Douglas-fir



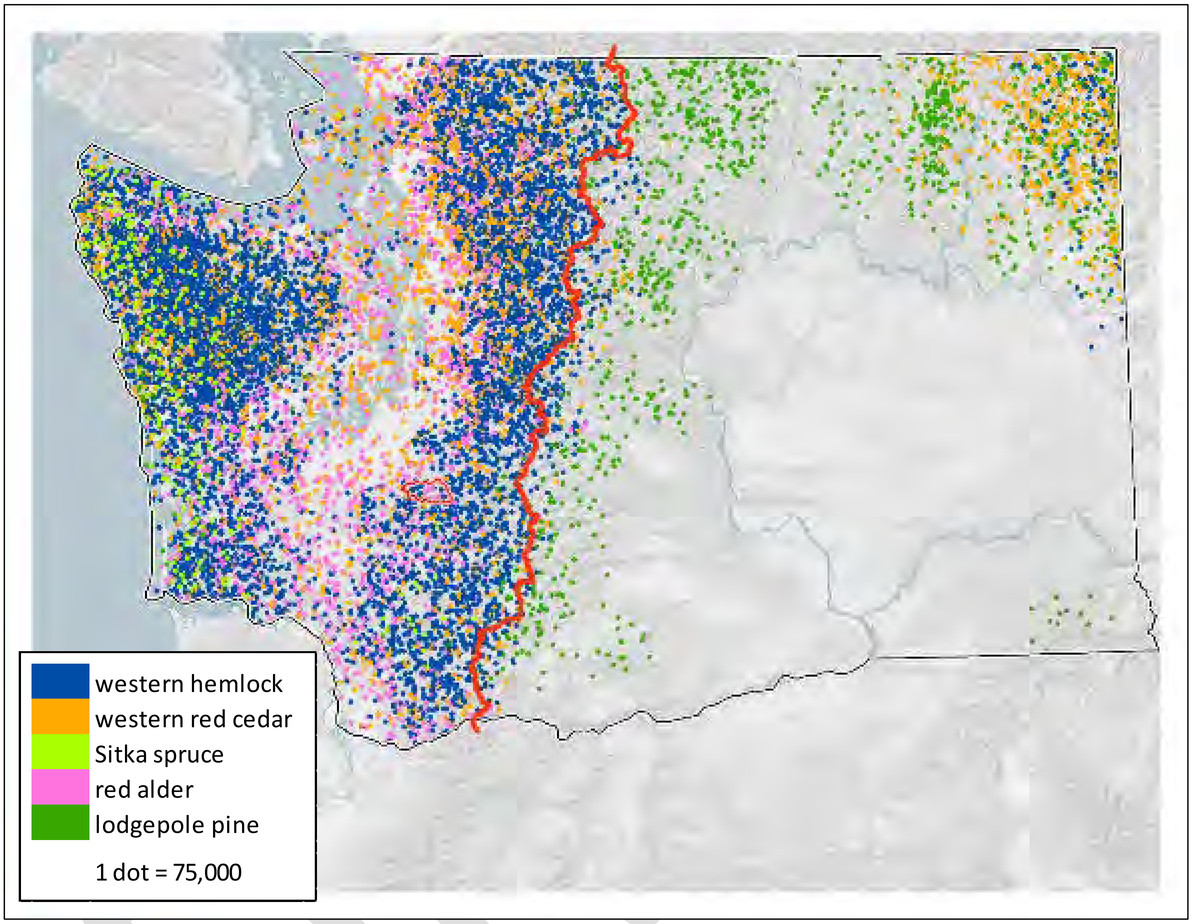
Basal Area Distribution – Mashel Watershed

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 97% of the basal area in the Mashel Watershed.



