Quantifying landscape spatial patterns: a collaborative forest management framework for tribal and federal lands

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Abstract

Quantifying landscape spatial patterns: a collaborative forest management framework for tribal and federal lands

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Presently, ecological conditions of landscapes are the result of ownerships, spatial pattern and dynamics of ownerships, and ecological interactions among individual ownerships. Ownerships are distinct jurisdictional units, however, forest spatial patterns, processes, functions, disturbances, and health conditions exceed current legal boundaries. Applying spatial and multivariate statistics across ownerships allows researchers and managers to quantify influences on ecological conditions and better identify objectives and alternatives for ecological issues. Research identified the value the Yakama Nation offers as an operational framework to implement collaborative planned treatment activities and promote development, planning, and implementation of future treatments. Analyses concluded increasing logging activity to enhance collaborative ecosystem restoration activities, sustain, and develop local industries and economies dependent on sustainable forest resources. Collaborative forest management networks like the Anchor Forest Pilot Project and Tapash Sustainable Forest Collaborative should review these results to determine applicability and identify opportunities for treatment implementation and sustained collaboration.

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1. Introduction

The region between the crests of the Washington Cascade Range and the xeric grass and sagebrush environments to the east has been dominated by dry and mesic mixed-conifer forests and woodlands (hereafter, "dry forests") since sometime shortly after the late-Pleistocene glacial terminations (Mack et al. 1979, Barnosky 1984, Whitlock 1992, Robbins and Wolf 1994). Prior to Euro-American settlement of western North America, dry forest environments burned frequently with low- and mixed-severity fires, important influences on spatial patterns of vegetation species and structures across the landscape for the past several millennia (Agee 2003, Hessburg et al. 2005). Historic fire ignitions in the region were of abiotic (i.e. lightning) and biotic (i.e. anthropogenic) origins (Taylor 1974, Agee 1993) and the resulting spatial patterns of landscape vegetation demonstrated complex interplays with other forest disturbances, successional processes, and disease and insect factors (Agee 2003, Lehmkuhl et al. 1994, Hessburg et al. 2000, Hessburg et al. 2005).

Differences between the Euro-American society and indigenous societies manifested in vast differences in water- and land-use practices resulted in dramatic and extensive environmental change throughout the region. As North America was settled by Euro-American culture, the continent was partitioned into numerous ownerships defined by ecologically arbitrary legal boundaries. Presently, ecological conditions of landscapes are the result of these ownership spatial patterns, management philosophies, and ecological interactions among individual ownerships. As a result of this recent history, current forest structures, compositions, and conditions are markedly altered from pre-Euro-American landscapes. Today, many of the forests in this region are vulnerable to uncharacteristically severe fire, insect, and disease events and in some area undergone extensive dieback.

The Yakama Nation and their ancestral civilizations have existed throughout the inland Pacific Northwest and surrounding regions since time immemorial. Since the creation of the Yakama Nation by the Treaty of 1855, and subsequent congressional and executive ratification of the treaty in 1859, the Yakama Nation has operated as a sovereign nation within the United States. Due to U.S. federal Indian policy and the policies of the Yakama Nation, management of the Yakama Indian Reservation's natural resources differs from adjacent and surrounding lands under non-tribal ownerships. However, recent incidents such as the Western Spruce Budworm epidemics of the 1990's and the 2008 Cold Springs fire serve as powerful reminders as to how forest spatial patterns, processes, functions, disturbances, and health conditions have deteriorated on tribal and non-tribal ownerships throughout the region.

To help address these types of forest health issues, the Yakama Nation independently managed their lands about the turn of century then in 2007 joined the Tapash Sustainable Forest Collaborative (TSFC). The TSFC formed with the mission, "To improve the ecosystem health and natural functions of the landscape through active restoration projects backed by best science, community input and adaptive management." (Tapash.org [updated 2007]). In 2007 the U.S. Forest Service, the Yakama Nation, the Washington State (WA) Department of Natural Resources, the WA Department of Fish and Wildlife, and The Nature Conservancy created and entered into a Memorandum of Understanding in achievement of mutual natural resource management goals to improve forest conditions and, at the same time, local economic and social well-being. In the TSFC Memorandum of Understanding (2007), "The parties recognize that they share common goals on the landscape and, by working together, can achieve more significant and durable outcomes than by working individually." (Tapash Memorandum of Understanding [updated 2007]).

As part of the Tapash Sustainable Forest Collaborative and the Okanogan-Wenatchee National Forest Restoration Strategy, the US Forest Service developed a vegetation mapping unit database for the Naches Ranger District. The Naches Ranger District GIS database was developed from aerial photo interpretation and ground validation for the Nile, Lower Rattlesnake, and Dry watersheds. The Naches Ranger District is currently using the database to inform dry forest restoration efforts by evaluating forest conditions, identifying treatments and alternatives, and prioritizing treatment areas within the three watersheds.

In an effort to participate in and enhance this collaborative process, the University of Washington Pacific Wildland Fire Sciences Lab developed a research project with the Yakama Nation and Naches Ranger District. The project developed a GIS database for the Yakama Tribal Forest – equivalent to the Naches Ranger District vegetation mapping unit database – in an attempt to collect comparable data to address questions about ownership effects on forest composition and structure throughout the TSFC Collaborative Forest Landscape Restoration Program area. The project also provided needed information on American Indian ecosystem management approaches to current issues for the broader scientific and management communities.

The project developed a framework for comparing existing landscape vegetation composition and spatial patterns based on potential vegetation composition and spatial patterns. Comparing existing vegetation assemblages between ownerships in areas with similar potential vegetation assemblages facilitated the assessment of actual, existing treatments and alternatives on landscape vegetation composition and associated spatial patterns. Through geospatial and multivariate statistical analyses, the research project quantified environmental and management regime factors on landscape vegetation composition and spatial patterns. The results from this research are useful for identifying and substantiating beneficial practices and their associated landscape patterns so that dry forest restoration efforts might be optimized across ownerships throughout the TSFC project area.

2. Objectives

Study premise:

Management regimes in similar, neighboring areas under different ownerships in the Southern Washington Cascades physiographic province have discernible results in forest cover and structure composition and spatial patterns.

Overarching objectives/ Potential outcomes:

- To use the study results to identify beneficial practices and associated landscape vegetation patterns to help bolster dry forest restoration efficiency across ownerships throughout the northwestern United States.

- To decrease the information gap in research on current American Indian ecosystem management and landscape ecology issues in the scientific dialogue and literature.

- To enhance the ongoing collaborative process through presentation, publication, and multiple ownership data contributions for the Tapash Sustainable Forest Collaborative project area.

Specific objectives:

- To identify similar watersheds in the Naches Ranger District and Yakama Tribal Forest based on potential vegetation.

- To develop a vegetation mapping unit GIS database for the Yakama Tribal Forest comparable to the Naches Ranger District vegetation mapping unit GIS database.

- To determine if existing landscape vegetation spatial patterns are similar for the selected Naches Ranger District and Yakama Tribal Forest watersheds.

- To identify main and interaction factors explaining significant amounts of variance in existing vegetation data for the selected Naches Ranger District and Yakama Tribal Forest watersheds.

3. Background

3.1 Historical Context

Large-scale climate change, disturbances (e.g. glaciers, volcanoes, fire, insects, diseases), and vegetation responses have fundamentally shaped Pacific Northwest landscapes over the last twenty thousand years (Barnosky 1984, Means et al. 1982, Robbins and Wolf 1994, Roberts 1998, Whitlock 1992). Temporal and spatial variation of disturbance events controlled landscape vegetation spatial patterns and future disturbance dynamics by maintaining variable tree densities, size classes, and species compositions (Weaver 1943, Camp 1999, Harrod 1999, Agee 2003, Hessburg et al. 2000, Hessburg et al. 2005). Modern climate conditions and landscape assemblages similar to those of the last several centuries established in the region some five thousand years before present (Minore 1979, Whitlock 1992, Sea and Whitlock 1995, Gugger and Sugita 2010).

During this same period, indigenous human populations established and expanded throughout the Pacific Northwest (Cressman 1962, Borden 1979, Hunn 1990, Robbins and Wolf 1994, Roberts 1998). Some evidence indicates that Pleistocene hunters in the Northwest used burning tens of thousands of years ago, but with the advent of modern conditions, relatively large indigenous populations had developed advanced management practices and fire was the primary management tool (Barrett and Arno 1982, Botkin 1995, Kimmerer and Lake 2001, Lewis 1973, Williams 2003). Over the past several hundred years, Euro-American settlement of the region manifested in major changes in water- and land-use practices set the stage for rapid, dramatic, extensive, and permanent environmental change. Euro-American culture substantially affected these landscapes through altered indigenous cultural and land management practices observed by the introduction of the horse, reduced population through disease and genocide, reduced land access through treaty and reservation policy, and loss of fire as management tool (Hessburg and Agee 2003, Hunn 1990, Robbins and Wolf 1994). Fire suppression and exclusion, mining, logging, and agricultural and urbanization practices are also important changes Euro-American culture brought to Pacific Northwest environments (Robbins and Wolf 1994, Hessburg and Agee 2003).

As a result of the environmental and human history of the Pacific Northwest, natural resource management is faced with major forest health issues exacerbated by climate change, property boundaries, poor forest harvest and management decisions, and the introduction of non-native vegetation, insects, and diseases. Subsequent to these conditions, land managers of the Yakama Nation increased tribal control of natural resource management in the 1990's and began to reinstate tools and techniques practiced prior to European settlement. However, current aggregate ecological conditions of landscapes are controlled by the spatial pattern and dynamics of individual owners and ecological interactions among those ownerships (Spies 2004). The next section outlines a framework developed to identify issues, prioritize treatment areas, and assess treatment alternatives across management regimes in dry and mesic mixed-conifer forests on the eastern slope of the Southern Washington Cascades.

3.2 Project Development

Federal, tribal, state, and private management regimes are distinct jurisdictional units, however, recent incidents such as the Western Spruce Budworm epidemic of the 1990's and the 2008 Cold Springs fire (Hummel et al. 2013) serve as powerful reminders as to how forest spatial patterns, processes, functions, disturbances, and health conditions exceed current legal boundaries in the region. In effort to help address these types of issues, the Yakama Nation joined the Tapash

Sustainable Forest Collaborative (TSFC) in 2007 (Tapash.org [updated 2007]). In 2007, the U.S. Forest Service, the Yakama Nation, the Washington State (WA) Department of Natural Resources, the WA Department of Fish and Wildlife, and The Nature Conservancy created and entered into a Memorandum of Understanding in achievement of mutual natural resource management goals (Tapash Memorandum of Understanding [updated 2007]). In the TSFC Memorandum of Understanding, "The parties recognize that they share common goals on the landscape and, by working together, can achieve more significant and durable outcomes than by working individually." (Tapash Memorandum of Understanding [updated 2007]).

As part of the Tapash Sustainable Forest Collaborative and the Okanogan-Wenatchee National Forest Restoration Strategy, the U.S. Forest Service developed a vegetation mapping unit database on the Naches Ranger District. The Naches Ranger District GIS database was developed for the Nile Creek, Lower Rattlesnake Creek, and Dry Creek watersheds, located approximately 20 kilometers northwest of Naches, WA. The Naches Ranger District is currently using the database to inform dry forest restoration efforts by evaluating forest health conditions, identifying treatments and alternatives, and prioritizing treatment areas within the three watersheds.

In an effort to participate in and enhance this collaborative process, the University of Washington Pacific Wildland Fire Sciences Lab developed a research project with the Yakama Nation and Naches Ranger District. The project developed a GIS database on the Yakama Tribal Forest – comparable to the Naches Ranger District vegetation mapping unit database – in an attempt to increase comparable data on lands throughout the TSFC project area. The project also attempted to decrease the information gap in research on current American Indian ecosystem management and landscape ecology issues in the scientific dialogue and literature.

This study is predicated on findings outlined in the Journal of Forestry Volume 95, Number 11 (1997), the Second Indian Forestry Management Assessment Team report (Gordon et al. 2003), Evergreen Magazine (winter 2005-2006), Rigdon (2006), Berry (2009), and Mason et al. (2012). The preceding literature identified discrepancies in tribal and non-tribal management regimes quantified by comparisons of total forest area, commercial timberland, annual allowable cut, harvest volumes, timber and fire management costs, timber harvest revenues, federal funding (forestry and fire), and personnel staffing. Prominently, in 2001 Indian forest management received $4.32 per acre less in federal funding than national forest management, but maintained equal budgets per acre per year while harvesting nearly 15 times more board feet per total forest acres (Gordon et al. 2003). The former conclusion is especially significant when treatment acres from Indian fuels management activities – which are not always included in harvest volume data – are included due their considerable extent, environmental effects, and funding allocations.

Indian ecosystem management regimes essentially doing more with less are complicated by restrictions imposed by needs to compensate for environmental deterioration on other ownerships (Gordon et al. 2006) and barriers to responsible integration of traditional knowledge into respective ecosystem management regimes (Stevenson 2005, Mason et al. 2012). While these results support an increased role of Indian ecosystem management to enhance ecosystem management on tribal and public lands, maintaining federal and state agencies and fostering stewardship-oriented private sector growth are important to uphold diversity, dynamism, and progression in management regimes, controls of aggregate ecological conditions. The findings discussed throughout the literature have been central in advancing the dialog and policy shaping current Indian ecosystem management and its role in the region and at a national level, but a need to further quantify management regime effects on landscape health condition across ownerships still exists.

This project developed a framework for comparing existing landscape vegetation structure, composition, and spatial patterns based on similarities in potential vegetation composition and spatial patterns. Comparing existing vegetation patterns between the Yakama Tribal Forest and the Naches Ranger District in areas with similar potential vegetation patterns facilitates assessment of actual, existing treatments and alternatives. The research project quantifies environmental and management regime influences on landscape vegetation spatial patterns and, in turn, forest health conditions through geospatial and multivariate statistical analyses. The results from this research are useful to identify beneficial practices and associated landscape spatial patterns that can help optimize forest health restoration across ownerships throughout the study area. The research is useful to promote restoration efficiency through identifying optima treatments, opportunities, and locations for the Tapash Sustainable Forest Collaborative efforts and activities to be realized.

4. Methods

4.1 Study Area

The general study area is the Southern Washington Cascades physiographic province delineated in Franklin and Dyrness (1973), with the project study area focused on the forest environments that span the zone from the central crests of the Cascades east to xeric grass and sagebrush dominated environments. Abiotic environmental gradients in the study area follow a crest-to-lowland, west-to-east trend, for example decreasing elevation, topographic relief, and precipitation with increasing temperature. Different soils types, Haplorthods and Haploxerolls separated by only a few kilometers, are found on eastern slopes of the Cascade Range because of abrupt changes in precipitation and concomitant changes from forest to grass-shrub vegetation (Franklin and Dyrness 1973). Environmental gradients, soils, tree species' tolerances, fires, insects, pathogens, glaciers, great floods, volcanoes, earthquakes, and temporal variation in climate have repeatedly shaped the region's forests and woodlands (Franklin and Dyrness 1973, Minore 1979, Robbins and Wolf 1994, Agee 2003, Hessburg and Agee 2003).

Conifer forests exhibit the greatest spatial extent and species abundance and richness in the study area with five deciduous and sixteen coniferous tree species identified in Lillybridge and Williams (2002). *Pinus ponderosa* forests are widely distributed in the study area as they occupy a narrow band approximately 15 to 30 km wide on the eastern flanks of the entire Cascade Range (Franklin and Dyrness 1973). At their upper limits, *P. ponderosa* forests may grade into forests of *Pseudotsuga menziesii*, *Abies grandis*, or *A. concolor* depending on the locale and at lower elevation limits into either grassland or *Artemisia* steppe (Franklin and Dyrness 1973). Dry and mesic mixed-conifer forests chiefly composed of *P. ponderosa*

(ponderosa pine), *Pseudotsuga menziesii* (Douglas-fir), and *Larix occidentalis* (western larch), and *Abies grandis* (grand fir) are the most common forest types in the study area.

Study sites on the Naches Ranger District (NRD) were non-randomly selected based on methods and objectives outlined in the Okanogan-Wenatchee National Forest Restoration Strategy: adaptive ecosystem management to restore landscape resiliency (2010). Yakama Tribal Forest study sites were non-randomly selected based on similarity of potential vegetation and biophysical settings to NRD study sites. This case study approach limited the scope of inference, but facilitated the assessment of actual, existing treatments and alternatives between ownerships on landscape vegetation composition and spatial patterns.

4.1.1 Naches Ranger District Sites

Three 12-digit Hydrologic Unit Code watersheds from the Watershed Boundary Dataset – downloaded from the Natural Resources Conservation Service GeoSpatial Data Gateway website – were selected in the Okanogan-Wenatchee National Forest, Naches Ranger District to focus dry forest restoration efforts. The selection of these sites was in response to mounting scientific evidence of late-successional habitat and associated species marginalization and increased risk of severe, intense wildfires and smoke production, insect and pathogen epidemics, health and property (personal and public) damage, and climate change impacts. Dry Creek-Naches River (5,769 ha), Nile Creek (8,294 ha), and Lower Rattlesnake Creek (14,960 ha), the selected study sites, are located approximately 20 kilometers northwest of Naches, Washington and encompass the wildland urban interface (see Figure 1). Location, historical practices, established and on-going multiple-use practices, scientific findings, local community and neighboring community interests, and desired future conditions established the selection of these watersheds to concentrate efforts of dry forest restoration.

4.1.2 Yakama Tribal Forest Sites

In the Yakama Nation Tribal Forest, three 12-digit Hydrologic Unit Code watersheds were selected from the Watershed Boundary Dataset based on spatial proximity and similarities in size and LANDFIRE potential vegetation to the Naches Ranger District (NRD) select watersheds.

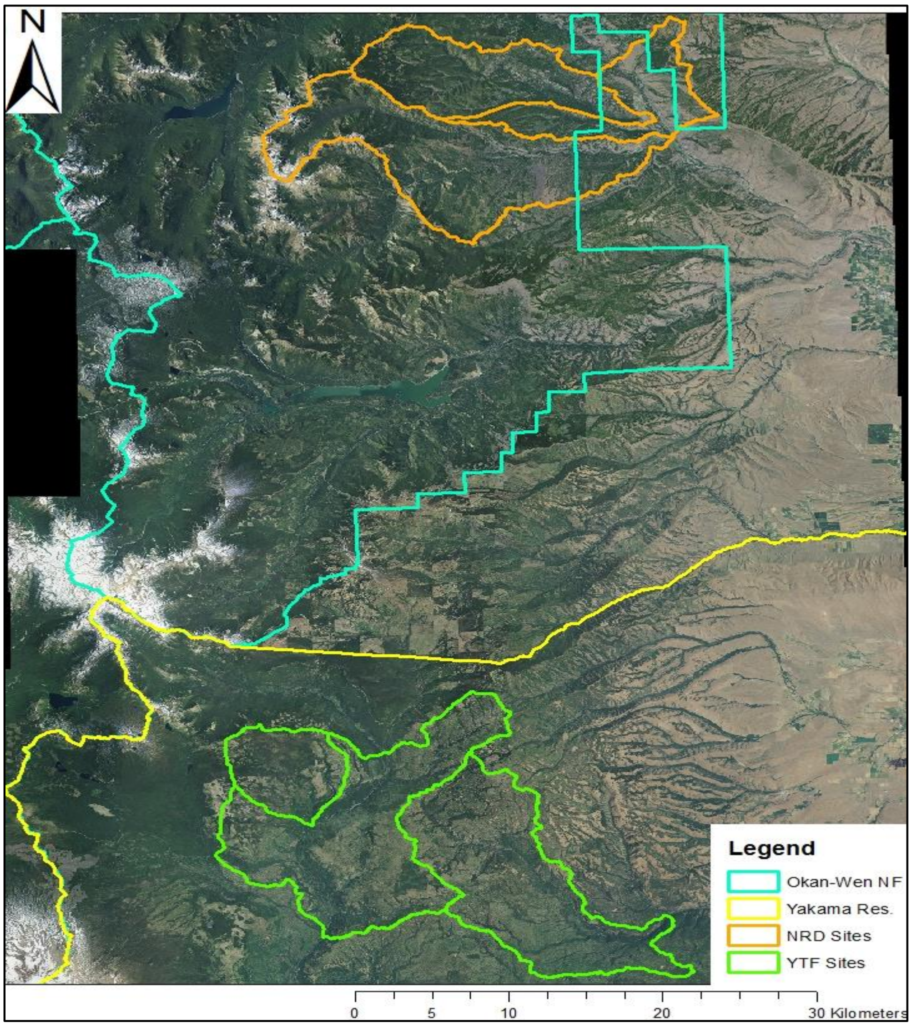

Figure 1 — Study Sites
The Naches Ranger District sample watersheds (outlined in orange) are located approximately 20 km northwest of Naches, WA in the Okanogan-Wenatchee National Forest (outlined in blue). The Yakama Tribal Forest sampled watersheds (outlined in green) are located approximately 25 km west of White Swan, WA on the Yakama Indian Reservation. The northeast aspect of Mount Adams is visible in the southwest corner of the map. The aerial photograph is the 2009 Yakima compressed county mosaic from the National Agriculture Imagery Program.

McCreedy Creek (4,566 ha), Headwaters Toppenish Creek (14,322 ha), and Swamp Creek-Klickitat River (15,858 ha), located approximately 25 km west of White Swan, Washington, were selected as the study sites for the Yakama Tribal Forest (see Figure 1). Similar to the NRD, location, historical practices, established and on-going multiple-use practices, etc., compounded with Yakama Nation interests, established the selection of these watersheds to concentrate efforts of dry forest restoration, scientific research, and collaboration with the Naches Ranger District and other neighboring management regimes.