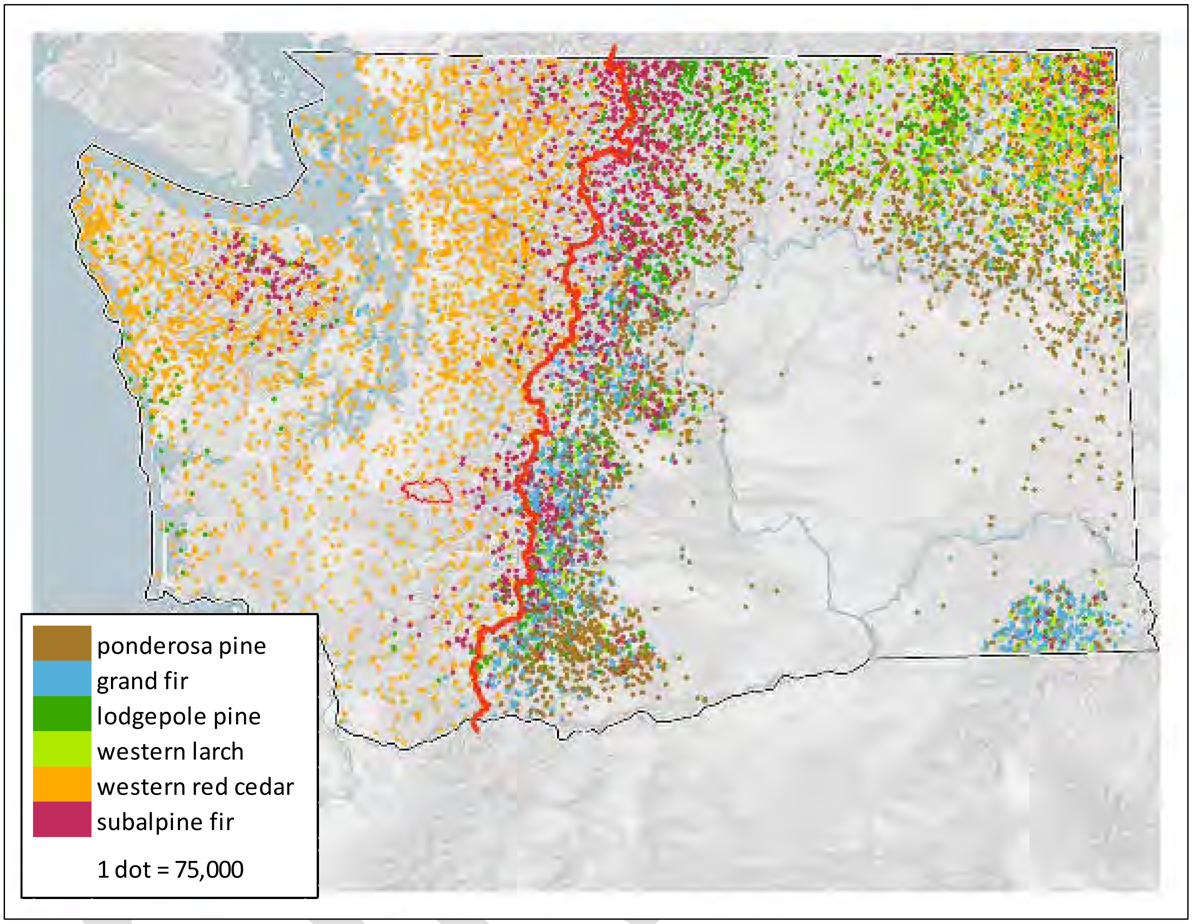
Basal Area Distribution – NW Coast Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 98% of the basal area in the NW Coast Zone.



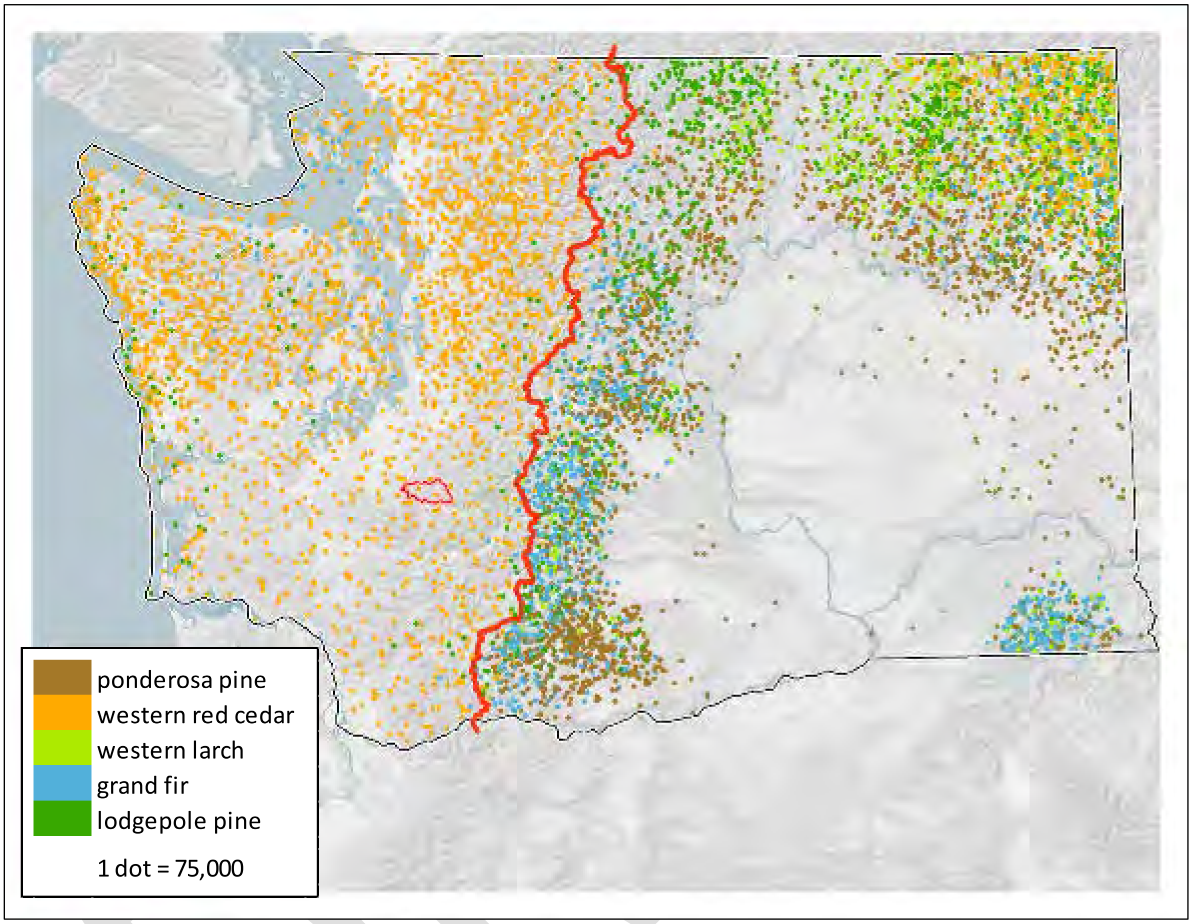
Basal Area Distribution – Eastside All Zones

The top six species after removing Douglas-fir. These species, plus Douglas-fir, account for 90% of the basal area in the 4 Eastside Zones.



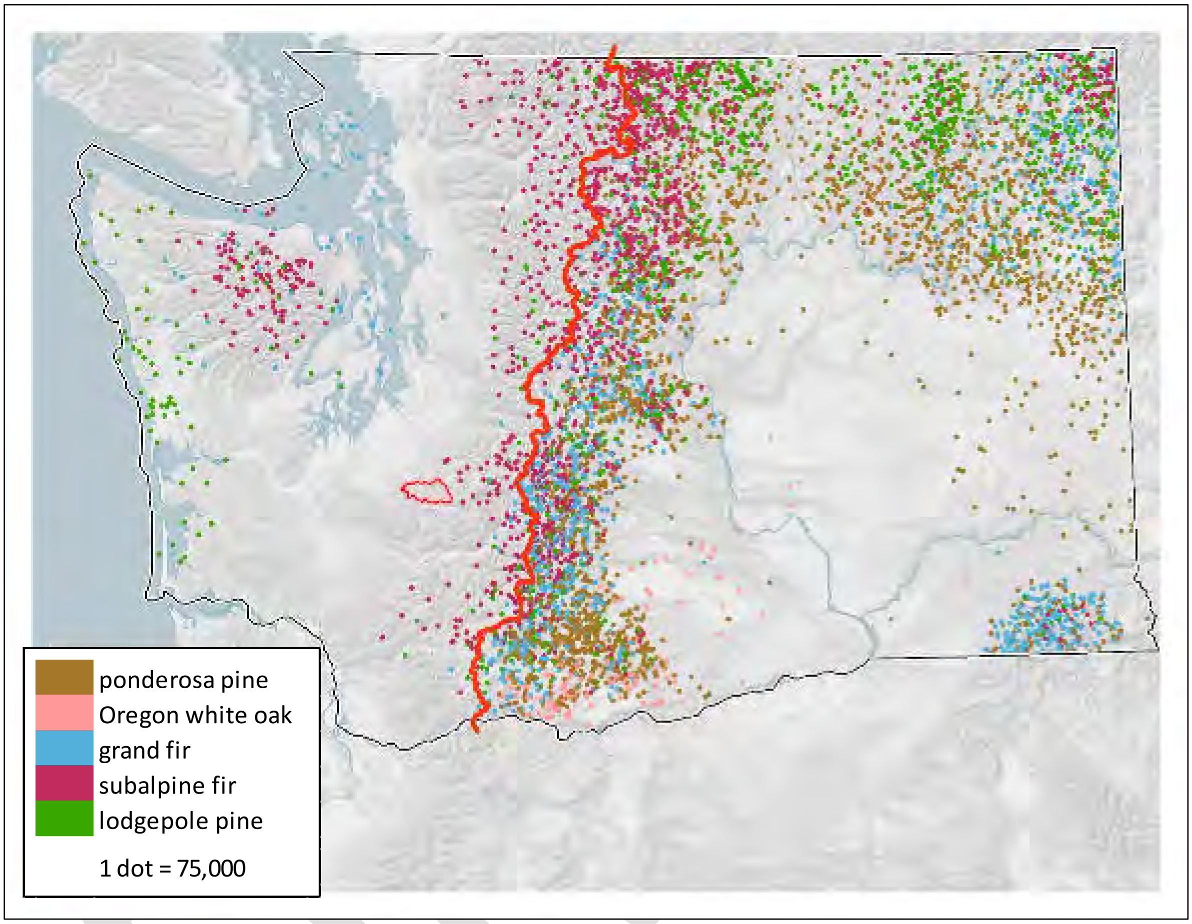
Basal Area Distribution – Northeast Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 91% of the basal area in the Northeast Zone.