4.2 Vegetation Mapping Data Preparation

Vegetation mapping was performed using ESRI ArcGIS 10.1 and 2006 and 2009 National Agriculture Imagery Program (NAIP) compressed county mosaics “53077_1n2006_1 Yakima” and “53077_1n2009_1 Yakima” downloaded from the Natural Resources Conservation Service GeoSpatial Data Gateway website. The NAIP provides 1 meter ground sample distance ortho imagery rectified to a horizontal accuracy within +/- 5 meters of reference digital ortho quarter quads from the National Digital Ortho Program or from the National Agriculture Imagery Program and within +/- 6 meters to true ground (UDSA-FSA-APFO 2009). Vegetation mapping units were delineated at a minimum size of 4 ha based on physiognomy of homogeneous areas of vegetation composition and structure for the six respective watersheds (Lehmkuhl et al. 1994). Following protocols from the Eastside Forest Ecosystem Health Assessment – modified and provided by the Naches Ranger District (NRD) – approximately twenty-five photo-interpreted attributes were recorded for each vegetation mapping unit (see Appendix 1).

The Cover Interpreter ArcGIS toolbar – downloaded from the USDA Forest Service Remote Sensing Applications Center Digital Mylar website – was used to corroborate forest crown closure and tree size class attributes of respective vegetation mapping units. Bing Maps Aerial Basemap was used in the context of the NAIP imagery to assist forest species, non-forests species, dead trees/snags, and logging entry interpretations. Using Generate Cover Type and Generate Structure ArcGIS tools (see Appendices 2 and 3) developed and provided by the USDA Forest Service Pacific Northwest Research Station, cover types and structural classes were derived from the raw, photo-interpreted attributes for individual vegetation mapping units.

Vegetation mapping unit derived cover and structure attributes served as individual and composite response variables for statistical analyses. Vegetation mapping unit polygon layers were used for ArcGIS geospatial analyses, attribute tables exported to text files for R multivariate analyses, and converted to 30-meter raster datasets for FRAGSTATS geospatial analyses. District and Pacific Northwest Research Station personnel performed vegetation-mapping procedures for the NRD, while University of Washington, School of Environmental and Forest Sciences and U.S. Forest Service Remote Sensing Applications Center personnel executed procedures for the Yakama Tribal Forest (YTF). Candid training and cooperation between the NRD photo-interpreters and the YTF photo-interpreters was essential to standardize and clarify procedures to produce consistent, high-quality vegetation mapping data.

4.3 LANDFIRE Data Preparation

Potential vegetation layers "LFc2001 (National – LF_100) us_100 Environmental Site Potential" and "LF2008 (Refresh – LF_110) us_110 Biophysical Settings" were downloaded from the U.S. Geological Survey LANDFIRE Data Distribution Site website. LANDFIRE potential vegetation layers were selected to provide consistent, spatially explicit plant community data at 30-meter resolution over the entire study area.

> [LANDFIRE] map units are based on NatureServe's Ecological Systems classification and represent the natural plant communities that may have been present during the reference period. Each Biophysical Settings (BPS) map unit is matched with a model of vegetation succession, and both serve as key inputs to the LANDSUM landscape succession model. As used in LANDFIRE, map unit names represent the natural plant communities that may have been present during the reference period. LANDFIRE uses BPS to depict reference conditions of vegetation across landscapes. The actual time period for this data set is a composite of both the historical context provided by the fire regime and vegetation dynamics models and the more recent field and geospatial data used to create it… Environmental Site Potential (ESP) map units represent the natural plant communities that would become established at late or climax stages of successional development in the absence of disturbance. They reflect the current climate and physical environment, as well as the competitive potential of native plant species. The ESP concept is similar to that used in classifications of potential vegetation, including habitat types and plant associations. (LANDFIRE 2012)

LANDFIRE data layers were clipped to the six study site watersheds using the Extract by Mask ArcGIS tool and used for FRAGSTATS geospatial statistical analyses. The clipped data attribute tables were exported to text files for R multivariate statistical analyses and converted to polygons using the Raster to Polygon (not simplified) ArcGIS tool for ArcGIS geospatial statistical analyses. BPS and ESP attributes were assigned to each vegetation mapping unit using the Zonal Statistics as Table (Statistic Type: Majority) ArcGIS tool for additional R multivariate analyses.

4.4 Topographic Data Preparation

National Elevation Dataset 30-Meter Digital Elevation Model (DEM) "46120 e!Yakima" was downloaded from Natural Resources Conservation Service GeoSpatial Data Gateway website and clipped to the six study site watersheds using the Extract by Mask ArcGIS tool. The clipped DEMs were converted into aspect degree and slope percent raster layers using the Aspect and Slope ArcGIS tools, respectively. Elevation (meter), aspect (degree), and slope (percent) values were assigned to each vegetation mapping unit using the Zonal Statistics as Table (Statistic Type: Mean) ArcGIS tool for R multivariate analyses, elevations were categorized into 50 meter classes and aspect into 10 degree classes.

4.5 Plot Data Preparation

Continuous Forest Inventory (CFI) data were provided by the Yakama Nation in collaboration with the Forest Development Program, Fuels Management Unit. Yakama Nation CFI plot data were collected in 2005 in accordance with forest inventory standards, protocols, and policies outlined in the U.S. Department of the Interior Indian Affair Manual Part 53 Chapter 8 and the Indian Forest Management Handbook 53 IAM 2-H Volume 2 Forest Management Planning (see Appendix 4). The general CFI sample design for the Yakama Reservation is a systematic grid of permanent fixed-area plots for the entire timberland classified ownership. CFI plots were clipped to the three Yakama Tribal Forest select watersheds, using the Intersect ArcGIS tool, to assess photo-interpretation accuracy with ground-sampled data.

4.6 Photo-Interpretation Accuracy Assessment

Rounding up to whole integers, twenty-five percent of the Yakama Nation Continuous Forest Inventory (CFI) plots within each Yakama Tribal Forest study site watershed were randomly selected for photo-interpretation accuracy assessment. The timber type attribute "TTY" and supplementary descriptive keys (Appendix 5) were used to infer and compare ground-sampled CFI cover type and overstory tree size class to corresponding photo-interpreted vegetation mapping cover type and overstory tree size class. Overstory size class and cover type detection errors and error vectors quantified photo-interpretation accuracy for derived cover types and structural classes on the Yakama Tribal Forest.

4.7 Geospatial Statistical Analyses (ArcGIS)

4.7.1 LANDFIRE Data

Spatial autocorrelation was measured for the respective Naches Ranger District and Yakama Tribal Forest aggregate watersheds to quantify similarities/differences in landscape spatial patterns of LANDFIRE potential vegetation layers between the two ownerships. Biophysical Settings (BPS) and Environmental Site Potential (ESP) polygon layer inputs to the Spatial Autocorrelation (Global Moran's I) ArcGIS tool (Conceptualization of Spatial Relationships: POLYGON_ CONTIGUITY_ (FIRST_ORDER), Standardization: None) were used to quantify potential plant community data spatial autocorrelation (Appendix 8). Degree of clustering for either high or low values associated to BPS and ESP plant community attributes were also measured to quantify similarities/differences in landscape spatial patterns of LANDFIRE potential vegetation layers between the two ownerships. BPS and ESP polygon layer inputs to the High/Low Clustering (Getis-Ord General G) ArcGIS tool (Conceptualization of Spatial Relationships: POLYGON_ CONTIGUITY_ (FIRST_ORDER), Standardization: None) were used to quantify potential plant community data degree and direction of clusters (Appendix 9).

4.7.2 Vegetation Mapping Unit Data

Spatial autocorrelation was measured for the respective Naches Ranger District and Yakama Tribal Forest aggregate watersheds to quantify similarities/differences in landscape spatial patterns of existing vegetation mapping units between the two ownerships. Cover type, structural class, and composite cover type-structural class polygon layer inputs to the Spatial Autocorrelation (Global Moran's I) ArcGIS tool (Conceptualization of Spatial Relationships: POLYGON_CONTIGUITY_ (FIRST_ORDER), Standardization: None) were used to quantify existing plant community data spatial autocorrelation (Appendix 8). Degree of clustering for either high or low values associated to cover type, structural class, and composite cover type-structural class attributes were also measured to quantify similarities/ differences in landscape spatial patterns of existing vegetation mapping units between the two ownerships. Cover type, structural class, and composite cover type-structural class polygon layer inputs to the High/Low Clustering (Getis-Ord General G) ArcGIS tool (Conceptualization of Spatial Relationships: POLYGON_ CONTIGUITY_ (FIRST_ORDER), Standardization: None) were used to quantify existing plant community data degree and direction of clusters (Appendix 9).

4.8 Geospatial Statistical Analyses (FRAGSTATS)

4.8.1 LANDFIRE Data

Biophysical Settings and Environmental Site Potential 30-meter raster layers clipped to the respective Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) aggregate watersheds were run in FRAGSTATS 3.4 to quantify similarities/differences in landscape spatial patterns of LANDFIRE potential vegetation layers between the two ownerships. Resulting FRAGSTATS class and landscape metric data were compiled into Microsoft Excel spreadsheets to assess connectivity, clustering, fragmentation, shape-complexity, diversity, composition, and interspersion of potential plant community data for the NRD relative to the YTF. The class and landscape FRAGSTATS metrics used to explore and quantify potential vegetation composition and spatial patterns in the study are briefly described in (Table 1), for full index lists, descriptions, comments, value ranges, and formulae refer to McGarigal and Marks (1995) and Appendices 6 and 7. The metrics chose to display and characterize spatial patterns, as well as diagnose factors responsible for those characteristics were selected from methodology outlined in Hessburg et al. (1999).

4.8.2 Vegetation mapping Unit Data

Vegetation mapping unit 30-meter raster layers clipped to the respective Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) aggregate watersheds were run in FRAGSTATS 3.4 to quantify similarities/differences in landscape spatial patterns of existing vegetation layers between the two ownerships. Resulting FRAGSTATS class and landscape metric data were compiled into Microsoft Excel spreadsheets to assess connectivity, clustering, fragmentation, shape-complexity, diversity, composition, and interspersion of existing plant community data for the NRD compared to the YTF. The class and landscape FRAGSTATS metrics used to explore and quantify existing vegetation landscape composition and spatial patterns in the study are briefly described in (Table 1), for full index lists, descriptions, comments, value ranges, and formulae refer to McGarigal and Marks (1995) and Appendices 6 and 7.

Table 1 — FRAGSTATS Indices
Brief descriptions of the FRAGSTATS indices used to quantify spatial patterns in the Naches Ranger District and Yakama Tribal Forest sampled watersheds. For full descriptions, comments, value ranges, and formulae see McGarigal and Marks (1995) and Appendices 6 and 7.

Acronym	Scale	Index name	Description
AREA_MN (hectares)	class or landscape	mean patch area	average patch size
NP (no.)	class or landscape	Number of patches	number of patches
PD (no. /100 ha)	class or landscape	patch density	number of patches in an area of 100 hectares
PLAND (%)	class	percentage of landscape	percentage of the landscape comprised of the corresponding patch type.
PLADJ (%)	class or landscape	percentage of like adjacencies	percentage of cell adjacencies involving the corresponding patch type that are like adjacencies
LPI (%)	class or landscape	largest patch index	percent of landscape comprised by the largest patch; approaches 0 when the largest patch in the landscape is increasingly small and 100 when the entire landscape consists of a single patch (i.e. largest patch comprises 100% of the landscape)
CONTAG (%)	landscape	contagion index	observed contagion over the maximum possible contagion for the given number of patch types; approaches 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of all pairwise adjacencies) and 100 when all patch types are maximally aggregated; i.e. landscape consists of single patch.
AI (%)	class or landscape	aggregation index	approaches 0 when the patch type are maximally disaggregated (i.e. when there are no like adjacencies), increases with increasing like adjacencies and equals 100 when the landscape/patch type consists of a single patch.
IJI (%)	class or landscape	interspersion and juxtaposition index	observed interspersion of edge types over the maximum possible interspersion; approaches 0 when patch types are clumped and approaches 100 when all patch types are equally adjacent to all other patch types
COHESION (%)	class or landscape	patch cohesion index	approaches 0 as the proportion of the landscape comprised of the focal patch decreases and becomes increasingly subdivided and less physically connected; increases as the patch type becomes more clumped or aggregated
SHDI (no.)	landscape	Shannon's diversity index	equals 0 when the landscape contains only 1 patch type, increases as number of different patch types increases and/or proportional distribution of area among patch types becomes more equitable

4.9 Multivariate Statistical Analyses (R)

Permutational multivariate analysis of variance (PERMANOVA) was used to test statistical significance of factors because the nature of this multivariate dataset and the strength of the test. PERMANOVA is well suited for multivariate ecological data because it requires no assumptions about normality or homogeneity of variance, integrates of Bray-Curtis distance measures, and uses permutations of data to calculate the pseudo-F statistic (Anderson 2001, Faith et al. 1987). Forward model selection was used to identify final PERMANOVA models for cover type, structural class, and composite class data because it is intuitive, simple to implement, works well in practice, may have lower prediction error than the full models, and time/resource constraints.

4.9.1 LANDFIRE Data

Biophysical Settings (BPS) and Environmental Site Potential (ESP) 30-meter raster layer attribute tables for the respective Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) watersheds were compiled into Microsoft Excel spreadsheets and pixel counts of respective potential vegetation community classes converted into hectares. BPS and ESP vegetation community (species) hectare abundances were organized into data matrices, saved as tab delimited text files, and loaded into R 2.14.0. Species data matrices were relativized by species maxima using the vegan package decostand R function to allow all species to contribute equally to differences between vegetation mapping units (plots). Relativized species abundance data matrices were converted into dissimilarity/distance matrices using the vegan package vegdist R function (Bray-Curtis distance measure) to serve as response variable matrices for multivariate analyses. Corresponding management regime (ownership) and environmental (watershed) data were organized into data matrices and loaded into R 2.14.0 to serve as explanatory variable matrices. Environmental and management regime variables explaining significant amounts of variance in species distance matrices were quantified using the vegan package adonis R function (permutational multivariate analysis of variance (PERMANOVA)) and forward sequential model selection based on F-models and permutation-derived p-values ($\alpha = 0.05$).

4.9.2 Vegetation mapping Unit Data

Vegetation mapping unit attribute tables for the respective Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) watersheds were compiled into Microsoft Excel spreadsheets and cover type, structural class, and composite cover type-structural class attribute values were converted into hectares. Cover type, structural class, and composite cover type-structural class (species) hectare abundances were organized into data matrices, saved as tab delimited text files, and loaded into R 2.14.0. Species data matrices were relativized by species maxima using the vegan package decostand R function to allow all species to contribute equally to differences between vegetation mapping units (plots). Relativized species abundance data matrices were converted into dissimilarity/distance matrices using the vegan package vegdist R function (Bray-Curtis distance measure) to serve as response variable matrices for multivariate analyses. Corresponding management regime (ownership, logging type) and environmental (watershed, elevation, aspect, slope, Biophysical Settings, Environmental Site Potential) data were organized into data matrices and loaded into R 2.14.0 to serve as explanatory variable matrices. Environmental and management regime variables explaining significant amounts of variation in the species distance matrices were quantified using the vegan package adonis R function (permutational multivariate analysis of variance (PERMANOVA)) and forward sequential model selection based on F-models and permutation-derived p-values ($\alpha = 0.05$).

5. Results

5.1 Photo-Interpretation Accuracy Assessment

Comparisons of photo-interpreted vegetation mapping units to selected Continuous Forest Inventory (CFI) plots within the Yakama Tribal Forest study sites showed cover type photo-interpretation was correct for 53.1% of the samples. Comparisons of the Yakama Tribal Forest CFI plot data to photo-interpreted overstory tree size were correct for 44.9% of the samples and uniformly erred within ± one size class for 42.8% of the samples (Table 2). Yakama Tribal Forest photo-interpreted overstory size class was under-predicted two size classes or more in 2% of the samples and over-predicted two size classes or more in 10.2% of the samples.

Table 2 — Accuracy results for the Yakama Tribal Forest photo-interpreted cover type and overstory size class (OSC) to ground-sampled Continuous Forest Inventory data and detection error vectors for overstory size class as percentages.

n = 49

Cover Type Accuracy	**OSC Accuracy**	**OSC Error Vector = –1**	**OSC Error Vector = 1**	**OSC Error Vector < –1**	**OSC Error Vector > 1**
53.1%	44.9%	22.4%	20.4%	2.0%	10.2%

5.2 LANDFIRE Data

5.2.1 Environmental Site Potential

Twenty-six different Environmental Site Potential classes were observed overall, 24 on the Naches Ranger District (NRD) and 21 on the Yakama Tribal Forest (YTF), but approximately 85% of the classes equaled less than 4% of the respective landscapes. Mesic mixed-conifer, dry-mesic mixed-conifer, and *Pinus ponderosa* woodland-savanna Environmental Site Potential (ESP) classes totaled 85.02% of the Naches Ranger District (NRD) and 90.67% of the YTF landscapes (Table 7). The NRD, at 6.78%, had greater landscape percentages in alpine and subalpine ESP classes compared to the YTF 3.95%.

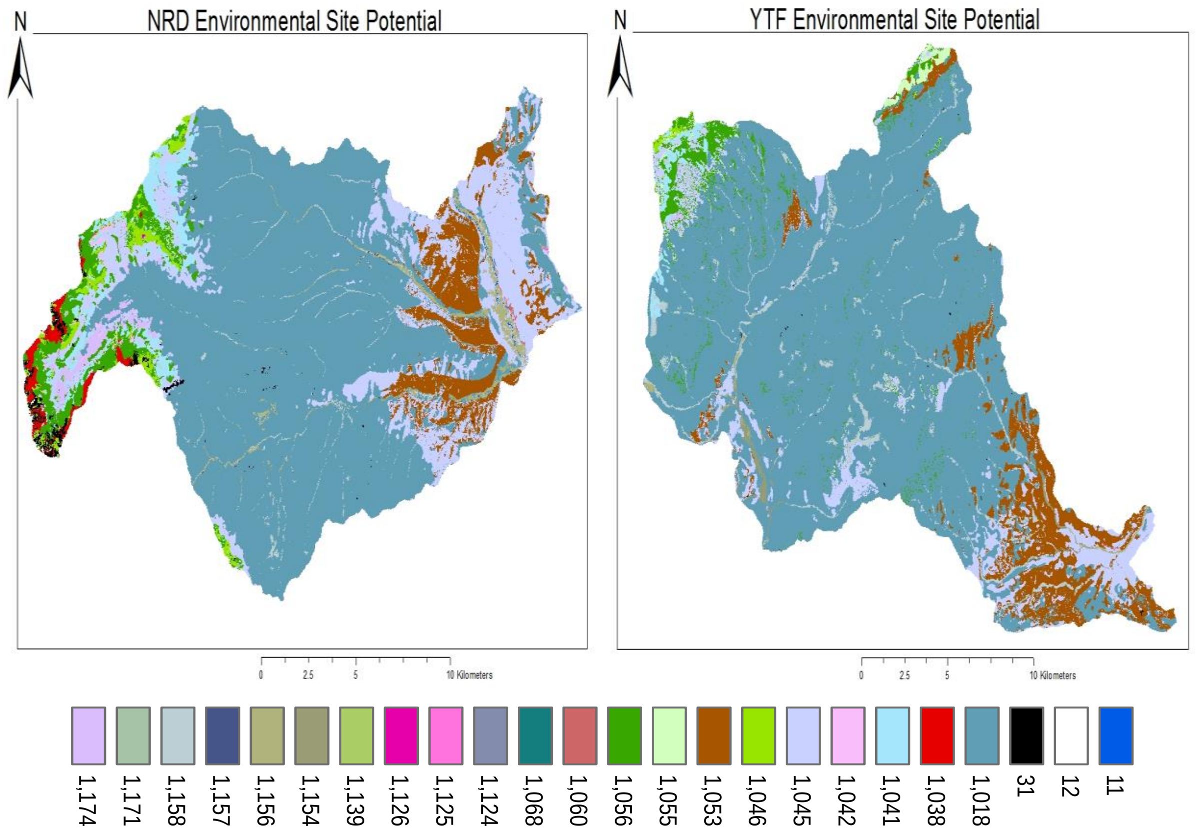

Figure 2 — Spatial patterns of LANDFIRE Environmental Site Potential (ESP) classes in the sampled watersheds of the Naches Ranger District (NRD) and the Yakama Tribal Forest (YTF) with ESP classes numerically coded. For complete ESP class numeric code descriptions see Appendix 12.

Class metrics for the mesic mixed-conifer ESP class quantified mean patch area, connectivity, and interspersion were similar for both landscapes. ESP mesic mixed-conifer class metrics indicated landscape proportion, patch density, and shape complexity were all greater than 16% higher on the YTF relative to the NRD (Table 7). Dry-mesic mixed-conifer class metrics for connectivity, interspersion, patch density, and shape complexity were similar on the two landscapes, but mean patch area and landscape proportion were approximately two times greater on the NRD than the YTF. *Pinus ponderosa* woodland-savanna class metrics were similar on both landscapes, but mean patch area was more than two times greater and patch density nearly two times lower on the YTF compared to the NRD.

Landscape spatial autocorrelation patterns of ESP classes exhibited a clustered pattern on the NRD and a dispersed pattern on the YTF (Table 3). The high-/ low-clusters analyses exhibited random patterns on both the NRD and the YTF landscapes (Table 4). Landscape metrics indicated similar mean patch area, patch density, connectivity, shape complexity, and diversity of ESP classes in the NRD and YTF landscapes (Table 9). ESP class landscape metrics for interspersion and diversity were greater on the NRD than the YTF. PERMANOVA quantified ownership and watershed main or interaction factors did not explain significant variances in ESP community composition data (Table 14).