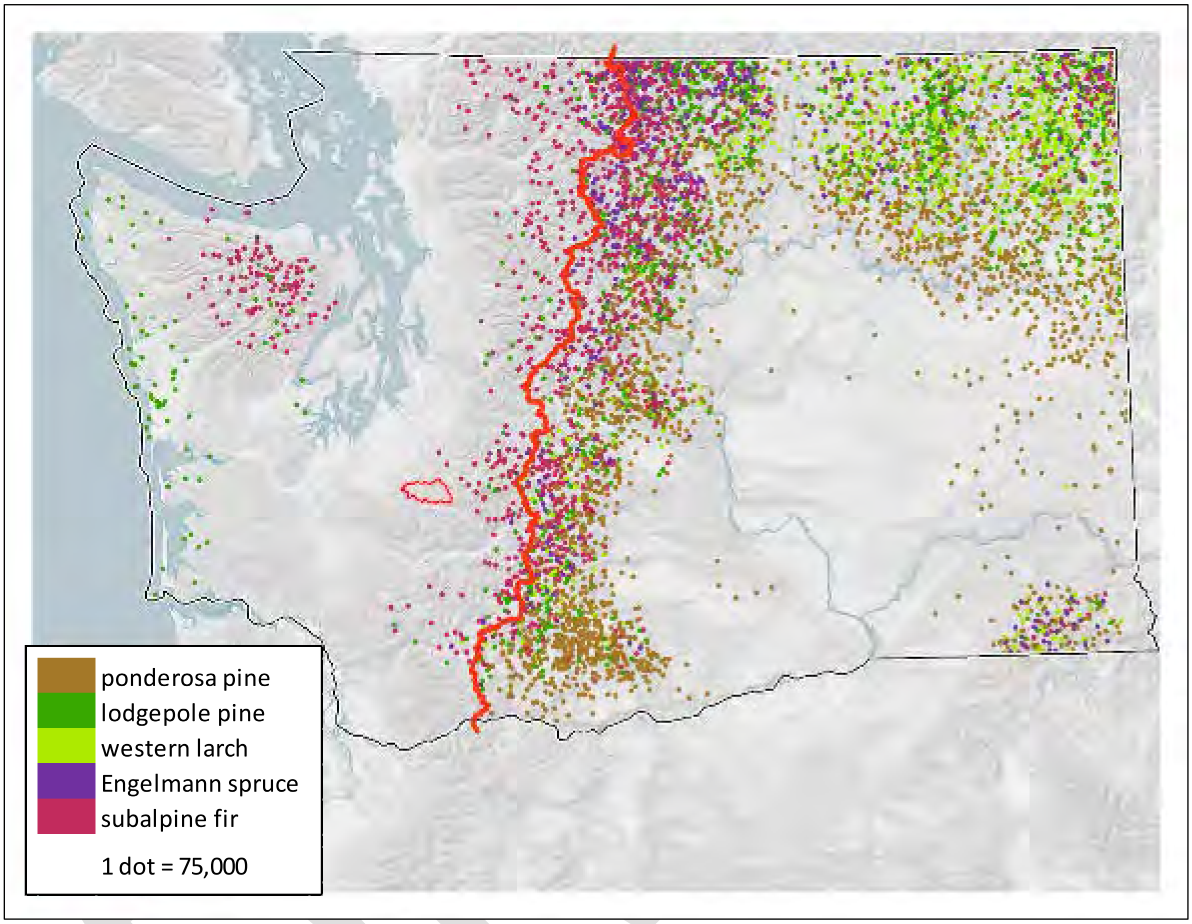
Basal Area Distribution – East Cascades South Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 93% of the basal area in the East Cascades South Zone.



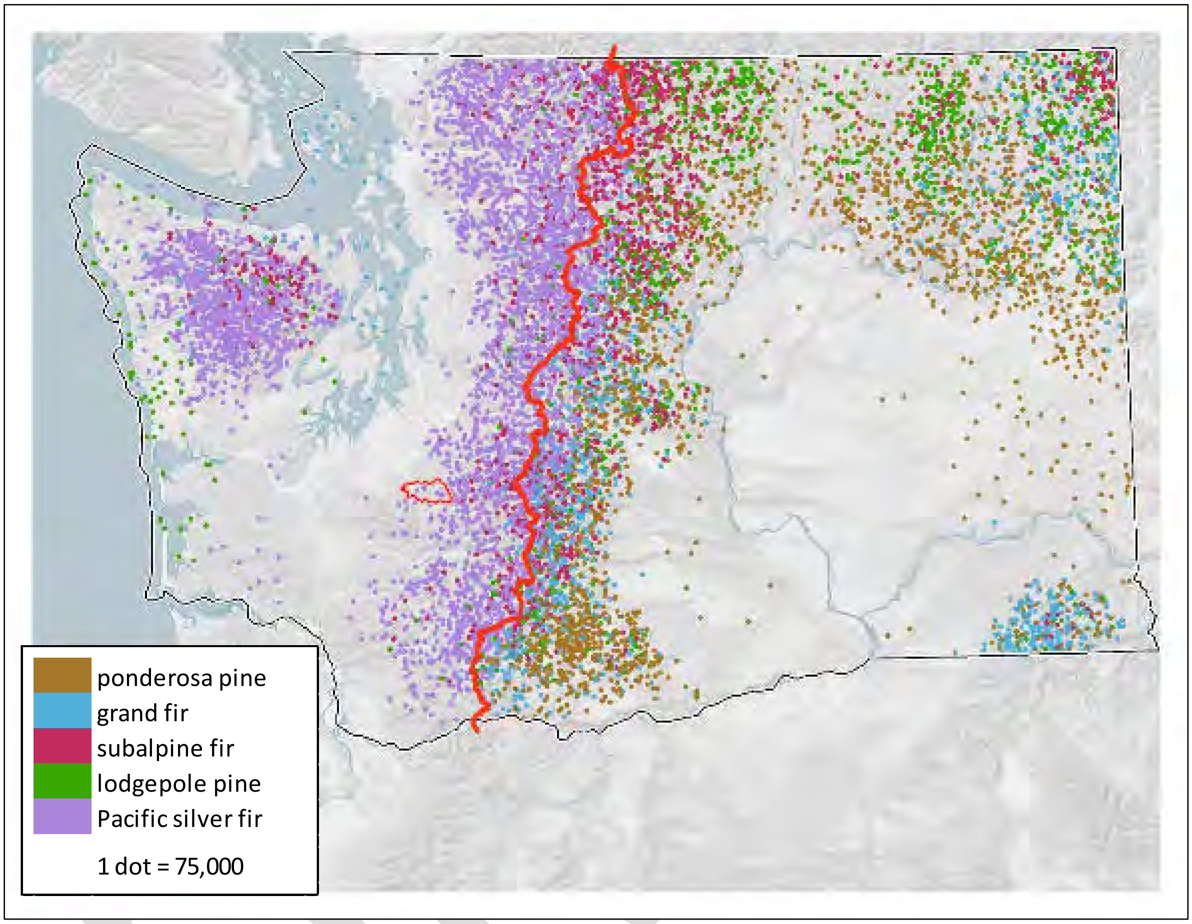
Basal Area Distribution – East Cascades Okanogan Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 96% of the basal area in the East Cascades Okanogan Zone.