5.2.2 Biophysical Settings

Thirty-four individual Biophysical Settings classes were observed in total, 32 on the Naches Ranger District (NRD) and 28 on the Yakama Tribal Forest (YTF), although over 85% of the classes equaled less than 4% of the respective landscapes. Mesic mixed-conifer, dry-mesic mixed-conifer, Steppe & Grassland, and mesic *Pinus ponderosa* savanna-woodland Biophysical Settings (BPS) classes equaled 82.89% of the NRD and 90.07% of the YTF landscapes. The NRD had greater landscape percentages in alpine and subalpine BPS classes at 7.03% compared to the YTF 3.96%.

BPS mesic mixed-conifer class metrics for connectivity, landscape proportion, and interspersion were similar on both landscapes (Table 8). BPS mesic mixed-conifer class metrics for patch density and shape complexity were approximately two times greater and mean patch area 2.5 times smaller on the YTF compared to the NRD. Class metrics for dry-mesic mixed-conifer BPS class quantified similar landscape proportion, but greater mean patch area, connectivity, and interspersion were observed on the NRD relative to the YTF. Class metrics quantified greater BPS dry-mesic mixed-conifer patch density and shape complexity on the YTF

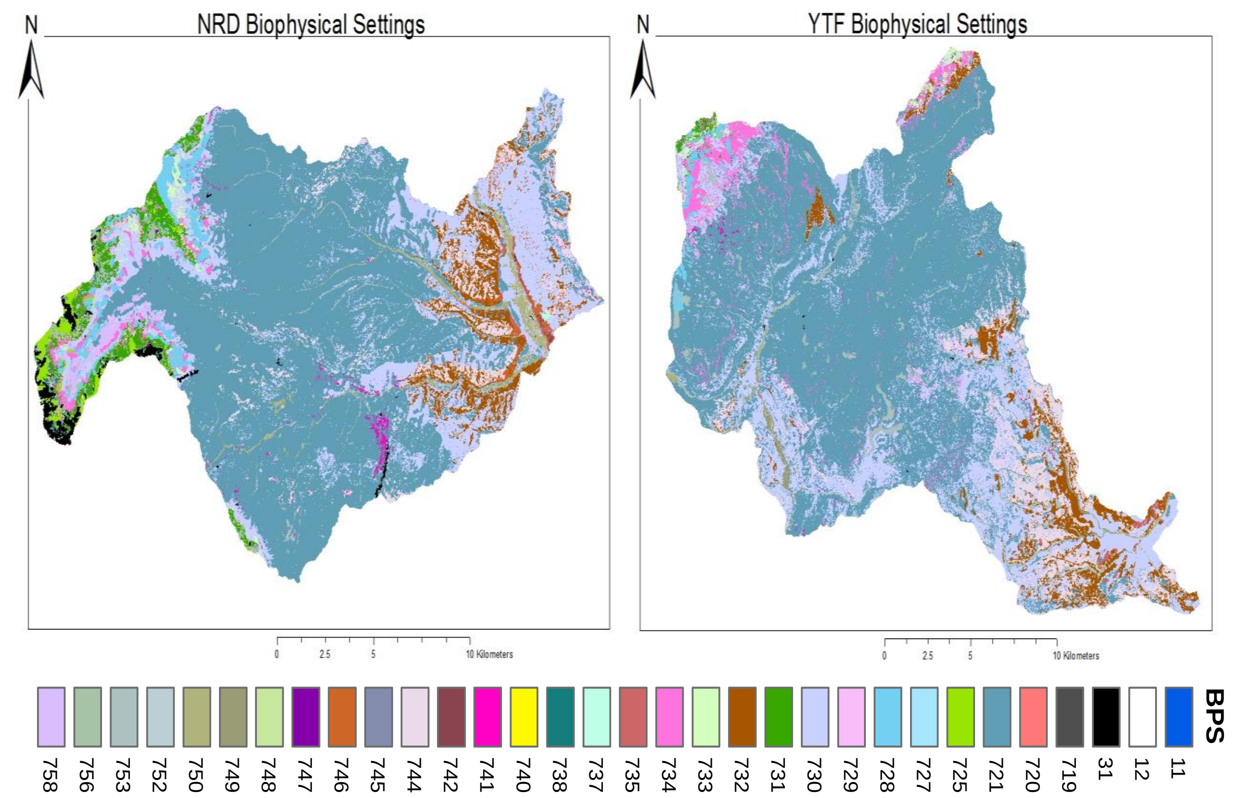

Figure 3 — Spatial patterns of LANDFIRE Biophysical Settings (BPS) classes in the sampled watersheds of the Naches Ranger District (NRD) and the Yakama Tribal Forest (YTF) with BPS classes numerically coded. For complete BPS class numeric code descriptions see Appendix 12.

relative to the NRD. Steppe & grassland class metrics recorded similar patch density, shape complexity, and interspersion on both landscapes, but the YTF had greater proportion, mean patch area, and connectivity than the NRD. Mesic *Pinus ponderosa* savanna-woodland exhibited similar class metrics across both landscapes.

Landscape spatial autocorrelation of BPS classes displayed a random pattern on the NRD and a dispersed pattern on the YTF (Table 3). The high-/ low-clusters analyses exhibited random patterns on both the NRD and the YTF landscapes (Table 4). Landscape metrics indicated similar patch density, mean patch area, connectivity, and diversity of BPS classes in the NRD and YTF landscapes, but shape complexity was greater for the YTF and interspersion and diversity were greater for the NRD (Table 9). PERMANOVA indicated ownership and watershed main or interaction factors did not explain significant variances in BPS community composition data (Table 14).

5.3 Vegetation Mapping Unit Data

5.3.1 Cover

Twenty-nine discrete cover types were observed in all, 27 on the Naches Ranger District (NRD) and 15 on the Yakama Tribal Forest (YTF), although nearly 80% of the cover types equaled less than 4% of their respective landscapes. *Pinus ponderosa* and *Pseudotsuga menziesii* cover types totaled the greatest percentages of landscapes equaling, respectively, 50.88% and 20.29% of the NRD and 54.96% and 15.74% of the YTF (Table 10). *Larix occidentalis* equaled 12.53% of the YTF landscape, but only 4.15% of the NRD landscape. *Abies amabilis* (5.22%), *Abies lasiocarpa/Picea engelmannii* (6.23%), and non-forest 2_2: annual grasses/ seeded wheatgrasses/ exotic forb (5.89%) cover types totaled 17.34% of the NRD, but equaled only 3.4% of the YTF landscape. In addition, six non-forest cover types observed on the NRD were absent on the YTF, including rock, water, cropland, urban/rural, pasture, and bare ground.

Class metrics for *Pinus ponderosa* cover types were similar in proportions, connectivity, and shape complexity on the NRD and YTF landscapes, but the YTF exhibited greater interspersion and mean patch area with lower patch density (Table 10). *Pseudotsuga menziesii* class metrics were similar for connectivity, shape complexity, interspersion, and patch density on the NRD and YTF landscapes, although greater mean patch area and landscape proportion were observed on the NRD compared to the YTF. *Larix occidentalis* covered the third greatest proportion of the YTF landscape, patches thereon were larger and more interspersed than on the NRD where the smaller, higher-density patches were clustered (Table 10, Figure4). *Abies lasiocarpa/ Picea engelmannii*, non-forest 2_2, and *Abies amabilis* were the third, fourth, and fifth most abundant cover types on the NRD, but the patches thereon were clustered with low interspersion.

On the NRD, landscape spatial autocorrelation (Global Moran's I) of cover types displayed a clustered pattern, while cover types on the YTF charted a random pattern (Table 5). Spatial analyses to identify patterns of either low values or high values clustered (Getis-Ord

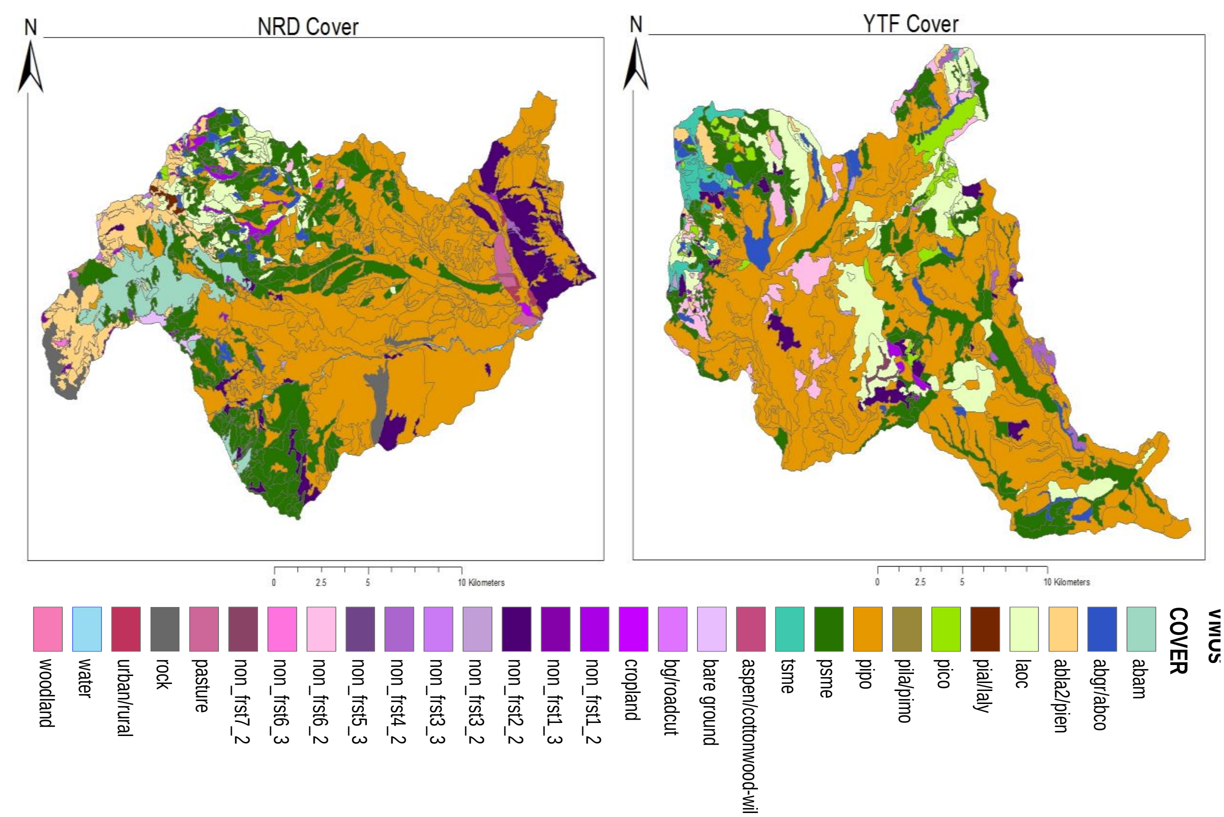

Figure 4 — Vegetation mapping unit spatial patterns of cover type patches in the sampled watersheds of the Naches Ranger District (NRD) and the Yakama Tribal Forest (YTF). Forested cover type codes refer to the first two letters of the genus and species, e.g. pipo- *Pinus ponderosa* (ponderosa pine), pila/pimo- *Pinus lambertiana*/*Pinus monticola* (sugar pine, western white pine). For cover type descriptions see Appendix 12.

General G) indicated a random pattern on the NRD, but low-clusters pattern on the YTF; low value cover types being shade-intolerant coniferous tree species (Table 6, Appendix 12). Cover type shape complexity, connectivity, and diversity landscape metrics were similar in the two landscapes, although diversity was greater on the NRD (Table 13). Landscape metrics also quantified cover type mean patch area was approximately 36.7% larger on the YTF than the NRD, where the smaller patches had 36.5% greater density and 17.4% less interspersion.

The PERMANOVA model produced from combined NRD and YTF cover type data identified ownership explained the greatest amount of variance in data over both landscapes (Table 15). The second, third, and fourth main factors explaining significant variance in combined cover type data were watershed, elevation, and logging type, respectively. Ownership-logging type interaction factor explained the most variance of the five observed in the model for data compiled from both landscapes.

PERMANOVA models run from cover type data separated by ownership found watersheds to be the most significant main factor on both the NRD and the YTF landscapes. After watershed, Environmental Site Potential (ESP) class and logging type explained the second and third greatest variance in NRD cover type data (Table 16). On the YTF, logging type and elevation explained the second and third greatest variance in respective cover type data (Table 17). Elevation and Biophysical Settings class were the final significant main effects in the NRD model and watershed-ESP class was the only significant interaction effect observed. Slope was the fourth and final main factor in the YTF cover type model, followed by watershed-logging type then watershed-elevation interaction effects.

5.3.2 Structure

Thirteen separate structure classes were observed in total, 11 on the Naches Ranger District (NRD) and 13 on the Yakama Tribal Forest (YTF), however approximately 54% of the structural classes equaled less than 4% of their respective landscapes. Stem exclusion open canopy (SEOC) structure class covered the greatest proportion of the YTF landscape at 37.68%, but only 12.75% of the NRD landscape. Understory reinitiation (UR) comprised the greatest proportion of the NRD at 47.36%, but only equaled 9.95% of the YTF. Young forest multi-strata (YFMS) equaled the second most abundant structure class on both landscapes, with 21.06% of the YTF and 17.90% of the NRD. Include the stand initiation (SI) class, at 9% of the YTF and 2.94% of the NRD, and approximately 80% of the respective landscapes categorized into these four structure classes (Table 11). Nearly 12% of the YTF landscape consisted of old forest structure classes, 5.80% old forest multi-strata and 5.88% old forest single-strata, while no old forest structure classes were observed on the NRD.

Understory reinitiation structure class metrics indicated landscape proportion was nearly five times greater and mean patch area and patch density nearly two times greater for the NRD than the YTF (Table 11). Class metrics for UR shape complexity, connectivity, and interspersion were also greater on the NRD than the YTF. On the YTF, SEOC was the most abundant structure class and landscape proportion was almost three times greater, mean patch area more than five times greater, and patch density almost two times lower than on the NRD (Table 11). Connectivity and interspersion class metrics for SEOC were higher on the YTF compared to the NRD, but shape complexity was greater on the NRD. Young forest multi-strata, the second most abundant structure class on each ownership, connectivity and shape complexity metrics were similar for the NRD and YTF. Class metrics also showed YFMS interspersion was 9.15% greater, landscape proportion 15% greater, mean patch area two times larger, and patch density nearly two times lower on the YTF relative to the NRD. Stand initiation structure class mean patch area was six times smaller with two times greater patch density on the NRD compared to the YTF, while connectivity and interspersion were greater and shape complexity lower on the YTF corresponding to the NRD. Mean patch area, connectivity, and shape complexity of stem exclusion closed canopy (SECC), the fourth largest percentage structure class on the NRD, were similar on both landscapes. However, SECC class metrics showed interspersion was 12.15% higher, landscape proportion over 2.5 times larger, and patch density 2.4 times greater on the NRD compared to the YTF.

Landscape spatial autocorrelation analyses (Global Moran's I) quantified clustered structure class patterns on both the NRD and YTF (Table 5). Getis-Ord General G high-/ low-clusters analyses indicated a random pattern on the YTF, but high-clusters on the NRD

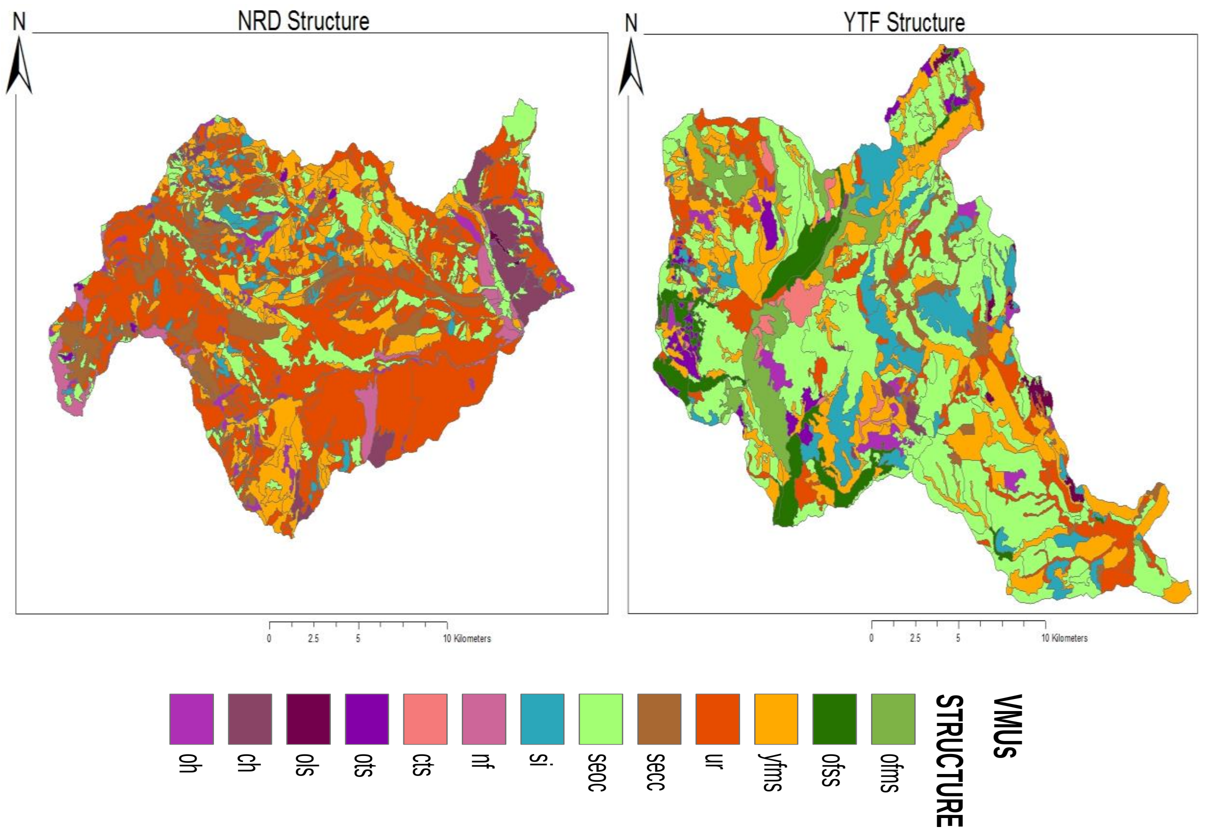

Figure 5 — Vegetation mapping unit spatial patterns of structural class patches in the sampled watersheds of the Naches Ranger District (NRD) and the Yakama Tribal Forest (YTF) landscapes. Forest structure class codes: si, stand initiation; seoc, stem exclusion open canopy; secc, stem exclusion closed canopy; ur, understory reinitiation; yfms, young forest multi-strata; ofss, old forest single strata; ofms, old forest multi-strata. For forest structure class visualizations see Appendix 11 and for non-forest cover type descriptions see Appendix 12.

landscape; high values correspond to non-forest structure classes (Table 6, Appendix 12). Landscape metrics denoted structure class mean patch area was nearly twice as large on the YTF relative to the NRD where patch density was nearly two times greater than on the YTF. Structure class connectivity, shape complexity, interspersion, and diversity landscape metrics were similar for the NRD and YTF, but interspersion and diversity were greater on the YTF (Table 13).

The final model from the PERMANOVA for structure class data combined from both landscapes quantified ownership main factor explained the most variance in the structure data (Table 18). The second, third, and fourth main factors explaining significant variance in combined structure class data were logging type, watershed, and Biophysical Settings (BPS) class, respectively. Logging type was a factor in all three significant interaction effects observed in the final combined structure composition model.

PERMANOVA run on independent structure composition data for the NRD and YTF landscapes yielded two very similar models, watershed was the primary factor explaining variance followed by logging type (Table 19 and 20). Next, BPS class main effect and watershed-logging type interaction effect were consecutive significant factors in the two final individual structure class models. Watershed-BPS class interaction effect and watershed-logging type-BPS class three-way interaction effect were additionally significant in the YTF model (Table 20).

5.3.3 Cover Structure Composite

Combining cover type and structure classes generated 77 distinct composite classes over both landscapes, 56 on the Naches Ranger District (NRD) and 52 on the Yakama Tribal Forest (YTF).

However, approximately 85% of the composite classes equaled less than 4% of their respective landscapes (Table 12). *Pinus ponderosa* understory reinitiation (PIPO UR) class covered the largest proportion of the NRD landscape at 30.51%, but only comprised 4.90% of the YTF. *Pinus ponderosa* stem exclusion open canopy (PIPO SEOC) class equaled the largest proportion of the YTF and second greatest proportion of the NRD at 24.58% and 9.48%, respectively. The second most abundant composite class on the YTF, *Pinus ponderosa* young forest multi-strata (PIPO YFMS), equaled 8.71% of that landscape and 7.92% of the NRD. *Pseudotsuga menziesii* young forest multi-strata (PSME YFMS) covered the third largest proportion of NRD at 7.93% and fifth greatest percentage of the YTF at 5.14%. The third greatest proportion composite class on the YTF, *Larix occidentalis* stem exclusion open canopy (LAOC SEOC), equaled 8.42%, but only 0.41% of the NRD landscape. *Pinus ponderosa* stand initiation (PIPO SI) was the fourth most abundant composite class on the YTF at 7.11% and equaled 0.72% of the NRD. *Pseudotsuga menziesii* understory reinitiation (PSME UR) equaled 7.09% of the NRD, the fifth most abundant composite class, and 3.23% of the YTF landscape.

Class metrics for PIPO UR indicated proportion was six times greater, mean patch area three times larger, patch density two times greater, and greater aggregation on the NRD compared to the YTF (Table 12, Figure 6). PIPO UR shape complexity, interspersion, and connectivity class metrics were similar on the two landscapes, but all were greater on the NRD. PIPO SEOC class metrics quantified landscape proportion was 2.5 times greater, mean patch area over five times larger, and patch density two times lower on the YTF compared to the NRD (Table 12). Shape complexity and connectivity metrics for PIPO SEOC were similar on both landscapes, but shape complexity was greater on the NRD while connectivity was greater on the YTF. PIPO SEOC interspersion was 28.1% greater on the YTF than the NRD. Landscape proportion, shape complexity, and connectivity of the PIPO YFMS class were similar on the two landscapes, but interspersion was 12.5% higher on the YTF. PIPO YFMS mean patch area was 2.5 times larger and patch density over two times lower on the YTF relative to the NRD.

PSME YFMS landscape proportion, mean patch area, patch density, shape complexity, connectivity, and interspersion were similar on both landscapes, but all metrics were higher on

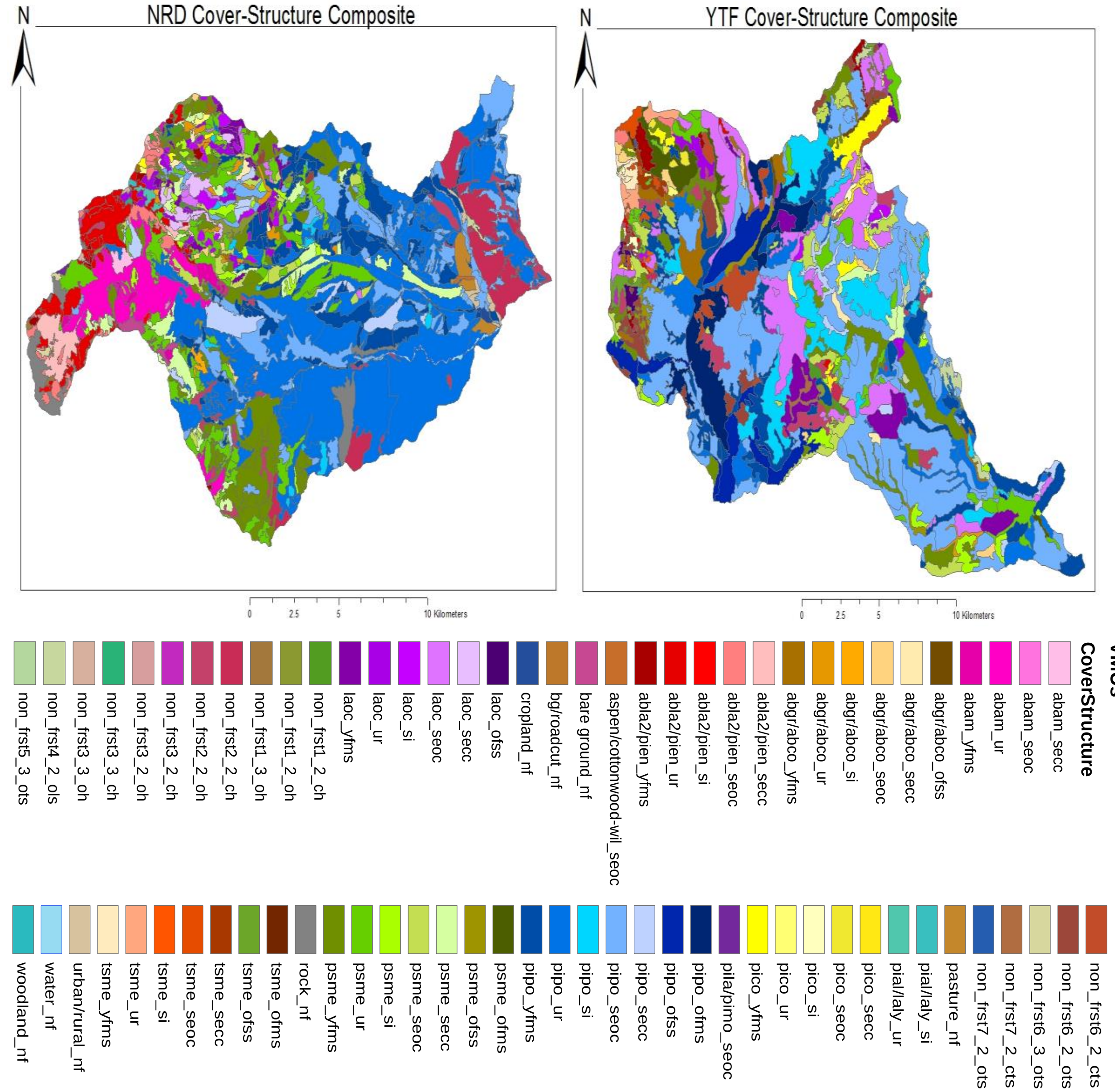

Figure 6 — Vegetation mapping unit spatial patterns of cover type and structure class composite patches in the sampled watersheds of the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF). Forest cover-structure composite codes combined cover type and structure class codes; e.g. psme_yfms, *Pseudotsuga menziesii* (Douglas-fir) young forest multi-strata. For composite class descriptions see Appendix 12.

the NRD. LAOC SEOC landscape proportion was 20 times greater, mean patch area nine times larger, patch density two times greater, and interspersion 32.4% greater on the YTF than the NRD (Table 12). Shape complexity and connectivity of LAOC SEOC was also higher on the YTF compared to the NRD landscape. Class metrics for PIPO SI identified landscape proportion was nearly ten times greater and mean patch area almost twelve times larger on the YTF in comparison to the NRD (Table 12). PIPO SI shape complexity and patch density were similar on the two landscapes, but interspersion and connectivity were greater on the YTF than the NRD. PSME UR mean patch area and connectivity metrics were similar for the two landscapes, but patch density was 2.5 times greater and landscape proportion two times greater on the NRD relative to the YTF. Interspersion and shape complexity metrics for PSME UR were 7.3% and 38.6% greater, respectively, on the NRD than the YTF.

Landscape spatial autocorrelation analyses (Global Moran's I) of composite classes indicated a clustered pattern on the NRD, while the YTF displayed a random pattern (Table 5). Composite class high-/low-clusters analyses (Getis-Ord General G) quantified a random pattern on the NRD landscape and low-clusters on the YTF landscape (Table 6). Landscape metrics calculated for the composite classes exhibited mean patch area nearly two times smaller and patch density almost two times greater on the NRD than the YTF. Shape complexity, connectivity, interspersion, and diversity landscape metrics were similar on the two landscapes, but interspersion and diversity were greater on the YTF (Table 13).

The final model produced from the PERMANOVA of the composite class data combined from both landscapes quantified ownership explained the greatest amount of variance in the data, followed by watershed (Table 21). Logging type and Environmental Site Potential (ESP) class main effects explained the third and fourth most variance, respectively, in the final composite class combined data model. Elevation and Biophysical Settings (BPS) class were the fifth and sixth main factors in the final model of combined composite class data. Ownership-logging type accounted for the most variance of interaction factors observed in the composite class combined data model, followed by the ownership-ESP class then the watershed -logging type interaction effects (Table 21).

PERMANOVA models produced from the individual NRD and YTF composite class datasets both quantified watershed main factor explained the most variance in respective data, followed by logging type. In the NRD model, ESP class and elevation explained the third and fourth greatest amounts of variance in the data (Table 22), while the YTF model third and fourth main factors were BPS class and elevation (Table 23). BPS class was the fifth and final main factor in the NRD model and watershed-logging type then watershed-ESP class interaction effects were the final terms in the model (Table 22). In the YTF model, watershed-logging type explained the most variance of interaction terms in the composite class data followed by watershed-BPS class, logging type-BPS class, and then logging type-elevation (Table 23).

5.4 Geospatial Statistical Analyses (ArcGIS)

5.4.1 LANDFIRE Data

Results from the Global Moran's I spatial autocorrelation analyses of LANDFIRE data varied by landscape ownership and, in the case of the Naches Ranger District (NRD), feature class type (Table 3). Biophysical Settings (BPS) and Environmental Site Potential (ESP) classes both charted dispersed spatial patterns on the Yakama Tribal Forest (YTF). On the NRD, spatial autocorrelation of BPS classes displayed a random pattern, while ESP classes exhibited a clustered pattern. Results from the Getis-Ord General G high/low clusters analyses quantified random patterns on both ownerships for both LANDFIRE potential vegetation types (Table 4).

Table 3 — Global Moran's I spatial autocorrelation results for sampled watersheds in the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) where features were LANDFIRE Biophysical Settings (BPS) or Environmental Site Potential (ESP) classes.

Moran's I	**α = 0.05**			
	BPS		**ESP**	
	NRD	**YTF**	**NRD**	**YTF**
Observed	0.0027	-0.0329	0.0395	-0.0235
Expected	-0.0000	-0.0000	-0.0001	-0.0001
z-score	0.4967	-7.0850	4.3627	-2.7207
p-value	0.6194	0	0	0.0065
Pattern	random	dispersed	clustered	dispersed

Table 4 — Getis-Ord General G high/low clustering results for sampled watersheds in the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) where features were LANDFIRE Biophysical Settings (BPS) or Environmental Site Potential (ESP) classes.

General G	**α = 0.05**			
	BPS		**ESP**	
	NRD	**YTF**	**NRD**	**YTF**
Observed	0.0002	0.0001	0.0005	0.0004
Expected	0.0002	0.0001	0.0005	0.0004
z-score	-0.8119	-0.2113	-0.1275	-0.7519
p-value	0.4167	0.8327	0.8985	0.4521
Pattern	random	random	random	random

5.4.2 Vegetation Mapping Unit Data

Results from the Global Moran's I spatial autocorrelation analyses for vegetation mapping unit data varied by landscape ownership and, in the case of the Yakama Tribal Forest (YTF), feature class type (Table 5). Cover type, structure class, and cover-structure composite class data charted clustered spatial autocorrelation patterns on the Naches Ranger District (NRD). Cover type and composite class data displayed random spatial autocorrelation patterns on the YTF, while structure class data, like the NRD, exhibited a clustered pattern.

Table 5 — Global Moran's I spatial autocorrelation results for sampled watersheds in the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) where features were vegetation mapping unit cover types, structure classes, or cover-structure composite classes.

Moran's I	**α = 0.05**					
	Cover		**Structure**		**Composite**	
	NRD	**YTF**	**NRD**	**YTF**	**NRD**	**YTF**
Observed	0.1051	-0.0008	0.0638	0.0614	0.1051	-0.0008
Expected	-0.0012	-0.002	-0.0012	-0.002	-0.0012	-0.002
z-score	5.124	0.0408	3.3139	2.2984	5.1258	0.0444
p-value	0	0.9675	0.0017	0.0215	0	0.9646
Pattern	clustered	random	clustered	clustered	clustered	random

The results from the Getis-Ord General G high/low clusters analyses of vegetation mapping unit data varied by landscape ownership and feature type (Table 6). On the YTF, cover type and composite class displayed patterns of low-clusters, while structure class demonstrated a random high/ low clusters pattern. Cover type and composite class charted random high/ low clusters patterns on the NRD, whereas structure class exhibited patterns of high-clusters.

Table 6 — Getis-Ord General G high/low clustering results for sampled watersheds in the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) where features were vegetation mapping unit cover types, structure classes, or cover-structure composite classes.

General G	**α = 0.05**					
	Cover		**Structure**		**Composite**	
	NRD	**YTF**	**NRD**	**YTF**	**NRD**	**YTF**
Observed	0.0065	0.0082	0.0064	0.0099	0.0065	0.0083
Expected	0.0063	0.0100	0.0063	0.0100	0.0063	0.0100
z-score	1.0488	-3.289	2.0595	-0.6693	1.0433	-3.2867
p-value	0.2943	0.001	0.0395	0.5033	0.2968	0.001
Pattern	random	low-clusters	high-clusters	random	random	low-clusters

5.5 Geospatial Statistical Analyses (FRAGSTATS)

5.5.1 LANDFIRE Data

5.5.1.1 Environmental Site Potential

FRAGSTATS class metrics revealed greater than 90% of the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) landscapes were in a handful of Environmental Site Potential (ESP) classes. The major ESP classes on both ownerships included dry and mesic forest and woodland communities (Table 7). Within the dominant ESP classes, metrics for connectivity and shape complexity were often similar on the two landscapes, while proportion, mean patch area, patch density, and interspersion metrics were variable. Metrics for ancillary ESP classes were irregular between the two landscapes and trends more difficult to identify.

Table 7 — Class metric results for sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patch types were LANDFIRE Environmental Site Potential classes. See Table 1 for metric descriptions.

LANDFIRE Environmental Site Potential (ESP) Class Metrics

	ESP Classes											
	Mesic Mixed-Conifer 1018		Dry-Mesic Mixed-Conifer 1045		PIPO Woodland, Savanna 1053		Mesic-Wet Subalpine Spruce-Fir 1056		Mnt. Riparian Woodland, Shrubland 1158		TSME Forest-Xeric 1041	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	33.61	29.54	6.69	2.91	5.58	12.45	3.64	0.54	0.45	1.45	5.83	4.65
PLAND (%)	61.83	73.67	16.08	8.19	7.11	8.81	4.08	3.16	1.25	3.58	2.79	0.86
NP (no.)	534	867	697	979	370	246	325	2016	810	862	139	64
PD (no. / 100 ha)	1.84	2.49	2.40	2.82	1.27	0.71	1.12	5.80	2.79	2.48	0.48	0.18
LPI (%)	57.69	70.30	4.77	1.74	2.28	5.44	0.85	0.73	0.04	0.30	0.47	0.15
ED (m/ha)	26.21	42.35	29.94	22.31	14.66	17.04	9.96	17.97	10.11	17.59	6.02	2.01
LSI	15.03	24.31	32.72	37.43	24.03	27.61	21.47	47.75	38.51	43.26	15.84	10.63
PLADJ (%)	96.63	95.44	85.61	78.92	84.13	85.03	81.22	56.75	39.35	63.13	83.27	80.55
IJI (%)	52.90	52.43	55.38	52.13	26.92	38.60	66.79	38.47	36.74	30.67	57.77	42.01
COHESION (%)	99.81	99.91	97.80	95.41	97.42	98.93	95.86	88.89	69.65	88.91	94.29	93.67
AI (%)	96.85	95.62	85.99	79.37	84.69	85.49	81.94	57.27	39.98	63.67	84.16	82.01

	ESP Classes											
	Subalpine Woodland, Parkland 1046		Dry-Mesic ABAM/TSHE/PSME 1174		Mesic Subalpine, Parkland 1038		Barren-Rock/ Sand/ Clay 031		Dry-Mesic Spruce-Fir 1055		Montane Riparian Systems 1154	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	2.29	1.43	4.85	1.54	4.20	0.09	1.48	0.33	0.32	1.84	0.27	2.91
PLAND (%)	1.52	0.14	1.04	0.07	0.98	0	0.77	0.04	0.20	0.64	0.16	0.56
NP (no.)	193	34	62	16	68	12	151	37	185	121	169	67
PD (no. / 100 ha)	0.67	0.10	0.21	0.05	0.23	0.03	0.52	0.11	0.64	0.35	0.58	0.19
LPI (%)	0.31	0.05	0.56	0.04	0.16	0	0.11	0.01	0.02	0.20	0.01	0.28
ED (m/ha)	4.87	0.64	2.50	0.26	2.21	0.04	3.48	0.30	1.66	1.87	1.60	2.27
LSI	17.54	8.43	10.41	4.41	10.93	3.43	17.70	7.25	16.22	11.45	16.87	14.03
PLADJ (%)	74.83	63.33	81.95	72.53	80.55	0	64.43	36.03	36.29	76.91	24.22	69.61
IJI (%)	55.64	37.68	52.99	48.21	42.01	40.96	57.39	30.20	35.12	56.49	47.82	43.62
COHESION	92.10	88.80	95.35	86.92	93.67	0	90.59	55.86	64.60	91.97	55.80	94.10

(%)												
AI (%)	75.92	66.21	83.39	77.34	82.01	0	65.75	39.52	37.77	78.79	25.36	71.15

	ESP Classes			
	Low Riparian Forest, Shrubland		Mesic TSHE/ ABAM Forest	
	1156		1042	
	NRD	YTF	NRD	YTF
AREA_MN (ha)	1.57	0.25	1.12	1.08
PLAND (%)	1.84	1.24	0.31	0
NP (no.)	248	70	81	1.00
PD (no. / 100 ha)	0.85	0.20	0.28	0
LPI (%)	0.72	0.08	0.09	0
ED (m/ha)	7.34	1.25	1.61	0.02
LSI	24.87	11.76	12.27	1.29
PLADJ (%)	64.87	62.07	61.14	62.50
IJI (%)	46.73	51.84	58.99	36.36
COHESION (%)	95.31	88.88	85.59	71.25
AI (%)	65.80	64.14	63.14	88.24

5.5.1.2 Biophysical Settings Class Metrics

Class metrics for Biophysical Settings (BPS) data, like Environmental Site Potential classes, showed few classes dominated both landscapes with a majority of classes in small proportions. Within the principal BPS classes, metrics for connectivity and interspersion were similar, while proportion, mean patch area, patch density and shape complexity metrics varied more between landscapes. Metrics for subordinate BPS classes were mercurial between the two landscapes and trends more difficult to identify than in major classes.

Table 8 — Class metric results for sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patch types were LANDFIRE Biophysical Settings classes. See Table 1 for metric descriptions.

LANDFIRE Biophysical Settings (BPS) Class Metrics

	BPS Classes											
	Mesic Mixed-Conifer		Dry-Mesic Mixed-Conifer		Steppe & Grassland		Mesic PIPO Savanna Woodland		Mnt. Riparian Woodland, Shrubland-Dry		Mesic-Wet Subalpine Spruce-Fir	
	721		730		744		732		753		734	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	17.98	7.05	1.89	1.36	1.09	1.67	2.11	2.38	0.44	1.44	0.75	0.54
PLAND (%)	55.26	56.52	19.04	21.7	4.21	6.51	4.38	5.34	1.22	3.58	1.31	3.19

NP (no.)	892	2785	2924	5557	1116	1352	603	780	802	863	509	2045
PD (no. / 100 ha)	3.07	8.01	10.07	15.99	3.85	3.89	2.08	2.24	2.76	2.48	1.75	5.88
LPI (%)	52.29	52.25	4.05	2.89	0.31	0.86	0.67	0.89	0.04	0.30	0.12	0.70
ED (m/ha)	59.75	95.66	60.75	90.01	20.94	26.55	19.07	20.43	9.97	17.58	6.78	18.81
LSI	34.93	60.32	60.19	91.23	43.81	49.18	39.27	41.69	38.27	43.24	25.31	49.62
PLADJ (%)	91.72	87.08	75.69	68.48	62.24	68.88	66.93	70.91	38.90	63.14	60.96	55.25
IJI (%)	41.84	37.23	48.75	36.70	40.33	40.84	39.37	44.10	35.72	39.86	58.64	43.39
COHESION (%)	99.86	99.85	97	97.35	89.54	94.84	95.16	95.03	69.55	88.71	82.88	89.65
AI (%)	91.94	87.27	76	68.72	62.78	69.32	67.49	71.41	39.53	63.68	61.92	55.75

	BPS Classes											
	Subalpine Woodland, Parkland		Low Riparian Forest, Shrubland		Barren-Rock/ Sand/ Clay		Subalpine, Alpine Dry Grassland		Dry-Mesic ABAM/ TSHE/ PSME Forest		Mesic-Wet Subalpine Spruce-Fir	
	731		750		031		756		758		725	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	1.93	1.19	1.87	1.24	5.08	0.52	0.96	0.16	4.99	1.37	2.36	0.18
PLAND (%)	2.54	0.21	1.60	0.25	1.24	0.01	1.21	0.13	1.03	0.07	0.99	0.03
NP (no.)	382	62	247	70	71	9	366	280	60	17	122	54
PD (no. / 100 ha)	1.32	0.18	0.85	0.20	0.24	0.03	1.26	0.81	0.21	0.05	0.42	0.16
LPI (%)	0.53	0.10	0.75	0.08	0.57	0	0.15	0	0.56	0.04	0.13	0.01
ED (m/ha)	10.40	1.11	7.31	1.25	3.19	0.11	7.15	1.41	2.51	0.26	2.82	0.29
LSI	28.45	12.05	24.63	11.76	13.26	4.07	28.33	18.15	10.45	4.58	13.25	8.19
PLADJ (%)	68.54	57.22	65.53	62.07	78.98	41.35	54.59	18.14	81.79	70.74	76.35	18.87
IJI (%)	58.80	51.79	44.48	50.99	62.09	14.93	55.13	59.82	53.67	48.68	57.31	44.65
COHESION (%)	94.87	91.28	95.41	88.88	95.29	62.80	88.43	35.83	95.38	86.56	90.12	47.34
AI (%)	69.31	59.33	66.46	64.14	80.25	48.31	55.48	18.99	83.24	75.57	77.74	20.94

	BPS Classes			
	TSME Forest-Xeric		Big Sagebrush Steppe	
	728		746	
	NRD	YTF	NRD	YTF
AREA_MN (ha)	5.07	3.65	0.37	0.15
PLAND (%)	2.64	0.78	0.88	0.01
NP (no.)	151	74	702	25
PD (no. / 100 ha)	0.52	0.21	2.42	0.07
LPI (%)	0.42	0.12	0.13	0
ED (m/ha)	6.28	2.41	6.39	0.12
LSI	16.91	13.22	29.29	5.46
PLADJ (%)	81.62	75.79	45.02	13.41
IJI (%)	66.43	64.52	44.90	39.14
COHESION (%)	94.04	91.76	78.39	32.57
AI (%)	82.52	77.20	45.88	15.94

5.5.1.3 LANDFIRE Landscape Metrics

Landscape metrics for connectivity, mean patch area, and patch density were similar on both the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) for both the Environmental Site Potential (ESP) and Biophysical Settings (BPS) LANDFIRE data. Shape complexity, while similar on both landscapes for the ESP data, was 22.6% greater for BPS on the YTF than the NRD (Table 9). ESP landscape metrics for interspersion were 17.7% greater and BPS 23.6% greater on the NRD compared to the YTF. The Shannon diversity metric was 27.3% greater for ESP data and 16.2% greater for BPS data on the NRD relative to the YTF. While the Simpson diversity metric was very similar for BPS data from the NRD and YTF landscapes, ESP data quantified 24.1% greater diversity on the NRD.