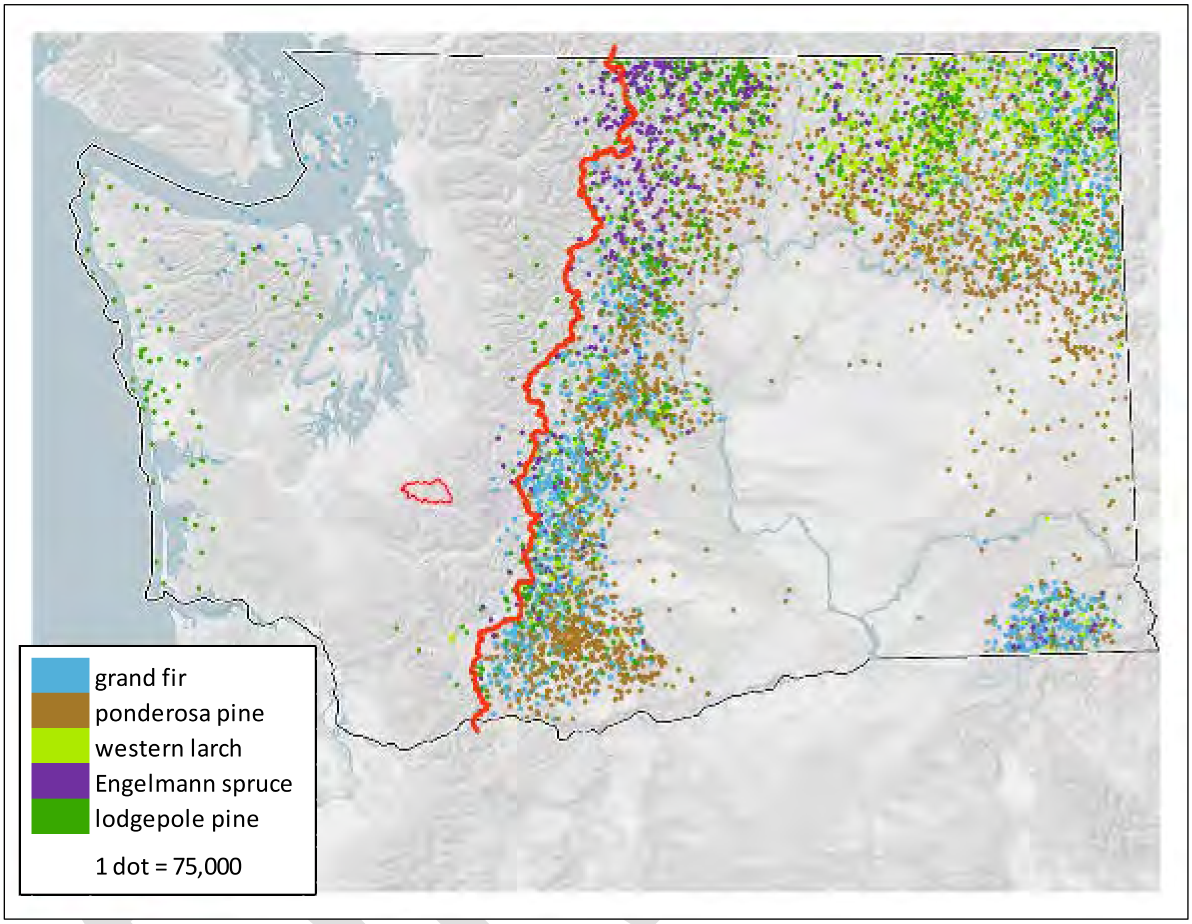
Basal Area Distribution – East Cascades Snoqualmie Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 88% of the basal area in the East Cascades Snoqualmie Zone.



Basal Area Distribution – Blue Mountains Zone

The top five species after removing Douglas-fir. These species, plus Douglas-fir, account for 96% of the basal area in the Blue Mountains Zone.



Appendix B: Specifications of Relevant Lidar Acquisitions

Acquisition	Vendor	Square Miles	Start Date	End Date	Sensor	Pulse Density (pulse/m2)
Colville 2016	The Atlantic Group	1888	Aug-16	Oct-16	Leica ALS-70 HP	13
Colville 2015	The Atlantic Group	742	Jul-15	Jul-15	Leica ALS-70 HP	18
Olympic and Kitsap Peninsulas Southwest Counties 2018	n/a	5100	n/a	n/a	n/a	n/a
Columbia Garfield Walla Walla Counties 2018	n/a	2900	n/a	n/a	n/a	n/a
Klickitat 2015	Quantum Spatial	515	Oct-14	Mar-15	Leica ALS70 & ALS80	> 8

Appendix C: Publically Available Lidar Datasets

Lidar data for Washington State is available through two sources, the Washington State Department of Natural Resources Geology Division Lidar Portal [5] and the Puget Sound Lidar Consortium [3]. All of the datasets, except one (Yakima 2013), are available from the DNR Lidar Portal. The following table provides information on the name and year of the acquisition as provided by each site. Metadata about each acquisition should be provided with the data.