Table 9 — Landscape metric results for the sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patches were LANDFIRE Environmental Site Potential or Biophysical Settings classes.

LANDFIRE Landscape Metrics				
	Environmental Site Potential		Biophysical Settings	
	NRD	YTF	NRD	YTF
AREA_MN (ha)	6.78	6.41	2.69	2.30
NP (no.)	4279	5422	10781	15111
PD (no. / 100 ha)	14.74	15.60	37.14	43.48
LPI (%)	57.96	70.30	52.29	52.25
ED (m/ha)	62.26	63.07	120.60	143.17
LSI	28.31	31.36	53.15	68.69
CONTAG (%)	71.73	76.88	65.76	67.56
IJI (%)	56.27	46.31	52.91	40.44
COHESION (%)	98.92	99.52	99.08	99.34
AI (%)	90.74	90.52	82.00	78.51
SHDI	1.39	1.01	1.67	1.40
SIDI	0.58	0.44	0.65	0.62

5.5.2 Vegetation Mapping Unit Data

5.5.2.1 Cover Type

Class metrics identified a general trend in cover type data where mean patch area was much larger on the Yakama Tribal Forest (YTF) and patch density greater on the Naches Ranger

District (NRD), even for classes with similar landscape proportions. For most cover types, connectivity and shape complexity class metrics were similar, while many discrepancies, often vast, were observed for interspersion metrics (Table 10). Class metrics also identified a greater proportion of the NRD landscape was classified as coniferous and non-forest cover types not observed on the YTF landscape.

Table 10 — Vegetation mapping unit (VMU) class metric results for the sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patches were cover types. See Table 1 for metric descriptions.

VMUs Cover Class Metrics

	Cover Type Classes											
	PIPO		LAOC		PICO		PSME		ABGR/ ABCO		ABAM	
	10		11		12		13		14		15	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	447.4	1591.2	36.51	161.3	11.91	52.11	125.3	103.2	15.10	61.59	252.4	—
PLAND (%)	50.88	54.96	4.15	12.53	0.25	2.70	20.29	15.74	1.30	3.01	5.22	—
NP (no.)	33	12	33	27	6	18	47	53	25	17	6	—
PD (no. / 100 ha)	0.11	0.03	0.11	0.08	0.02	0.05	0.16	0.15	0.09	0.05	0.02	—
LPI (%)	42.24	39.23	1.36	3.09	0.08	1.53	5.50	2.71	0.15	0.71	4.24	—
ED (m/ha)	18.21	17.36	4.96	8.12	0.43	2.81	17.76	14.38	2.36	3.73	3.70	—
LSI	11.88	12.23	10.63	11.13	3.77	8.00	17.30	17.72	8.92	10.15	7.07	—
PLADJ (%)	97.06	97.34	90.79	94.94	86.46	92.13	93.23	92.80	86.17	90.58	94.54	—
IJI (%)	54.17	62.51	46.82	68.91	44.27	71.43	54.49	57.26	45.81	62.37	40.27	—
COHESION (%)	99.77	99.84	97.07	98.50	92.01	97.85	98.79	98.29	93.26	96.73	99.08	—
AI (%)	97.30	97.55	91.59	95.37	89.68	93.04	93.60	93.18	87.53	91.42	95.27	—

	Cover Type Classes											
	ABLA2/ PIEN		TSME		PIAL/ LALY		PILA/ PIMO		ASP/CW/WIL		Rock	
	16		18		19		20		21		28	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	164.3	26.64	12.60	86.91	19.77	—	14.67	—	17.17	—	81.85	—
PLAND (%)	6.23	1.15	0.04	2.25	0.20	—	0.05	—	0.06	—	1.97	—
NP (no.)	11	15	1	9	3	—	1	—	1	—	7	—
PD (no. / 100 ha)	0.04	0.04	0	0.03	0.01	—	0	—	0	—	0.02	—
LPI (%)	3.09	0.39	0.04	1.47	0.12	—	0.05	—	0.06	—	0.83	—
ED (m/ha)	4.53	1.57	0.11	1.68	0.33	—	0.06	—	0.12	—	1.56	—
LSI	8.50	7.09	2.25	6.19	3.21	—	1.88	—	2.04	—	5.64	—
PLADJ (%)	93.99	89.30	80.71	93.34	87.33	—	84.97	—	85.00	—	92.92	—
IJI (%)	70.91	77.51	31.39	83.86	30.23	—	16.94	—	25.42	—	32.69	—
COHESION	99.00	95.45	91.71	98.12	93.78	—	92.33	—	92.91	—	97.62	—

(%)												
AI (%)	94.66	90.67	88.28	94.35	90.92	—	92.33	—	91.76	—	94.10	—

Cover Type Classes

	Water 29		BG/ Roadcut 34		Bare Ground 35		Cropland 43		Urban/ Rural 44		Pasture 45	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	1.87	—	—	10.17	27.02	—	15.98	—	30.72	—	50.65	—
PLAND (%)	0.31	—	—	0.03	0.37	—	0.11	—	0.32	—	0.70	—
NP (no.)	48	—	—	1	4	—	2	—	3	—	4	—
PD (no. / 100 ha)	0.17	—	—	0	0.01	—	0.01	—	0.01	—	0.01	—
LPI (%)	0.10	—	—	0.03	0.20	—	0.09	—	0.13	—	0.40	—
ED (m/ha)	1.81	—	—	0.08	0.49	—	0.18	—	0.57	—	0.52	—
LSI	13.69	—	—	2.05	3.97	—	2.24	—	4.39	—	2.64	—
PLADJ (%)	56.16	—	—	80.09	88.43	—	88.03	—	86.28	—	94.42	—
IJI (%)	20.46	—	—	34.31	33.69	—	38.30	—	36.60	—	38.90	—
COHESION (%)	90.42	—	—	90.74	95.08	—	92.90	—	94.71	—	96.42	—
AI (%)	58.01	—	—	88.73	91.08	—	93.01	—	89.06	—	95.46	—

Cover Type Classes

	Woodland 47		Non_Frst1_2 native bunchgrass 49		Non_Frst1_3 native bunchgrass 50		Non_Frst2_2 annual grass, exotic forb 52		Non_Frst3_2 native moist site herb 55		Non_Frst3_3 native moist site herb 56	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	8.55	17.78	12.38	7.27	—	55.12	35.51	6.30	15.08	8.25	—
PLAND (%)	—	0.02	1.04	0.43	0.13	—	5.89	2.25	0.02	0.22	0.09	—
NP (no.)	—	1	17	12	5	—	31	22	1	5	3	—
PD (no. / 100 ha)	—	0	0.06	0.03	0.02	—	0.11	0.06	0	0.01	0.01	—
LPI (%)	—	0.02	0.28	0.13	0.04	—	1.87	0.46	0.02	0.08	0.03	—
ED (m/ha)	—	0.05	2.27	0.71	0.29	—	5.69	2.36	0.05	0.40	0.18	—
LSI	—	1.40	9.86	5.46	4.56	—	10.87	7.64	1.47	4.03	3.00	—
PLADJ (%)	—	85.26	82.97	86.42	76.86	—	92.10	91.77	82.14	86.04	81.45	—
IJI (%)	—	33.72	47.84	62.44	24.79	—	34.17	67.18	0	70.15	23.28	—
COHESION (%)	—	89.88	94.92	92.56	89.04	—	97.77	96.08	88.20	93.42	89.77	—
AI (%)	—	95.29	84.43	88.63	80.96	—	92.78	92.77	93.50	89.12	86.82	—

Cover Type Classes

	Non_Frst4_2 sagebrush/ bitterbrush 58		Non_Frst5_3 mahogany 62		Non_Frst6_2 mountain shrub 64		Non_Frst7_2 wet site shrub 66		Non_Frst6_3 mountain shrub 70	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	15.89	32.82	6.57	—	16.11	50.00	3.96	36.63	14.31	—
PLAND (%)	0.11	0.76	0.05	—	0.11	3.74	0.01	0.21	0.10	—
NP (no.)	2	8	2	—	2	26	1	2	2	—
PD (no. / 100 ha)	0.01	0.02	0.01	—	0.01	0.07	0	0.01	0.01	—

LPI (%)	0.09	0.33	0.04	—	0.06	0.81	0.01	0.20	0.06	—
ED (m/ha)	0.24	1.05	0.10	—	0.16	3.58	0.08	0.42	0.15	—
LSI	3.11	6.05	1.92	—	2.03	9.30	2.64	4.16	2.25	—
PLADJ (%)	83.29	88.70	83.56	—	89.25	92.24	57.95	85.20	87.26	—
IJI (%)	20.04	46.74	30.69	—	17.98	58.77	7.59	11.07	31.58	—
COHESION (%)	93.73	96.14	91.16	—	92.71	96.71	85.07	96.34	92.34	—
AI (%)	88.02	90.39	91.39	—	94.25	93.02	68.92	88.34	92.5	—

5.5.2.2 Structure Class

Class metrics identified a general trend in structure class data where mean patch area was much larger on the Yakama Tribal Forest (YTF) and patch density much greater on the Naches Ranger District (NRD), even for classes with similar landscape proportions (Table 11). Class metrics for connectivity were similar on both landscapes for structure classes, while shape complexity was similar for forest structure classes but varied among non-forest classes. YTF structure classes displayed greater interspersion in comparison to the NRD. Landscape proportion of non-forest structure classes was 32.5% greater for the NRD compared to the YTF. While nearly 12% of the YTF landscape classified as old forest structures, no old forest structure classes were observed on the NRD.

Table 11 — Vegetation mapping unit (VMU) **c**lass metric results for the sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patches were structure classes. See Table 1 for metric descriptions.

VMUs Structure Class Metrics

	Structural Classes											
	Stand Initiation		Stem Exclusion Open Canopy		Stem Exclusion Close Canopy		Understory Reinitiation		Young Forest Multi-Strata		Old Forest Multi-Strata	
	10		11		12		13		14		15	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	14.97	97.71	31.90	174.6	65.78	64.68	196.3	72.03	57.08	114.35	—	251.8
PLAND (%)	2.94	9.00	12.75	37.68	7.71	2.98	47.36	9.95	17.90	21.06	—	5.80
NP (no.)	57	32	116	75	34	16	70	48	91	64	—	8
PD (no. / 100 ha)	0.20	0.09	0.40	0.22	0.12	0.05	0.24	0.14	0.31	0.18	—	0.02
LPI (%)	0.34	1.55	1.09	8.83	1.09	1.50	31.98	1.65	3.45	2.97	—	2.52
ED (m/ha)	5.09	6.63	17.11	21.97	8.29	4.43	29.84	9.96	18.50	18.42	—	4.37
LSI	12.77	10.77	21.11	17.99	12.82	12.10	19.54	15.49	19.18	19.46	—	8.55
PLADJ (%)	86.87	94.22	89.58	95.28	91.85	88.69	95.00	92.10	92.01	93.17	—	94.27

IJI (%)	60.74	69.86	64.44	74.49	63.47	55.76	75.87	67.99	67.62	74.43	—	72.12
COHESION (%)	93.50	97.99	96.41	99.05	97.25	98.27	99.63	97.79	98.00	98.41	—	98.60
AI (%)	87.77	94.73	90.02	95.53	92.44	89.53	95.24	92.57	92.39	93.49	—	94.90

	Structural Classes									
	Old Forest Single Strata 16		Open Herbland 17		Closed Herbland 18		Open Low Shrubland 20		Open Tall Shrubland 22	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	170.2	14.80	33.47	80.48	17.93	15.89	32.84	12.35	32.94
PLAND (%)	—	5.88	2.45	2.12	4.72	0.77	0.11	0.76	0.26	2.09
NP (no.)	—	12	48	22	17	15	2	8	6	22
PD (no. / 100 ha)	—	0.03	0.17	0.06	0.06	0.04	0.01	0.02	0.02	0.06
LPI (%)	—	1.71	0.28	0.46	1.66	0.24	0.09	0.33	0.06	0.49
ED (m/ha)	—	4.87	4.92	2.20	3.85	1.18	0.24	1.05	0.41	2.40
LSI	—	9.71	14.37	7.51	8.26	6.33	3.11	6.06	3.55	8.37
PLADJ (%)	—	93.54	83.08	91.69	93.29	88.35	83.29	88.69	87.48	90.64
IJI (%)	—	74.74	63.65	70.23	72.07	77.62	29.50	68.89	64.23	65.99
COHESION (%)	—	98.25	93.98	96.08	98.00	94.07	93.73	96.14	92.25	96.11
AI (%)	—	94.17	84.75	92.71	94.06	90.01	88.02	90.38	90.68	91.67

	Structural Classes			
	Closed Tall Shrubland 23		Non-Forest / Non-Range 24	
	NRD	YTF	NRD	YTF
AREA_MN (ha)	3.96	72.08	17.17	9.27
PLAND (%)	0.01	1.87	3.79	0.05
NP (no.)	1	9	64	2
PD (no. / 100 ha)	0	0.03	0.22	0.01
LPI (%)	0.01	0.81	0.83	0.03
ED (m/ha)	0.08	1.69	4.83	0.12
LSI	2.64	6.06	11.45	2.45
PLADJ (%)	57.95	92.86	89.63	82.77
IJI (%)	10.74	58.46	60.31	46.89
COHESION (%)	85.07	97.06	96.44	90.41
AI (%)	68.92	93.96	90.45	89.03

5.5.2.3 Cover Structure Composite

Metrics for composite classes, created from consolidating cover type and structure class data, charted a general trend of larger mean patch area on the Yakama Tribal Forest (YTF) and greater patch density on the Naches Ranger District (NRD) (Table 12). A large proportion of the NRD classified as *Pinus ponderosa* understory reinitiation, and YTF as *Pinus ponderosa* stem exclusion open canopy, but both ownerships demonstrated extensive distribution among minor composite classes. While composite class metrics for connectivity were similar on the NRD and YTF, shape complexity and interspersion were mercurial, but shape complexity tended to be greater on the NRD and interspersion greater on the YTF.

Table 12 — Vegetation mapping unit (VMU) class metric results for the sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patches were cover type and structure class composite classes. See Table 1 for metric descriptions and Appendix 12 for composite class descriptions.

VMUs Cover-Structure Composite Class Metrics

	Composite Classes											
	PIPO SI 1010		PIPO SEOC 1011		PIPO SECC 1012		PIPO UR 1013		PIPO YFMS 1014		PIPO OFMS 1015	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	13.03	154.5	36.69	194.1	59.04	32.30	245.9	81.05	35.92	89.00	—	372.5
PLAND (%)	0.72	7.11	9.48	24.58	2.24	1.12	30.51	4.90	7.92	8.71	—	4.29
NP (no.)	16	16	75	44	11	12	36	21	64	34	—	4
PD (no. / 100 ha)	0.06	0.05	0.26	0.13	0.04	0.03	0.12	0.06	0.22	0.10	—	0.01
LPI (%)	0.16	1.47	1.09	5.28	0.85	0.52	21.00	0.82	1.22	1.01	—	2.52
ED (m/ha)	1.24	4.46	11.70	14.25	2.04	1.94	18.39	5.10	9.42	8.57	—	2.82
LSI	6.23	8.12	16.69	14.31	5.82	8.75	15.03	11.01	14.52	14.35	—	6.46
PLADJ (%)	86.97	95.09	90.45	95.35	93.15	86.59	95.20	91.97	90.91	92.17	—	94.97
IJI (%)	52.00	63.63	52.07	72.42	56.73	53.75	59.84	55.21	57.35	65.51	—	56.65
COHESION (%)	92.69	98.35	96.66	98.73	96.83	96.69	99.56	97.52	96.70	97.57	—	98.77
AI (%)	88.83	95.67	90.97	95.66	94.26	87.94	95.51	92.64	91.48	92.67	—	95.71

	Composite Classes											
	PIPO OFSS 1016		LAOC SI 1110		LAOC SEOC 1111		LAOC SECC 1112		LAOC UR 1113		LAOC YFMS 1114	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	245.9	12.61	37.98	14.94	139.3	62.87	29.52	16.62	55.69	19.88	137.6
PLAND (%)	—	4.25	0.83	0.33	0.41	8.42	0.87	0.09	1.09	0.64	0.96	2.77
NP (no.)	—	6	19	3	8	21	4	1	19	4	14	7
PD (no. / 100 ha)	—	0.02	0.07	0.01	0.03	0.06	0.01	0	0.07	0.01	0.05	0.02
LPI (%)	—	1.35	0.17	0.20	0.15	2.08	0.41	0.09	0.14	0.47	0.30	1.01
ED (m/ha)	—	2.63	1.29	0.37	0.79	5.81	1.17	0.15	1.88	0.62	1.69	1.85
LSI	—	6.24	6.16	2.99	5.26	9.78	5.33	2.41	7.79	3.73	7.60	5.27
PLADJ (%)	—	95.11	87.96	91.51	85.54	94.57	89.89	86.43	86.79	92.46	86.24	94.91
IJI (%)	—	61.46	65.08	51.54	54.67	80.90	65.68	25.76	74.37	59.75	68.12	62.46
COHESION (%)	—	98.43	92.43	95.54	92.98	98.27	96.90	94.63	93.37	97.08	94.63	98.10
AI (%)	—	95.86	89.72	94.19	87.96	95.10	91.63	91.60	88.29	94.37	87.83	95.84

	Composite Classes											
	LAOC OFMS 1115		LAOC OFSS 1116		PICO SI 1210		PICO SEOC 1211		PICO SECC 1212		PICO UR 1213	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	—	—	49.28	6.21	19.50	—	18.43	—	40.56	10.98	15.62
PLAND (%)	—	—	—	0.28	0.02	0.17	—	0.42	—	0.35	0.11	0.22
NP (no.)	—	—	—	2	1	3	—	8	—	3	3	5
PD (no. / 100 ha)	—	—	—	0.01	0	0.01	—	0.02	—	0.01	0.01	0.01
LPI (%)	—	—	—	0.20	0.02	0.08	—	0.09	—	0.20	0.07	0.10
ED (m/ha)	—	—	—	0.43	0.05	0.28	—	0.64	—	0.69	0.22	0.38
LSI	—	—	—	3.72	1.29	3.14	—	4.63	—	5.45	2.67	3.71
PLADJ (%)	—	—	—	88.63	84.06	87.69	—	88.55	—	85.10	85.79	87.38
IJI (%)	—	—	—	58.65	27.32	49.78	—	58.18	—	54.29	47.04	57.24
COHESION (%)	—	—	—	95.73	88.12	93.91	—	93.29	—	95.99	92.12	95.99
AI (%)	—	—	—	91.43	95.87	91.27	—	90.80	—	87.49	90.62	87.49

	Composite Classes											
	PICO YFMS 1214		PSME SI 1310		PSME SEOC 1311		PSME SECC 1312		PSME UR 1313		PSME YFMS 1314	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	10.80	76.05	12.32	41.73	18.51	54.50	40.56	98.25	46.72	51.05	63.94	57.61
PLAND (%)	0.11	1.53	1.06	1.32	1.28	2.98	2.94	0.85	7.09	3.23	7.93	5.14
NP (no.)	3	7	25	11	20	19	21	3	44	22	36	31
PD (no. / 100 ha)	0.01	0.02	0.09	0.03	0.07	0.05	0.07	0.01	0.15	0.06	0.12	0.09
LPI (%)	0.05	1.10	0.14	0.37	0.21	0.55	0.49	0.47	0.86	0.84	3.39	1.27
ED (m/ha)	0.20	1.21	2.11	1.64	2.19	2.88	3.99	1.09	9.07	3.33	7.89	5.62
LSI	2.76	4.53	8.70	7.06	8.26	8.62	10.03	5.50	14.84	9.11	12.33	11.75
PLADJ (%)	85.42	94.10	85.13	90.10	87.06	91.95	89.67	90.34	90.16	91.83	92.29	91.65
IJI (%)	54.69	67.96	65.24	62.26	66.39	76.31	66.30	58.56	74.71	69.22	73.33	67.86
COHESION (%)	91.01	97.82	92.37	95.98	93.79	96.73	96.20	97.67	96.90	96.90	97.90	97.06
AI (%)	90.18	95.34	86.61	91.38	88.44	92.81	90.60	91.95	90.76	92.66	92.87	92.31

	Composite Classes											
	PSME OFMS 1315		PSME OFSS 1316		ABGR/ABCO SI 1410		ABGR/ABCO SEOC 1411		ABGR/ABCO SECC 1412		ABGR/ABCO UR 1413	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	169.1	—	66.22	24.62	—	8.34	32.16	15.84	40.05	15.37	66.15
PLAND (%)	—	1.46	—	0.76	0.17	—	0.17	0.56	0.06	0.23	0.64	0.19
NP (no.)	—	3	—	4	2	—	6	6	3	2	12	1
PD (no. / 100 ha)	—	0.01	—	0.01	0.01	—	0.02	0.02	0.01	0.01	0.04	0
LPI (%)	—	1.15	—	0.34	0.15	—	0.06	0.15	0.10	0.15	0.12	0.19
ED (m/ha)	—	1.42	—	1.39	0.30	—	0.35	0.69	0.29	0.24	1.14	0.46
LSI	—	5.50	—	7.39	3.09	—	3.73	4.43	3.04	2.33	6.08	4.82
PLADJ (%)	—	92.64	—	86.31	86.75	—	83.90	90.39	86.74	92.13	86.51	81.97
IJI (%)	—	69.96	—	52.35	42.84	—	34.36	54.49	57.28	21.10	71.12	37.38
COHESION (%)	—	98.24	—	97.01	95.22	—	91.07	94.98	92.93	95.56	93.19	96.47
AI (%)	—	93.89	—	87.93	90.64	—	87.69	92.40	90.69	95.35	88.47	85.16

	Composite Classes											
	ABGR/ABCO YFMS		ABGR/ABCO OFMS		ABGR/ABCO OFSS		ABAM SEOC		ABAM SECC		ABAM UR	
	1414		1415		1416		1511		1512		1513	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	9.29	63.05	—	—	—	38.70	5.94	—	74.34	—	256.9	—
PLAND (%)	0.16	1.81	—	—	—	0.22	0.02	—	0.26	—	4.43	—
NP (no.)	5	10	—	—	—	2	1	—	1	—	5	—
PD (no. / 100 ha)	0.02	0.03	—	—	—	0.01	0	—	0	—	0.02	—
LPI (%)	0.06	0.71	—	—	—	0.14	0.02	—	0.26	—	3.82	—
ED (m/ha)	0.34	2.07	—	—	—	0.45	0.06	—	0.23	—	3.57	—
LSI	3.78	7.24	—	—	—	4.56	1.59	—	1.88	—	7.43	—
PLADJ (%)	83.14	91.31	—	—	—	84.36	79.55	—	93.40	—	93.78	—
IJI (%)	52.98	69.41	—	—	—	43.21	0	—	31.43	—	66.88	—
COHESION (%)	90.51	96.79	—	—	—	95.51	87.85	—	96.69	—	99.08	—
AI (%)	87.02	92.42	—	—	—	87.36	91.30	—	96.80	—	94.57	—

	Composite Classes											
	ABAM YFMS		ABLA2/PIEN SI		ABLA2/PIEN SEOC		ABLA2/PIEN SECC		ABLA2/PIEN UR		ABLA2/PIEN YFMS	
	1514		1610		1611		1612		1613		1614	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	30.06	—	10.23	—	19.55	28.44	120.7	—	51.02	9.45	8.09	49.63
PLAND (%)	0.52	—	0.11	—	1.28	0.25	1.25	—	3.34	0.19	0.25	0.71
NP (no.)	5	—	3	—	19	3	3	—	19	7	9	5
PD (no. / 100 ha)	0.02	—	0.01	—	0.07	0.01	0.01	—	0.07	0.02	0.03	0.01
LPI (%)	0.31	—	0.04	—	0.40	0.13	1.09	—	1.78	0.06	0.06	0.39
ED (m/ha)	0.67	—	0.24	—	2.09	0.26	1.15	—	3.01	0.41	0.51	0.90
LSI	3.93	—	3.19	—	8.40	2.55	4.46	—	7.62	4.49	4.58	5.14
PLADJ (%)	90.36	—	82.70	—	86.88	91.67	92.95	—	92.64	83.20	83.87	90.12
IJI (%)	53.92	—	51.51	—	63.37	54.27	51.68	—	76.91	54.85	52.77	61.39
COHESION (%)	95.47	—	90.87	—	95.55	94.83	98.04	—	97.65	92.00	90.89	96.31
AI (%)	92.63	—	87.44	—	88.26	94.77	94.45	—	93.55	86.43	86.93	91.88

	Composite Classes											
	TSME SI		TSME SEOC		TSME SECC		TSME UR		TSME YFMS		TSME OFMS	
	1810		1811		1812		1813		1814		1815	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	11.93	—	20.48	—	120.9	—	99.45	12.60	65.70	—	16.92
PLAND (%)	—	0.07	—	0.47	—	0.35	—	0.57	0.04	0.38	—	0.05
NP (no.)	—	2	—	8	—	1	—	2	1	2	—	1
PD (no. / 100 ha)	—	0.01	—	0.02	—	0	—	0.01	0	0.01	—	0
LPI (%)	—	0.05	—	0.28	—	0.35	—	0.31	0.04	0.36	—	0.05
ED (m/ha)	—	0.14	—	0.51	—	0.47	—	0.36	0.11	0.35	—	0.12
LSI	—	2.45	—	4.05	—	3.70	—	3.03	2.25	2.97	—	2.50
PLADJ (%)	—	84.72	—	90.44	—	89.81	—	93.48	80.71	92.16	—	81.38
IJI (%)	—	38.05	—	59.79	—	57.21	—	56.92	33.73	53.85	—	46.70
COHESION (%)	—	91.89	—	94.71	—	97.43	—	97.16	91.71	97.19	—	92.86
AI (%)	—	90.34	—	92.63	—	92.35	—	95.54	88.28	94.65	—	87.93

	Composite Classes											
	TSME OFSS		PIAL/LALY SI		PIAL/LALY UR		PILA/PIMO SEOC		ASP/CW/WIL SEOC		Rock NF	
	1816		1910		1913		2011		2111		2824	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	63.14	11.07	—	24.12	—	14.67	—	17.10	—	81.90	—
PLAND (%)	—	0.36	0.04	—	0.17	—	0.05	—	0.06	—	1.98	—
NP (no.)	—	2	1	—	2	—	1	—	1	—	7	—
PD (no. / 100 ha)	—	0.01	0	—	0.01	—	0	—	0	—	0.02	—
LPI (%)	—	0.31	0.04	—	0.12	—	0.05	—	0.06	—	0.83	—
ED (m/ha)	—	0.45	0.07	—	0.26	—	0.06	—	0.12	—	1.56	—
LSI	—	3.83	1.74	—	2.70	—	1.88	—	2.04	—	5.64	—
PLADJ (%)	—	89.77	83.74	—	88.15	—	84.97	—	85.00	—	92.91	—
IJI (%)	—	54.86	11.74	—	29.87	—	13.77	—	29.39	—	45.91	—
COHESION (%)	—	96.78	91.14	—	94.32	—	92.33	—	92.91	—	97.62	—
AI (%)	—	92.24	92.38	—	92.20	—	92.33	—	91.76	—	94.09	—

	Composite Classes											
	Water NF		BG/ Roadcut NF		Bare Ground NF		Cropland NF		Urban/ Rural NF		Pasture NF	
	2924		3424		3524		4324		4424		4524	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	1.85	—	—	10.17	27.02	—	15.98	—	30.75	—	50.69	—
PLAND (%)	0.31	—	—	0.03	0.37	—	0.11	—	0.32	—	0.70	—
NP (no.)	49	—	—	1	4	—	2	—	3	—	4	—
PD (no. / 100 ha)	0.17	—	—	0	0.01	—	0.01	—	0.01	—	0.01	—
LPI (%)	0.10	—	—	0.03	0.20	—	0.09	—	0.13	—	0.40	—
ED (m/ha)	1.82	—	—	0.08	0.49	—	0.18	—	0.57	—	0.52	—
LSI	13.77	—	—	2.05	3.97	—	2.24	—	4.39	—	2.66	—
PLADJ (%)	56.17	—	—	80.09	88.43	—	88.03	—	86.28	—	94.39	—
IJI (%)	31.54	—	—	35.15	44.96	—	40.91	—	39.72	—	46.90	—
COHESION (%)	90.38	—	—	90.74	95.08	—	92.90	—	94.71	—	96.43	—
AI (%)	58.02	—	—	88.73	91.08	—	93.01	—	89.06	—	96.42	—

	Composite Classes											
	Woodland NF		Non_Frst1_2 OH		Non_Frst1_2 CH		Non_Frst1_3 OH		Non_Frst2_2 OH		Non_Frst2_2CH	
	4724		4917		4918		5017		5217		5218	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	—	8.55	15.68	7.17	14.43	28.02	7.29	—	16.47	51.69	175.9	12.16
PLAND (%)	—	0.02	0.59	0.19	0.45	0.24	0.13	—	1.65	1.93	4.24	0.32
NP (no.)	—	1	11	9	9	3	5	—	29	13	7	9
PD (no. / 100 ha)	—	0	0.04	0.03	0.03	0.01	0.02	—	0.10	0.04	0.02	0.03
LPI (%)	—	0.02	0.28	0.05	0.16	0.13	0.04	—	0.24	0.46	1.66	0.13
ED (m/ha)	—	0.05	1.32	0.39	0.98	0.31	0.29	—	3.14	1.81	2.81	0.56
LSI	—	1.40	7.55	4.89	6.47	2.97	4.59	—	11.03	6.34	6.48	4.77
PLADJ (%)	—	85.26	82.68	81.59	82.95	90.15	76.79	—	84.83	92.66	94.46	86.27
IJI (%)	—	22.63	67.30	55.12	62.49	52.62	42.89	—	47.80	73.33	42.46	75.98
COHESION	—	89.88	94.54	89.55	94.25	94.76	89.07	—	94.20	96.61	98.39	92.16

(%)												
AI (%)	—	95.29	84.62	84.78	85.20	93.24	80.88	—	86.01	93.75	95.27	88.82

	Composite Classes											
	Non_Frst3_2 OH 5517		Non_Frst3_2 CH 5518		Non_Frst3_3 OH 5617		Non_Frst3_3 CH 5618		Non_Frst4_2 OLS 5820		Non_Frst5_3 OTS 6222	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	6.30	—	—	15.08	8.82	—	7.11	—	15.89	32.84	6.57	—
PLAND (%)	0.02	—	—	0.22	0.06	—	0.02	—	0.11	0.76	0.05	—
NP (no.)	1	—	—	5	2	—	1	—	2	8	2	—
PD (no. / 100 ha)	0	—	—	0.01	0.01	—	0	—	0.01	0.02	0.01	—
LPI (%)	0.02	—	—	0.08	0.03	—	0.02	—	0.09	0.33	0.04	—
ED (m/ha)	0.05	—	—	0.40	0.12	—	0.06	—	0.24	1.05	0.10	—
LSI	1.47	—	—	4.03	2.57	—	1.67	—	3.11	6.06	1.92	—
PLADJ (%)	82.14	—	—	86.04	81.63	—	81.01	—	83.29	88.69	83.56	—
IJI (%)	0	—	—	58.83	30.50	—	16.16	—	16.95	54.55	31.08	—
COHESION (%)	88.20	—	—	93.42	90.10	—	88.91	—	93.73	96.14	91.16	—
AI (%)	93.50	—	—	89.12	87.91	—	91.43	—	88.02	90.38	91.36	—

	Composite Classes									
	Non_Frst6_2 OTS 6422		Non_Frst6_2 CTS 6423		Non_Frst7_2 OTS 6622		Non_Frst7_2 CTS 6623		Non_Frst6_3 OTS 7022	
	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF	NRD	YTF
AREA_MN (ha)	16.11	34.33	—	72.42	—	3.78	3.96	69.48	14.36	—
PLAND (%)	0.11	2.08	—	1.67	—	0.01	0.01	0.20	0.10	—
NP (no.)	2	21	—	8	—	1	1	1	2	—
PD (no. / 100 ha)	0.01	0.06	—	0.02	—	0	0	0	0.01	—
LPI (%)	0.06	0.49	—	0.81	—	0.01	0.01	0.20	0.06	—
ED (m/ha)	0.16	2.37	—	1.30	—	0.03	0.08	0.39	0.15	—
LSI	2.03	8.27	—	5.02	—	1.38	2.64	3.98	2.25	—
PLADJ (%)	89.25	90.71	—	93.72	—	78.57	57.95	85.56	87.30	—
IJI (%)	29.92	71.12	—	54.91	—	8.87	6.17	0.73	34.27	—
COHESION (%)	92.71	96.14	—	97.18	—	84.71	85.07	96.56	92.36	—
AI (%)	94.25	91.74	—	94.91	—	92.96	68.92	88.78	92.52	—

5.5.2.4 Vegetation Mapping Unit Landscape Metrics

Landscape metrics quantified mean patch area was nearly two times larger and patch density nearly two times lower on the Yakama Tribal Forest (YTF) relative to the Naches Ranger District (NRD) for cover type, structural class, and composite class data (Table 13). Shape complexity and connectivity landscape metrics were similar between the NRD and YTF landscapes for cover, structure, and composite data. Interspersion was 17.3% greater for cover type data, but marginally greater for structure class and composite class data on the YTF relative to the NRD. Landscape metrics for diversity were similar on the NRD and YTF, but cover type demonstrated greater diversity on the NRD, while structural class and composite class diversity metrics were greater on the YTF.

Table 13 — Vegetation mapping unit landscape metric results for the sampled watersheds in the Naches Ranger District and Yakama Tribal Forest where patches were cover types, structure classes, or cover-structure composite classes. See Table 1 for metric descriptions.

VMUs Landscape Metrics	**Cover Type**		**Structural Class**		**Composite**	
	NRD	**YTF**	**NRD**	**YTF**	**NRD**	**YTF**
AREA_MN (ha)	96.39	152.39	57.34	104.34	43.90	81.18
NP (no.)	301	228	506	333	661	428
PD (no. / 100 ha)	1.04	0.66	1.74	0.96	2.28	1.23
LPI (%)	42.24	39.23	31.98	8.83	21.00	5.28
ED (m/ha)	33.45	29.15	46.58	39.64	52.26	43.10
LSI	16.05	15.54	21.64	20.43	24.06	22.04
CONTAG (%)	70.77	67.41	58.97	56.66	60.51	57.52
IJI (%)	52.94	64.01	68.32	72.33	65.51	71.12
COHESION (%)	99.24	99.38	98.94	98.49	98.33	97.83
AI (%)	95.17	95.72	93.11	94.19	92.68	94.04
SHDI	1.66	1.52	1.61	1.89	2.72	2.96
SIDI	0.69	0.65	0.72	0.79	0.87	0.91

5.6 Multivariate Statistical Analyses (R)

5.6.1 LANDFIRE Data

No combinations of ownership and watershed main or interaction effects explained a significant amount of variance in the Environmental Site Potential or Biophysical Settings LANDFIRE data for the Naches Ranger District and Yakama Tribal Forest select watersheds (Table 14).

Table 14 — PERMANOVA models from LANDFIRE Environmental Site Potential (ESP) and Biophysical Settings (BPS) data where ownership and watershed main and interaction factors are explanatory variables evaluated for significance at $\alpha = 0.05$, permutations = 999. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 LANDFIRE Factor	**DF**	**ESP SS**	**MS**	**F Stat**	**p-value**	**BPS SS**	**MS**	**F-Stat**	**p-value**
Ownership	1	0.308	0.3075	0.6267	0.992	0.301	0.3013	0.6111	0.999
Watershed	5	1.459	0.2919	0.5837	1	1.454	0.2908	0.5816	1
Ownership	1	0.308	0.3075	0.6151	0.993	0.301	0.3013	0.6026	1

+ Watershed	4	1.152	0.2879	0.5759	1	1.153	0.2882	0.5764	1
Ownership:Watershed	5	1.459	0.2919	0.5837	1	1.454	0.2908	0.5816	1

5.6.2 Vegetation mapping Unit Data

5.6.2.1 Cover

Ownership main effect explained the greatest amount of variance in the cover type data combined from the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) landscapes (Table 15). In descending levels, watershed, elevation, logging type, Biophysical Settings (BPS) class, and slope main effects also explained significant variance in the combined cover type data. Five interaction effects also explained significant variance in the combined cover type data, logging type observed in three (Table 15).

Table 15 — PERMANOVA model produced from combined Naches Ranger District and Yakama Tribal Forest vegetation mapping unit cover type data where ownership, watershed, elevation, logging type, Biophysical Settings (BPS) class, and slope main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05					
Total Cover					
Factor	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Ownership	1	6.15	6.1518	17.118	0.01
+ Watershed	4	23.21	5.8034	16.148	0.01
+ Elevation	29	50.17	1.7301	4.814	0.01
+ Logging type	4	5.08	1.2695	3.533	0.01
+ BPS class	18	8.39	0.4660	1.297	0.03
+ Slope	76	30.76	0.4047	1.126	0.03
+ Ownership : Logging type	4	2.73	0.6820	1.898	0.02
+ Ownership : BPS class	9	4.50	0.5005	1.393	0.04
+ Watershed : Elevation	88	35.89	0.4078	1.135	0.01
+ Watershed : Logging type	12	6.72	0.5601	1.559	0.01
+ Ownership : Elevation : Logging type	91	35.46	0.3896	1.084	0.04
Residuals	1024	368.0	0.3594		

The NRD cover type data quantified watershed main factor explained the greatest amount of variance, followed by Environmental Site Potential (ESP) class then logging type (Table 16). Elevation and BPS class main effects also explained significant variance in the NRD cover type data. The only significant interaction effect observed for the NRD cover type model was the Watershed-ESP class factor.

Table 16 — PERMANOVA model produced from Naches Ranger District (NRD) vegetation mapping unit cover type data where watershed, Environmental Site Potential (ESP) class, logging type, and Biophysical Settings (BPS) class main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **NRD Cover** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Watershed	2	18.63	9.3169	27.069	0.01
+ ESP class	11	22.12	2.0113	5.844	0.01
+ Logging type	4	6.51	1.6282	4.731	0.01
+ Elevation	29	22.4	0.7724	2.244	0.01
+ BPS class	15	7.08	0.4717	1.371	0.01
+ Watershed : ESP class	9	5.66	0.6288	1.827	0.01
Residuals	782	269.2	0.3442		

Watershed main effect explained the greatest amount of variance in the cover type data from the YTF, followed by logging type (Table 17). Elevation and slope were the two final main effects that explained significant variance in YTF cover type data. Watershed-logging type and watershed-elevation were the only two interaction effects to explain significant variance in the YTF cover type model.

Table 17 — PERMANOVA model produced from Yakama Tribal Forest (YTF) vegetation mapping unit cover type data where watershed, logging type, elevation, and slope main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **YTF Cover** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Watershed	2	4.58	2.2899	5.833	0.01
+ Logging type	4	3.449	0.8624	2.197	0.01
+ Elevation	22	16.55	0.7523	1.916	0.01
+ Slope	57	25.59	0.449	1.144	0.01
+ Watershed : Logging type	7	4.741	0.6773	1.725	0.01
+ Watershed : Elevation	25	11.33	0.4534	1.155	0.03
Residuals	390	153.1	0.3926		

5.6.2.2 Structure

Ownership main effect explained the greatest amount of variance in the structure class data combined from the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) landscapes (Table 18). Logging type and watershed main factors, respectively, explained the second and third greatest amounts of variance in the combined structure class data with Biophysical Settings (BPS) class then elevation being the two final significant main effects. Three interaction effects also explained significant variance in the combined structure class data, logging type observed in all three (Table 18).

Table 18 — PERMANOVA model produced from combined Naches Ranger District and Yakama Tribal Forest vegetation mapping unit structure class data where ownership, logging type, watershed, Biophysical Settings (BPS) class, and elevation main and interaction factors were significant ($\alpha = 0.05$, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **Total Structure** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Ownership	1	9.39	9.3861	23.329	0.01
+ Logging type	4	9.77	2.4426	6.071	0.01
+ Watershed	4	8.21	2.0518	5.099	0.01
+ BPS class	18	13.87	0.7705	1.915	0.01
+ Elevation	29	14.27	0.4922	1.223	0.02
+ Ownership : Logging type	4	6.11	1.5283	3.799	0.01
+ Logging type : Watershed	12	9.45	0.7872	1.957	0.01
+ Logging type : Watershed : BPS class	61	26.89	0.4408	1.096	0.05
Residuals	1227	493.7	0.4023		

PERMANOVA for NRD structure class data determined watershed explained the most variance of main factors, followed by logging type then BPS class (Appendix 14 Table 19). Watershed-logging type was the only interaction effect observed explaining significant variance in NRD structure class.

Table 19 — PERMANOVA model produced from Naches Ranger District (NRD) vegetation mapping unit structure class data where watershed, logging type, and Biophysical Settings (BPS) class main and interaction factors were significant ($\alpha = 0.05$, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 NRD Structure Factor	DF	SS	MS	F Stat	p-value
Watershed	2	3.86	1.9303	4.847	0.01
+ Logging type	4	8.65	2.1637	5.433	0.01
+ BPS class	17	12.73	0.7491	1.881	0.01
+ Watershed : Logging type	5	4.93	0.9865	2.477	0.01
Residuals	824	328.2	0.3983		

Watershed main factor explained the greatest amount of variance in YTF structure class data, trailed by logging type then BPS class (Appendix 14 Table 20). Watershed-logging type explained the most variance of significant interaction effects for YTF structure class, followed by watershed-BPS class. The watershed-logging type-BPS class three-way interaction factor also explained significant variance in YTF structure class data.

Table 20 — PERMANOVA model produced from Yakama Tribal Forest (YTF) vegetation mapping unit structure class data where watershed, logging type, and Biophysical Settings (BPS) class main and interaction factors were significant ($\alpha = 0.05$, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 YTF Structure Factor	DF	SS	MS	F Stat	p-value
Watershed	2	3.928	1.9639	4.759	0.01
+ Logging type	4	7.921	1.9804	4.799	0.01
+ BPS class	10	5.822	0.5822	1.411	0.01
+ Watershed : Logging type	7	4.245	0.6064	1.469	0.01
+ Watershed : BPS class	9	4.754	0.5283	1.280	0.02
+ Watershed : Logging type : BPS class	19	9.023	0.4749	1.151	0.05
Residuals	456	188.17	0.4127		

5.6.2.3 Cover Structure Composite

Cover type-structure class composite data from the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) landscapes identified ownership explained the greatest amount of variance in the combined data. In descending levels, watershed, logging type, Environmental Site

Potential (ESP) class, elevation, and Biophysical Settings (BPS) class main factors also explained significant variance in combined composite data (Table 21). Ownership-logging type explained the greatest amount of variance of the four significant interaction effects observed for composite data combined from the NRD and YTF landscapes.