Table 5: Publically available lidar dataset sources, names, and years

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2002	Clallam	2001-2002	Clallam County
2002	Clark		
2002	Quilault	2002	Quinault River
2002	Rainier West		
2002	St Helens		
2002	Willapa		
2003	Darrington	2010	Miscellaneous Snohomish County - NFSTIL
2003	King	2003	King County
2003	SnoHoCo Northwest	2010	Miscellaneous Snohomish County - NW
2003	SnoHoCo Skykomish	2010	Miscellaneous Snohomish County – Sky
2003	SnoHoCo Southwest	2010	Miscellaneous Snohomish County - SW
2004	KingCo Snoqualmie River		
2004	SnoHoCo Snoqualmie	2010	Miscellaneous Snohomish County - Snoq
2004	St Helens Nov		
2004	St Helens Oct		
2005	Coeur D Alene		
2005	Lewis Extra		
2005	Lewis Yakima	2003; 2005; 2003; 2005	Lewis County; Lewis County; Yakima County; Yakima County
2005	Lower Columbia	2005	Lower Columbia River
2005	Puget Lowlands	2000-2005; 2005	Puget Sound Lowlands; Olympic Peninsula
2005	SnoHoCo Sauk River	2010	Miscellaneous Snohomish County - Sauk
2005	Snohomish	2005-2006	Snohomish County\DNR Dataset
2005	Yacolt	2005	Yacolt Burn State Forest 2005 - DNR
2006	Ahtanum		
2006	Gorge		
2006	Lewis	2006	Lewis County
2006	North Puget USGS	2006	USGS North Puget Sound LIDAR survey

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2006	Siouxon		
2006	SnoHoCo East		
2006	SnoHoCo HatIsland		
2006	SnoHoCo Hazel		
2006	SnoHoCo West		
2006	Toutle		
2007	OrWa Rivers A	2007	Eastern Washington and Oregon River Corridors
2007	OrWa Rivers B	2007	Eastern Washington and Oregon River Corridors
2007	OrWa Rivers C	2007	Eastern Washington and Oregon River Corridors
2007	Rainier	2009	Mount Rainier National Park
2007	SnoHoCo Index Galena	2007	Snohomish County
2007	Spokane		
2007	SR410 DOT	2007	WA DOT
2007	Toutle River		
2008	Cold Springs		
2008	Colville		
2008	Dungeness River		
2008	NE WA		
2008	Yakima		
2008	Yakima City		
2009	Buckhorn		
2009	Douglas	2009	Douglas County
2009	Elwah	2009	Elwah
2009	KingCo Lower White River		
2009	KingCo Newaukum		
2009	KingCo SF Snoqualmie River		
2009	KingCo Snoqualmie N		
2009	KingCo Snoqualmie S		
2009	KingCo Vashon		
2009	Lewis	2009	Lewis County
2009	Nooksack River	2009	Nooksack River
2009	San Juan	2009	San Juan County and Lummi Island
2009	Snohomish River	2009	Snohomish River Estuary
2009	SWWA FEMA	2009	Southwest Washington

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2009	Toutle St Helens		
2009	Wenatchee	2009	USGS Wenatchee
2010	Coast USACE		
2010	Columbia A		
2010	Columbia B		
2010	Columbia C		
2010	Columbia D		
2010	Columbia E		
2010	Glacier Peak		
2010	KingCo Big Spring Creek		
2010	KingCo Boise Creek		
2010	KingCo Carlin Creek		
2010	KingCo Cedar River		
2010	KingCo DesMoines Creek		
2010	KingCo May Creek		
2010	KingCo Mid Green River		
2010	KingCo SF Snoqualmie River		
2010	KingCo Tolt River		
2010	Kittitas Valley Creeks		
2010	Toutle River		
2010	Wenas Valley	2009-2010	USGS Wenas Valley
2011	Condit Dam		
2011	KingCo Allen Lake Outlet		
2011	KingCo Bear Creek		
2011	KingCo Boise Creek		
2011	KingCo Briscoe		
2011	KingCo Carnation		
2011	KingCo Cedar River		
2011	KingCo Miller River		
2011	KingCo Raging River		
2011	KingCo Sinnera		
2011	KingCo Skykomish River		
2011	KingCo Snoqualmie River		
2011	KingCo Snoqualmie River North		
2011	KingCo Snoqualmie River S		
2011	KingCo Teufel		
2011	KingCo Tolt River		