Table 21 — PERMANOVA model produced from combined Naches Ranger District and Yakama Tribal Forest vegetation mapping unit cover type and structure class composite data where ownership, watershed, logging type, Environmental Site Potential (ESP) class, elevation, and Biophysical Settings (BPS) class main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **Total Composite** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Ownership	1	3.69	3.6923	8.191	0.01
+ Watershed	4	10.14	2.5354	5.625	0.01
+ Logging type	4	6.60	1.6488	3.658	0.01
+ ESP class	13	13.01	1.0006	2.219	0.01
+ Elevation	29	20.85	0.7191	1.595	0.01
+ BPS class	17	9.26	0.5445	1.208	0.02
+ Ownership : Logging type	4	4.35	1.0870	2.411	0.01
+ Ownership : ESP class	5	2.69	0.5381	1.194	0.04
+ Watershed : Logging type	12	8.87	0.7388	1.639	0.01
+ Watershed : ESP class	16	7.97	0.4979	1.105	0.04
Residuals	1255	565.7	0.4508		

Composite data from the NRD found watershed explained the most variance of main factors, followed by logging type then ESP class (Table 22). Elevation and BPS class were the final significant main effects for the NRD composite data model. Watershed-logging type and watershed-ESP class interaction factors also explained significant variance in composite data for the NRD.

Watershed main effect explained the greatest amount of variance in composite data for the YTF, followed by logging type (Table 23). BPS class and elevation main factors explained the third and fourth greatest amounts of variance, respectively, in YTF composite data. Logging type occurred in three of the four significant interaction effects observed in the YTF composite data PERMANOVA model.

Table 22 — PERMANOVA model produced from Naches Ranger District (NRD) composite vegetation mapping unit cover type and structure class data where watershed, logging type, Environmental Site Potential (ESP) class, elevation, and Biophysical Settings (BPS) class main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **NRD Composite** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Watershed	2	7.19	3.5935	8.107	0.01
+ Logging type	4	7.14	1.7850	4.027	0.01
+ ESP class	11	11.77	1.0698	2.414	0.01
+ Elevation	29	17.76	0.6123	1.381	0.01
+ BPS class	15	7.44	0.4959	1.119	0.03
+ Watershed : Logging type	5	4.43	0.8860	1.999	0.01
+ Watershed : ESP class	9	4.71	0.5232	1.181	0.03
Residuals	777	344.4	0.4432		

Table 23 — PERMANOVA model produced from Yakama Tribal Forest (YTF) composite vegetation mapping unit cover type and structure class data where watershed, logging type, Biophysical Settings (BPS) class, and elevation main and interaction factors were significant (α = 0.05, permutations = 99) explanatory variables. The '+' indicates subsequent terms in the additive model and the ':' indicates interaction terms.

PERMANOVA α = 0.05 **YTF Composite** **Factor**	**DF**	**SS**	**MS**	**F Stat**	**p-value**
Watershed	2	2.954	1.4773	3.236	0.01
+ Logging type	4	4.319	1.0798	2.365	0.01
+ BPS class	10	7.032	0.7032	1.540	0.01
+ Elevation	21	11.413	0.5435	1.190	0.01
+ Watershed : Logging type	7	4.461	0.6373	1.396	0.01
+ Watershed : BPS class	9	4.822	0.5357	1.173	0.01
+ Logging type : BPS class	14	7.223	0.5159	1.130	0.01
+ Logging type : Elevation	42	20.674	0.4923	1.078	0.04
Residuals	398	181.70	0.4565		

6. Discussion

The following subsections discuss environmental and management regime effects on landscape composition and spatial patterns, and ecological implications thereof, observed in the sampled watersheds. This project developed a framework to quantify existing environmental factors, treatments, and alternatives between ownerships on landscape vegetation composition and spatial patterns, in potentially similar areas. The case study approach facilitated the evaluation of selected factors on current landscape composition and patterns, but limited the scope of inference to the sampled sites and other watersheds that meet the similarity criteria outlined in the methodologies.

6.1 Photo-Interpretation Accuracy

Erroneous photo-interpretation of nearly half the samples in the Yakama Tribal Forest (YTF) could account for some absence of cover types thereon, otherwise observed on the Naches Ranger District (NRD). A portion of errors in the photo-interpreted forest cover type samples may be attributed to misclassification due to variations in cover type and timber type definitions used to assess accuracy (Appendices 2 and 5).

Overstory size class, the structural data component of the photo-interpretation assessment, was accurately recorded or erred within ± one overstory size class in 87.7% of samples. Some errors in the overstory size class photo-interpretation assessment, particularly the skew toward over-predicting size, could be the result of comparing plot and remote-sensed data collected in different years. Plot data overstory size class was recorded in 2005 while aerial photos used to detect overstory size class were collected in 2009, allowing time for growth and dieback and subsequent errors. Empirical data from the NRD would improve project validity through providing comparable photo-interpretation accuracy assessment across ownerships.

6.2 Trends in LANDFIRE Data

Elevation and riparian effects were evident in maps of Environmental Site Potential (ESP) and Biophysical Settings (BPS) for the Naches Ranger District (NRD) and Yakama Tribal Forest (Figure 2, 3). The clustered spatial patterned observed for ESP data on the NRD, and not the Yakama Tribal Forest (YTF), was due in part to vegetation communities organized along an east-west elevation gradient and the relatively larger alpine/subalpine component thereon. On the YTF, ESP data likely charted a dispersed spatial pattern due to a comparatively smaller alpine/subalpine extent and the prominent northeast-southwest riparian influence of the Klickitat River drainage through the central portion of the landscape.

LANDFIRE ESP and BPS data both model vegetation based on geography, biophysical characteristics, and succession stages, but BPS models include an approximation of historical disturbance regimes. A key difference between ESP and BPS data was the modeled vegetation response to integrated disturbance effects, foremost the presence and abundance of the steppe and grassland class and increased dry-mesic mixed-conifers abundance in BPS data. Consistent riparian and elevation effects coupled with disturbance regimes incorporated in BPS data continued the dispersed spatial pattern of LANDFIRE data on the YTF. On the NRD, vegetation response to disturbance regimes incorporated in BPS marked a shift from clustered ESP data to a random spatial pattern for BPS data. Fire effects increased richness, area, and interspersion of dry forest, shrubland, and grassland classes in BPS data. These potential landscape conditions created by fire in the selected watersheds decreased area of late-successional species and dense, closed canopy structures which spatially isolated high-intensity/ severity fires and decreased severe fire, insect, and disease vulnerability, following trends outlined in Agee (2003), Camp (1999), Edmonds et al. (2000), Harrod (1999), Hessburg and Agee (2003), and Hessburg et al. (2000, 2005, 2007).

Figures and metrics displayed and quantified greater vegetation community richness and diversity for BPS compared to ESP and greater potential vegetation community richness and diversity on the NRD relative to the YTF. While the larger alpine/subalpine component on the NRD accounted for a portion of greater potential vegetation richness and diversity observed thereon, both landscapes were predominantly composed of a few similar ESP and BPS classes homogeneous across ownerships. Mesic and dry-mesic mixed-conifers classes accounted for approximately three-quarters of the ESP and BPS data from the NRD and YTF landscapes, *Pinus ponderosa* woodland-savanna, montane riparian woodland/shrubland, and mesic-wet subalpine spruce-fir classes were principal in the remaining quarter. Minor BPS classes were more evenly distributed than ESP classes on both landscapes, but both ESP and BPS minor classes were more evenly distributed on the NRD than the YTF. Increased fire effects increased landscape diversity, creating a mosaic of conditions suitable to broad fish and wildlife habitat needs, resilient to climate change, and less vulnerable to severe insect, fire, and disease (Agee 2003, Hessburg and Agee 2003, Hessburg et al. 2005, 2007)

Multivariate statistical analyses quantified no significant effects of ownership or watershed on ESP or BPS composition data, i.e. similar potential vegetation communities based on comparable biophysical properties. Although differences in LANDFIRE class and landscape spatial patterns were observed between ownerships, effects of few, major ESP and BPS classes consistent across ownerships quantified potentially similar landscapes. Mesic and dry-mesic mixed-conifers classes dominated both landscapes and increased fire effects creating landscape conditions less vulnerable to severe fire, disease, and insect disturbances and (Hessburg et al. 2000, 2005). Potential vegetation demonstrated differences between ESP and BPS data, but fire effects were disproportionately necessary to maintain spatial patterns on the NRD, relative to the YTF. Given the multivariate statistic results, spatial statistic results remain important for interpreting trends in potential landscape composition and spatial patterns and comparisons to existing data.

6.3 Trends in Vegetation Mapping Unit Data

6.3.1 Cover Type

Elevation and riparian effects were apparent in the photo-derived cover type maps of the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) (Figure 4), though spatial statistic results were not uniform across ownerships or LANDFIRE data. Cover type landscape pattern was clustered on the NRD, consistent with Environmental Site Potential (ESP) results, while YTF cover type spatial autocorrelation differed from NRD cover, Biophysical Settings (BPS), and ESP results. High/low clusters analyses were uniform between ESP, BPS, and cover type data on the NRD, but identified low value cover type classes (i.e. shade-intolerant conifers) clustered on the YTF, again departed from NRD and potential vegetation data. These differences in spatial statistics between LANDFIRE potential vegetation and existing cover type data affirm significant ownership effects while maintaining intrinsic spatial autocorrelation effects. Management on the NRD has led to cover type conditions similar to potential landscape conditions absent of fire, increasing late-successional species and associated high-intensity/ severity fire, insect, and disease vulnerability (Camp 1999, Hessburg and Agee 2003, Hessburg et al. 2005).

Landscape spatial statistics imply management activities on the NRD have resulted in cover type patterns analogous to ESP condition, i.e. modeled climax vegetation communities in the absence of disturbance. Conversely, spatial statistics infer management activities on the YTF have altered cover type landscape patterns from corresponding ESP and BPS data and NRD cover type results, but identified similarities with NRD BPS pattern, i.e. modeled vegetation communities with an approximation of historical disturbance regimes. Spatial statistics showed YTF management led to increased shade-intolerant species, decreasing vulnerabilities outlined in Camp (1999), Hessburg and Agee (2003), Hessburg et al. (2005, 2007). Trends in ownerships and potential vegetation were observed between cover type spatial statistics, as well, spatial metrics were equally important to quantify trends in ownership and environmental factors.

The pattern observed in potential vegetation, i.e. landscapes predominantly composed of a few similar classes consistent across ownerships, was repeated in spatial metrics for photo-derived cover type data. Approximately half of each landscape classified as *Pinus ponderosa* cover types and coupled with *Pseudotsuga menziesii* cover, totaled more than 70% of their respective ownerships, distribution more uniform in NRD data. *Larix occidentalis,* non-forest 6_2: mountain shrub, *Abies grandis/Abies concolor*, and *Pinus contorta* were foremost minor cover types on the YTF and *Abies amabilis*, *Abies lasiocarpa/Picea engelmannii*, non-forest 2_2: annual grasses/seeded wheatgrasses/exotic forb, and *Larix occidentalis* on the NRD, distribution more uniform in NRD data. Spatial metrics recorded similar cover type composition between ownerships, but greater richness, evenness, and diversity were observed on the NRD compared to the YTF, a pattern consistent with ESP and BPS metrics.

Although spatial metrics for ESP and BPS data varied by ownerships and focal classes, trends in photo-derived cover type spatial metrics were more conspicuous and less dependent on focal cover class. Similarities between shape complexity, richness, evenness, and diversity of photo-derived cover types to ESP and BPS data were observed, but shifts in mean patch area, patch density, and interspersion trends support significant management regime effects. Management on the YTF expanded early seral forest cover types with high interspersion of shade-tolerant forest, shrublands, and grasslands, creating landscape conditions less vulnerable and more resilient to severe fire, insect, and disease events (Camp 1999, Hessburg et al. 2000, 2005).

Differences between NRD and YTF cover type landscape spatial autocorrelation statistics warranted separate multivariate analyses for ownerships, but ownership effects observed in LANDFIRE spatial statistics and metrics were anticipated and evaluated in cover type multivariate statistics. Multivariate statistical analyses quantified ownership the primary factor explaining variation in cover type data combined from the NRD and YTF landscapes. Watershed and elevation environmental factors accounted for the second and third most variation in combine cover type data followed by logging type, BPS class, and then slope. Ownership-logging type was the foremost interaction effect explaining significant variance in combined cover type data and separately ownership and logging type were in three of four subsequent interaction factors. Main and interaction factors explaining significant variations in cover type data combine from both landscapes confirmed management regime effects and maintained certain analogous environmental effects while others varied between ownerships.

Multivariate statistical analyses for individual ownerships detected watershed effect the primary factor explaining variation in cover type data on both landscapes. On the NRD, ESP class and logging type explained the second and third most variance followed by elevation and BPS class with watershed-ESP class the only observed interaction effect. Logging type and elevation explained the second and third most variance in cover type data on the YTF followed by slope then watershed-logging type and watershed-elevation interaction factors. Main and interaction factors for respective cover type data affirmed significant management regime effects quantified by greater logging type factors observed in the YTF model, while environmental effects varied by ownerships and more extensive factors were observed on the NRD.

Analyses summarized environmental and management effects on cover type were variable between ownerships. On the NRD, management has led to cover type conditions similar to potential landscape conditions absent of fire, increasing late-successional species and correlated vulnerability to severe fire, insect, and disease (Camp 1999, Hessburg and Agee 2003, Hessburg et al. 2005). Increased logging activity on the YTF expanded early seral forest cover types with high interspersion of shade-tolerant forest and shrubland and grassland cover types. YTF management created cover type landscape conditions less vulnerable and more resilient to severe fire, insect, and disease events demarcated in Camp (1999), Hessburg and Agee (2003), Hessburg et al. (2000, 2005, 2007).

6.3.2 Structure Class

Elevation and riparian effects remained evident in the photo-derived structure class maps of the Naches Ranger District (NRD) and Yakama Tribal Forest (YTF) (Figure 5), but spatial autocorrelation statistic results were uniform across ownerships and NRD Environmental Site Potential (ESP) data. Structure class registered clustered spatial autocorrelation patterns on both landscapes and while the same pattern was observed in ESP data on the NRD, YTF structure departed from corresponding LANDFIRE data, corroborating significant ownership effects and similarity in structure class across ownerships. High/low clusters analyses were consistent between ESP, BPS, and structure class data on the YTF, but identified high value structure classes (i.e. non-forest classes) clustered on the NRD. High-clusters departure observed between NRD structure class, potential vegetation, and YTF structure data maintain significant ownership effects and is primarily the result of alpine/subalpine features and development/land-use change in the wildland-urban interface. Clusters of non-forest structure classes on the NRD decrease vulnerability to severe fire, insect, and disease events, but effects remain localized because they are spatially isolated (Hessburg et al. 2005) and potentially ineffective in extreme events due to surrounding high-risk conditions.

Spatial statistics for NRD structures class resembled ESP data, while structure class spatial statistics on the YTF more closely resembled NRD structure class and ESP data than respective LANDFIRE data. The landscape spatial statistics imply management activities on the NRD have resulted in structure class patterns similar to ESP condition (i.e. modeled climax vegetation communities in the absence of disturbance), but altered non-forest spatial patterns. Conversely, spatial statistics infer management activities on the YTF have altered structure class landscape spatial patterns from corresponding ESP and BPS conditions, but identified similarities with NRD structure class and ESP patterns.

Structural classes on the NRD followed the trend observed in LANDFIRE and cover type data where two classes totaled approximately three-quarter of the landscape, understory reinitiation structure class comprised nearly half and young forest multi-strata almost twenty percent. Spatial metrics quantified greater structure class richness, evenness, and diversity on the YTF relative to the NRD, a considerable departure from potential vegetation and cover type results. Stem exclusion open canopy structure class composed nearly forty percent of the YTF, approximately twenty percent in young forest multi-strata, and another ten percent in understory reinitiation totaled nearly 70% of the YTF landscape. The absence of old forest structure classes observed on the NRD while nearly twelve percent of the YTF landscape classified as old forest structures, largely contributed to increased richness, evenness, and diversity observed in YTF structure class data. Greater landscape proportion in open and old forest structure classes suggests a landscape less susceptible and more resilient to severe insect, fire, and disease events (Agee 2003, Hessburg and Agee 2003, Hessburg et al. 2000, 2005).

Trends in spatial metric results for photo-derived structural class were noticeable like cover type results, but varied by ownerships and focal classes like ESP and BPS spatial metrics. Similarities in connectivity metrics between landscapes regardless of ownership or structure class remained consistent with LANDFIRE and cover data trends, opposite several other spatial metrics. Structure class data on the YTF displayed lower shape complexity and greater richness, evenness, and diversity compared to the NRD, contrasting metric results for ESP, BPS, and cover type data. Greater mean patch area, interspersion, and lower patch density observed for YTF structure class spatial metrics relative to NRD, were uniform with cover type and departed from ESP and BPS metrics. Discrepancies between ownerships and LANDFIRE potential vegetation data observed in spatial statistics and metrics substantiate a significant ownership effect on structure class spatial patterns.

Multivariate statistical analyses quantified ownership the principal factor explaining variation in structure class data combined from the NRD and YTF landscapes. Given identical spatial autocorrelation statistics, a significant ownership effect observed in structure class multivariate analyses is more likely a result of management activity than spatial location. Logging type then watershed effects explained second and third most variance in combined NRD and YTF structure class data followed by BPS class, elevation, ownership-logging type the foremost interaction effect, and logging type present in both subsequent interaction factors.

Ownership and environmental main effects were consistent across individual NRD and YTF structure class models, quantifying watershed the primary factor, logging type the secondary, and BPS the tertiary factor explaining variation in respective structure data. Watershed-logging type was the sole interaction effect in the NRD structure class model and leading in the YTF, but watershed-BPS class and watershed-logging type-BPS class interaction factors were additionally significant in the YTF model. Multivariate statistics for structure class data quantified a significant ownership effect albeit similar spatial autocorrelation, the consequence of more extensive logging type factors observed on the YTF than the NRD. Increased logging activity on the YTF, relative to the NRD, led to increased open and old forest structure classes, higher interspersion with closed forest and non-forest classes, and greater richness and diversity. Conditions observed on the YTF are nearer to landscape dynamics with lower risk of and higher resilience to severe disturbances described in Edmonds et al. (2000), Harrod et al. (1999), Hessburg and Agee (2003), and Hessburg et al. (2000, 2005, 2007).

6.3.3 Composite Class

The 77 individual composite classes produced from combining photo-derived cover type and structure class data exhibited greater richness, evenness, and diversity than LANDFIRE potential vegetation. Greater composite class richness observed on the Naches Ranger District (NRD) was a product of greater cover types observed thereon, although greater composite class evenness and diversity recorded on the Yakama Tribal Forest (YTF) were attributed to greater structure classes thereon. Spatial statistics for composite class quantified random spatial autocorrelation with low-clusters on the YTF and clustered spatial autocorrelation with random high-/low-clusters on the NRD, results uniform with cover type data trends. Similarities in connectivity metrics between ownerships and composite classes, greater patch density, and lower mean patch area and interspersion on the NRD relative to the YTF were consistent with cover type and structure data trends. Greater composite class evenness, diversity, and lower shape complexity observed for YTF metrics compared to NRD was uniform with structure data trends, although greater richness for NRD data relative to YTF matched cover type trends.

The spatial statistics and metrics validated composite class spatial patterns varied by landscapes as results of significant ownership and environmental effects. Composite class spatial patterns on the YTF departed from corresponding potential vegetation and NRD data, corroborating significant spatial autocorrelation and ownership effects. On the NRD, composite class spatial patterns resembled Environmental Site Potential (ESP) conditions, supporting fundamental environmental effects namely alpine/subalpine features and vegetation succession dynamics in absence of disturbances. Greater areas of early seral forest species and open and old forest structures, interspersion of late seral forest species, structures, and non-forest classes, and diversity demonstrate lower risk of and higher resilience to severe disturbance (Camp 1999, Harrod et al. 1999, Hessburg and Agee (2003), and Hessburg et al. 2000, 2005) on the YTF relative to the NRD. Spatial statistical analyses identified significant environmental and ownership effects on composite class spatial patterns, although multivariate statistics were equally enlightening to quantify and interpret trends in composite class data.

Similar to cover and structure models, multivariate statistics quantified ownership the leading factor explaining variation in composite class data combined from the NRD and YTF landscapes. Discrepancies in NRD and YTF composite class spatial autocorrelation statistics warranted separate multivariate analyses for ownerships, but ownership effects observed in LANDFIRE data and spatial metrics were expected in multivariate statistics. Similar to the cover type model, watershed accounted for second most variance in combined composite class data, but logging type explained third most variation indicative of increased effects observed in structure class models. ESP class, elevation, and then Biophysical Settings (BPS) class environmental effects included the final significant main factors in the composite class model for data combined across ownerships. Ownership-logging type was the foremost interaction effect explaining significant variance in combine composite class data and ownership and logging type factors separately were present in two of three subsequent interaction effects.

Multivariate statistical analyses for composite class data separated by ownerships identified watershed the primary factor and logging type the second factor explaining significant variance in both models. LANDFIRE features explained third most variance in respective composite class data, ESP in the NRD and BPS for the YTF, elevation the fourth main factor in each model, and BPS factor additionally significant in the NRD model. Watershed-logging type was the leading interaction effect for individual composite class models followed by watershed-ESP on the NRD and watershed-BPS on the YTF and two additional logging type interactions observed in the YTF model. Multivariate statistics for combined and individual composite class data maintained significant ownership and environmental effects observed in component cover type and structure class data.