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2011	KingCo White		
2011	KingCo Wilderness Rim		
2011	Kittitas	2011	Kittitas (Colockum)
2011	Kittitas FEMA	2011	Kittitas County
2011	Pierce	2010	Pierce County
2011	Quinault	2011	Quinault River Basin
2011	Rattlesnake	2011	Rattlesnake
2011	Thurston	2011	Thurston County
2011	Toutle River		
2012	Cedar River		
2012	Cle Elum River		
2012	Colville		
2012	Elwah		
2012	Gold Creek		
2012	Grays Harbor	2012	Chehalis River, Lewis and Grays Harbor Counties
2012	Hoh	2012-2013	Hoh River Watershed
2012	Jefferson Clallam	2012	Jefferson and Clallam County and Elwa River
2012	KingCo Cove Creek		
2012	KingCo Dockton		
2012	KingCo Newaukum		
2012	KingCo Patterson		
2012	KingCo Pautzke		
2012	KingCo Vashon		
2012	KingCo White		
2012	Manastash Creek		
2012	Quinault	2012	Quinault Acquisition -USGS
2012	Rainier		
2012	Toutle River		
2012	Upper Naches	2012	Upper Naches River
2013	Bellingham	2013	Bellingham
2013	Clark		
2013	Entiat	2013	Entiat - USGS
2013	Hoh	2012-2013	Hoh River Watershed
2013	KingCo Boise Creek		
2013	KingCo Carlin Creek		

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2013	KingCo Lower Cedar River		
2013	KingCo NF Snoqualmie River		
2013	KingCo Reddington		
2013	KingCo SF Skykomish River		
2013	KingCo Snoqualmie River		
2013	Nooksack	2013	Nooksack River
2013	Saddle Mountain	2013	Saddle Mountain
2013	San Juan	2013	San Juan County
2013	SnoHoCo Railway		
2013	Tulalip	2013	Tulalip Partnership
2013	Turnbull	2012-2013	Turnbull National Refuge and Surrounding Area
2013	Wallula	2013	Hanford 2013 (Wallula)
2013	Winston		
		2013	Yakima
2014	BPA I5		
2014	Cedar River A	2014	Cedar River Watershed
2014	Cedar River B	2014	Cedar River Watershed
2014	Colockum		
2014	Colville		
2014	Island	2014	Island County
2014	Metro		
2014	OESF		
2014	Redmond	2014	City of Redmond
2014	SnoHoCo Oso A		
2014	SnoHoCo Oso B		
2014	SnoHoCo Oso C		
2014	Stillaguamish	2014	Oso Stillaguamish Landslide Area
2014	Swinomish	2014	Swinomish
2014	Wasco Del4		
2014	Willapa Delivery 1	2014	Willapa River Valley Delivery 1
2014	Willapa Delivery 2	2014	Willapa River Valley Delivery 2
2014	Winston		
2014	Yakama Wetlands		
2014	Yakima Bumping		
2014	Yakima K2K		
2015	Bainbridge	2015	Bainbridge Island

DNR Lidar Portal		Puget Sound Lidar Consortium	
DNR Year	DNR Name	PSLC Year	PSLC Name
2015	Baker		
2015	Chelan	2015	OLC Chelan FEMA
2015	Colville	2016	Colville National Forest
2015	Glacier Peak	2015	Glacier Peak
2015	Hood Canal		
2015	Klickitat	2015	Klickitat DNR 2015
2015	Little Naches River		
2015	Loomis Loup Loup		
2015	Okanogan		
2015	Solduc	2015	Clallam DNR 2015
2015	Speelyai	2015	Cowlitz DNR 2015
2015	Spokane	2015	Spokane
2015	Teanaway	2015	Teanaway Community Forest
2015	Tieton River		
2015	Upper Chehalis		
2015	Wasco A		
2015	Wasco B		
2015	Yakima Benton		
2016	Colville		
2017	King County	2016	Western King County
2016	Loomis Loup Loup		
2016	Mount Adams		
2016	NE WA		
2016	Whispering Ridge		
2016	North Puget		
2017	SWWA Foothills		
2017	Walla Walla	2017	Walla Walla
2017	White Pass		
2018	Olympic and Kitsap Peninsulas Southwest Counties		
2018	Columbia Garfield Walla Walla Counties		
2018	Green River Watershed and Tacoma		