Extensive logging type effects observed in YTF data and fundamental environmental effects observed in NRD data quantified existing composite class landscape composition and spatial patterns varied by individual ownerships. Trends observed between ESP, cover type, and structure class data for the NRD maintain environmental conditions like alpine/subalpine features and topography were primary effects for current composition and spatial patterns observed on that landscape. Conversely, trends observed between NRD data and cover type, structure class, and LANDFIRE data for the YTF affirm ownership and logging type were primary effects for existing composition and spatial patterns observed on the YTF landscape. Increased area of late seral forests species and dense, closed forest structures with open, early seral forest and non-forest composite classes isolated on the NRD, determined landscape conditions more at risk and less resilient to severe disturbances (Camp 1999, Edmonds et al. (2000), Hessburg et al. 2000, 2005) than the YTF.

6.4 Limitations

Data collection performed using remote sensing techniques is an important limitation of the research project. Errors between plot and photo-interpreted data for the Yakama Tribal Forest (YTF) were explicitly identified, but no post-assessment corrections were attempted. Naches Ranger District (NRD) photo-interpreted data did not have accompanying plot-level data, thus no photo-interpretation accuracy assessment is available for the NRD.

Statistical analyses to quantify differences in the data are another source of noteworthy limitations of the project. Keane and others (2011) determined the Sorenson's Index, the dissimilarity index used in project analyses, has utility in evaluating landscape differences, but a new set of statistics are needed for a more comprehensive analysis of departure. Fewer defining classes were a strong limitation on index performance found in Keane and others (2011) and individual cover type and structure class attributes totaled less than thirty and/or twenty classes in some analyses.

The selection process employed to determine study sites is an additional limitation of the research project. Sites were non-randomly selected on the NRD to focus dry forest restoration, YTF study sites were non-randomly selected based on similarity of potential vegetation and biophysical settings to NRD study sites. This case study technique facilitated the assessment of management and environmental factors on current landscape composition and spatial patterns, but limited the scope of inference to the sampled sites and other watersheds that meet the similarity criteria outlined in the methodologies.

Management regime effects, represented by ownership and logging type in analyses, are useful evaluations but are an additional limitation. While the YTF and NRD landscapes classify by distinct ownership, spatial autocorrelation explained a large portion of differences between landscapes, confounding the ownership effect. Logging type, an important forest management consideration and significant factor in project results, limited the analyses to mechanical treatments and did not consider variable responses to forest insect disturbances (i.e. insecticide application) or prescribed or wildland fire effects on spatial patterns.

7. Conclusion

Current forest spatial patterns and issues throughout the study area and surrounding region are the result of a robust environmental and anthropogenic history, which includes a rapid, dramatic, extensive, and permanent environmental change throughout the region. Environmental history of the research study area spans several hundred millennia and features disturbance events such as great floods, glaciation, climate change, volcanoes, fires, insects, and pathogens. Anthropogenic history of the research study area encompasses tens of millennia and partitions into two discrete categories defined by a dramatic chronology. The vast majority of human history and resource management in the study area applies to ancestral civilizations of the Yakama Nation and the remainder to Euro-American culture, initiating some two hundred years ago. Today, ecological conditions of landscapes are controlled by the spatial pattern and dynamics of individual owners and ecological interactions among those ownerships (Spies 2004).

Research and management continues to increase understating of ecological conditions and declining ecosystem health factors. Increasing efforts to mitigate declining health and enhance ecosystem restoration acknowledged the need for collaboration across ownerships. In 2007, cooperators formed the Tapash Sustainable Forest Collaborative in recognition of common goals on the landscape and working together to achieve more significant and durable outcomes than by working individually. The results from this research project are relevant to Tapash Sustainable Forest Collaborative and Anchor Forest Pilot Project undertakings and provide support to enhance implementation of respective planned treatment activities.

Project analyses identified several important results, particularly regarding collaborative forest management activities. Greater areas of open and old forest stand structures with dense multiple-story stands more interspersed on the Yakama Tribal Forest (YTF) compared to the Naches Ranger District (NRD) is a result of increased YTF logging activity. Forest cover types and potential vegetation are similar between ownerships, largely *Pinus ponderosa* and *Pseudotsuga menziesii*, but displayed greater diversity, richness, and patch density on the NRD than the YTF, primarily a result of environmental factors. As a result of increased logging activity, structure classes and composite cover-structure classes quantified greater diversity, mean patch area, interspersion, and greater structural richness on the YTF.

This project has shown increasing active management has the potential to enhance ecosystem restoration activities outlined in Tapash Sustainable Forest Collaborative documents. Analyses also concluded increasing logging activity to sustain and develop local industries and economies dependent on sustainable forest resources. This research project identified the value the YTF offers as an operational framework to implement planned treatment activities and promote development, planning, and implementation of future harvesting activity throughout the Tapash Sustainable Forest Collaborative project area. Collaborative forest management networks like the Anchor Forest Pilot Project and Tapash Sustainable Forest Collaborative should review these results to determine applicability and identify opportunities for treatment implementation and sustained collaboration.

8. Implications

The first recommendation is increasing active management to enhance ecosystem restoration activities outlined in Tapash Sustainable Forest Collaborative literature. Greater areas of open forest and old forest stands with dense multiple-story stands more interspersed on the Yakama Tribal Forest (YTF) than the Naches Ranger District (NRD) are the results of increased, well-designed silvicultural activities. The results identified the valuable partnership the YTF offers as an operational framework to implement planned treatment activities within the Tapash Collaborative Forest Landscape Restoration Program (CFLRP) proposal area. Yakama Nation infrastructure and human resource capacity position them to implement mechanical treatments within the Tapash CFLRP proposed areas. The Yakama Nation is also a favorable partner for the Forest Service because opportunities for stewardship contracts pursued through the Tribal Forest Protection Act (2004) may streamline treatment implementation.

The second recommendation is increasing logging activity to sustain and develop local industries and economies dependent on sustainable forest resources. The YTF is a demonstration of adaptive forest management backed by longstanding stewardship utilization values that support multiple industrial and cultural uses. Recent and current harvesting intensities observed on the YTF supply tribal sawmill operations, but in achieving stewardship utilization, long-term sustainable timber supply cannot be restricted to reservation boundaries. Increasing active silvicultural operations provides opportunities to accomplish Tapash CFLRP proposed treatments and sustain tribal sawmill operations while creating and maintaining jobs in forestry and timber mill industries. Results and recommendations suggest Tapash Sustainable Forest Collaborative and Anchor Forest Pilot Project coordinate to improve development, planning, and implementation of harvesting activity.

The third recommendations are to expand research by including consistent empirical data, more study sites, and data and analyses of specific hazards and departures from natural variation. Empirical data designed to uniformly collect data between ownerships and validate photo-interpretation is recommended to enhance current analyses and develop a framework for correlating photo-derived data to empirical data. Increasing study sites improves statistical power and increases the extent of inference, but may require automated photo-interpretation tools be used to complete additional sites across multiple ownerships on a large scale. Assembling more study sites across the landscape allows opportunities for collaboration between ownerships to progress or develop and issues to be recognized and resolved at local to regional scales.

Additional data and analyses are recommended to improve understanding of ownership effects, specific hazards, and departure of current conditions from historic natural variation within the sampled watersheds. Analyzing wildland and prescribed fire data and variable insect infestation response within the sampled sites will improve understanding of ownership effects on existing forest spatial patterns by quantifying non-mechanical treatment activities. Several computer programs are available that quantify specific forest hazards and effects and current conditions departure from historic natural variation conditions, using data similar to that used in this project analyses. Applying these analyses to existing data will quantify additional factors explaining variation in spatial patterns, advise treatment location and activities, and is the most transparent recommendation to implement.

The fifth and final recommendation is to integrate the framework developed from this project into the Tapash Sustainable Forest Collaborative and Anchor Forest Pilot Project. The data and framework from this project have potential to enhance these ongoing collaborative forest management networks through improved coordination in planning and implementation of treatment activities and standardizing data and monitoring protocols used to evaluate restoration effectiveness.

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Appendix 1: Photo Interpretation Key

Photo Interpretation Key
For each interpreted vegetation polygon, record the following data:
(Updated May 12, 2009)

A. Basin or subbasin. Options are:

1 = Deschutes (DES)	18 = Lemhi (LMH)	35 = Upper Middle Fork Salmon (UMS)
2 = Grande Ronde (GRO)	19 = Lochsa (LOC)	36 = Yaak (YAA)
3 = Methow (MET)	20 = Lost (LST)	37 = Bitterroot (BTR)
4 = Pend Oreille (PEN)	21 = Lower Flathead (LFH)	38 = North Fork Flathead (NFF)
5 = Wenatchee (WEN)	22 = Lower Henrys (LHE)	39 = Middle Fork Flathead (MFF)
~~6 = Yakima (YAK)~~	23 = Lower John Day (LJD)	40 = South Fork Flathead (SFF)
7 = Kettle (KET)	24 = Medicine Lodge (MDL)	41 = Stillwater (STW)
8 = San Poil (SPO)	25 = Palisades (PSD)	42 = Flathead Lake (FHL)
9 = Silvies (SIL)	26 = Palouse (PLS)	43 = Franklin D. Roosevelt (FDR)
10 = Big Wood (BWD)	27 = Snake Headwaters (SHW)	44 = Middle Columbia-Hood (MCH)
11 = Blackfoot Mtn. (BFM)	28 = South Fork Clearwater (SFC)	45 = Entiat (ENT)
12 = Boise-Mores (BOM)	29 = South Fork Salmon (SFS)	46 = Naches (NAC)
13 = Burnt (BUR)	30 = Swan (SWN)	47 = Lower Yakima (LYK)
14 = Crooked Rattlesnake (CRT)	31 = Upper John Day (UJD)	48 = Upper Yakima (UYK)
15 = Donner und Blitzen (DUB)	32 = Upper Klamath Lake (UKL)	
16 = Flint Rock (FLR)	33 = Upper Owyhee (UOW)	
17 = Lake Walcott (LWC)	34 = Upper Coeur d' Alene (UCD)	

B. Subwatershed and Overlay Numbers. Record the sample subwatershed number and that of the mylar overlay.

C. Polygon Number. Number vegetation polygons in a continuous series for each subwatershed. Record the number of the polygon in column C, in the center of the polygon on the resource aerial photos, and in the center of the polygon on the mylar overlay of the orthophoto.

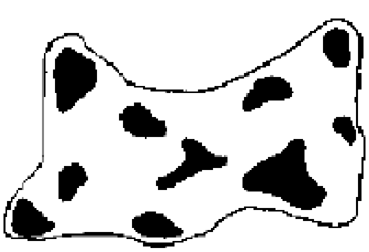
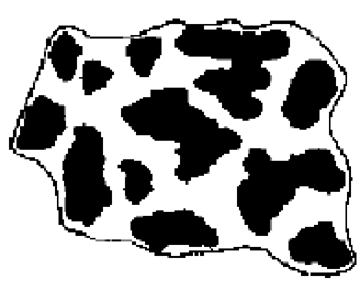
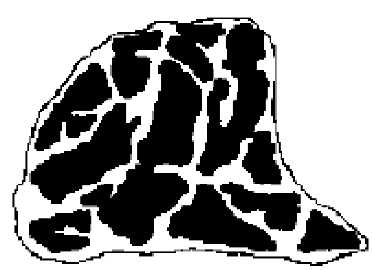
D. Photo Number. Record the photo number for each polygon. List the photo series number only when it changes.

D_2. Line Number. Record the flight line number (BLM photos only) to enable future identification of photos.

E. Total Crown Closure-Forest types -- and – F. Overstory Crown Closure-Forest types.

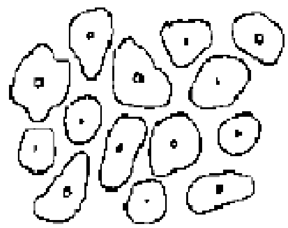
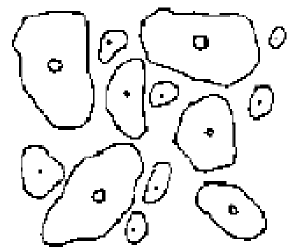
Estimate TCC and OCC (trees only) to the nearest 10% for each forested polygon. A new polygon is drawn according to total crown closure alone when two adjacent polygons are similar for all attributes, but the difference in average total crown closure for the two polygons is > 20%.

G. Clumpiness. Is tree cover naturally clumpy? Options: 1 = yes, 2 = no. If yes, clumps are:

Widely scattered = 1	Moderately Dense = 2	Dense = 3
		

Average clump size is: 1 = small (< 1 ac); 2 = medium (1-5 ac); 3 = large (> 5 ac and < 10 ac).

H. Crown Differentiation. Estimate the degree of differentiation among overstory tree crowns.

Overstory Crown Differentiation Options		
Low = 1 (< 30% difference)	**Moderate = 2 (30 to 100% difference)**	**High = 3 (> 100% difference)**
		

I. Canopy Layers-Forest Types.

Options:
1. single canopy layer;
2. two canopy layers;
3. more than two canopy layers visible.

J. Riparian or Wetlands. Indicate whether a forest or nonforest polygon occurs in a riparian or wetland area.

Options:
Riparian or wetland: 1 = yes
2 = no

K. Nonforest Type.

Options:
30 = rock (all)
31 = water (lake, pond)
32 = wet meadow, marsh (year-round saturated soils)[1]
33 = alpine meadow
34 = dry meadow (only seasonally saturated soils)[1]
35 = grass/forb (after logging)
36 = shrubland (with at least 5% canopy cover)[1,2]
37 = bare ground (burned or logged)
38 = bare ground (slumps, erosion)
39 = agriculture cropland
40 = urban/rural
41 = pasture (irrigated grasses/forbs)
42 = grassland (with at least 20% canopy cover)[1,2]
43 = woodland (< 10% total tree cover and at least 2 trees/acre)[1]
(used for DES, GRO, MET, PEN, WEN, YAK, KET, SPO, SIL basins only;)
(option 43 is not used for basins 10-36 listed under column A)
44 = bare ground (road-cuts or side-cast adjacent to state or interstate highways)
45 = Stream channel and non-vegetated floodplains
46 = grass/forb (after wildfire)
47 = sand dune
48 = glacier
49 = bare ground (dry lake beds, playa, etc)

Notes: Nonforest types have < 10% total tree crown closure.
Columns J, K, L, S, and T are completed for all nonforested types on the polygon data entry form.

[1] If option 32, 33, 34, 36, 42, or 43 is selected, additional data entry may be required in columns U and V.
[2] If option 36 or 42 is selected, additional data entry may be required in column W.

L. Logging Entry.	Visible logging entry is interpreted. Past logging entry options: 1 = no logging apparent 2 = regenerated (clearcut, shelterwood, seedtree harvests) 3 = selectively harvested (selective harvest, overstory removal, final removal) 4 = thinned (commercial, precommercial) 5 = patch clearcut (see note below*)
*Estimate the percentage of the polygon area in clearcut patches to the nearest 10%; clearcut patches are < 10 ac.	

M / N. Tree Density. Overstory trees/ac and understory trees/ac are given from reliable data sources (e.g., TSE, stocking surveys, inventory plots, MSS, NSS) where available; data sources are recorded and provided with the vegetation polygon data entry forms. Where no data are available, enter a dash "-" or a value of –99 if numeric field, do not enter an estimate.

O / P. Size Classes.

Overstory (O) and understory (P) size classes are estimated. If there is more than one understory layer, record the size class of the understory with the dominant crown closure.

options:	Size class
1 = seedlings and saplings	< 5.0" DBH
2 = poles	5 to 8.9" DBH
3 = small trees	9 to 15.9" DBH
4 = medium trees	16 to 25.0" DBH
5 = large trees	> 25.0" DBH

Q / R. Species-Forest Types. Recorded for forested polygons only. Polygons must have 10% or more total crown closure to be considered forested. All species that are 20% or more of total basal area must be recorded. (e.g. If the total polygon basal area is estimated at 90 sq ft., PSME and LAOC each contribute 36 sq. ft., and PIMO contributes 18 sq. ft., OS species would be coded 69, PSME/LAOC/PIMO.) New combinations may be added, and coded using new numbers. Convention requires assignment of codes in blocks of 10 to either the overstory or understory. Dominant OS is by BA/ac; dominant US is by trees/ac. All columns but K, T, U, V, and W are completed for forested types on the polygon data entry form.

OS species options:

1 = PIPO	ponderosa pine
2 = LAOC	western larch
3 = PICO	lodgepole pine
4 = PSME	Douglas-fir
5 = ABGR/ABCO	grand fir/white fir
6 = ABAM	Pacific silver fir
7 = ABLA2/PIEN	subalpine fir/Engelmann spruce
8 = TSHE/THPL	western hemlock/western redcedar
9 = TSME	mountain hemlock
10 = PIAL/LALY	whitebark pine/subalpine larch
11 = PIMO/PILA	western white pine/sugar pine
12 = Hardwood	e.g., maple, birch, poplar (OR/WA only)
13 = Juniper	e.g., JUOC, JUSC
14 = ABPR	noble fir
15 = ABMA	Shasta red fir
16 = PIPO/PIMO/PILA	ponderosa pine/western white pine/sugar pine
17 = PIPO/PSME	ponderosa pine/Douglas-fir
18 = PSME/TSME	Douglas-fir/mountain hemlock
19 = PICO/PIEN	lodgepole pine/Engelmann spruce
50 = TSME/ABCO	mountain hemlock/white fir
51 = PSME/PIEN	Douglas-fir/Engelmann spruce
52 = CADE	incense cedar
53 = LAOC/PICO	western larch/lodgepole pine
54 = PSME/LAOC	Douglas-fir/western larch
55 = PIFL	limber pine
56 = PIPU	blue spruce
57 = PIED	pinyon pine
58 = PIGL	white spruce
59 = Maple	maple
60 = Birch	birch
61 = Aspen	aspen
62 = Cottonwood	cottonwood
63 = PSME/PIFL	Douglas-fir/limber pine
64 = PIED/JUSC OR PIED/JUOC	pinyon pine/juniper
65 = PSME/PIMO	Douglas-fir/western white pine
66 = ABGR/PIMO	grand fir/western white pine
67 = ABLA2/PIMO	subalpine fir/western white pine
68 = LAOC/PIMO	western larch/western white pine
69 = LAOC/PICO/PIMO	western larch/lodgepole pine/western white pine
70 = LAOC/PIPO	western larch/ponderosa pine
71 = LAOC/PIEN	western larch/Engelmann spruce
72 = PICO/ABLA2	lodgepole pine/subalpine fir
73 = PICO/PSME	lodgepole pine/Douglas-fir
74 = PICO/ABGR	lodgepole pine/grand fir
75 = PSME/ABGR	Douglas-fir/grand fir
76 = ABLA2/PIFL	subalpine fir/limber pine
77 = ABGR/PIEN	grand fir/Engelmann spruce
78 = PSME/ASPEN	Douglas-fir/Aspen
79 = PICO/ASPEN	lodgepole pine/aspen
90 = ABLA2/PSME	subalpine fir/Douglas-fir
91 = ABGR/PIPO	grand fir/ponderosa pine
92 = ABGR/ABLA2	grand fir/subalpine fir
93 = ABGR/LAOC	grand fir/western larch
94 = Russian Olive	Russian Olive
95 = ABLA2/PIAL	subalpine fir/whitebark pine
96 = ABLA2/LALY	subalpine fir/subalpine larch
97 = ABLA2/LAOC	subalpine fir/western larch
98 = PIAL/PICO	whitebark pine/lodgepole pine

US species options:

20 = PIPO	ponderosa pine
21 = LAOC/PICO	western larch/lodgepole pine
22 = PSME/ABGR/ ABCO/ABAM	Douglas-fir/grand fir/white fir/Pacific silver fir
23 = TSHE/THPL	western hemlock/western redcedar
24 = TSME	mountain hemlock
25 = ABLA2/PIEN	subalpine fir/Engelmann spruce
~~26 = Hardwood~~	~~e.g., maple, birch, poplar (OR/WA only)~~
27 = Juniper	e.g., JUOC, JUSC
~~28 = grass/forb~~	~~grass/forb~~
~~29 = shrub~~	~~shrub~~
~~30 = bare ground~~	~~bare ground~~
31 = PICO	lodgepole pine
32 = PIPO/PICO	ponderosa pine/lodgepole pine
33 = PIPO/PSME	ponderosa pine/Douglas-fir
34 = ABGR/ABCO	grand fir/white fir
35 = ABLA2/PSME	subalpine fir/Douglas-fir
36 = TSME/PICO	mountain hemlock/lodgepole pine
37 = PSME/TSME	Douglas-fir/mountain hemlock
38 = PICO/PIEN	lodgepole pine/Engelmann spruce
39 = PIAL/LALY	whitebark pine/subalpine larch
40 = ABMA	Shasta red fir
41 = CADE	incense cedar
42 = PIMO	western white pine
43 = PSME/LAOC	Douglas-fir/western larch
44 = PSME/PIEN	Douglas-fir/Engelmann spruce
45 = PIFL	limber pine
46 = PIPU	blue spruce
47 = PIED	pinyon pine
48 = PIGL	white spruce
49 = PIEN/ABGR	Engelmann spruce/grand fir
80 = Maple	maple
81 = Birch	birch
82 = Aspen	aspen
83 = Cottonwood	cottonwood
84 = PSME/PIFL	Douglas-fir/limber pine
85 = PICO/PSME	lodgepole pine/Douglas-fir
~~86 = Xete~~	~~beargrass~~
87 = ABAM	Pacific silver fir
88 = PICO/ABLA2	lodgepole pine/subalpine fir
89 = ABLA2/PIAL	subalpine fir/whitebark pine
100 = PICO/ABGR	lodgepole pine/grand fir
101 = THPL/ABGR	western redcedar/grand fir
102 = ABLA2/PSME	subalpine fir/Douglas-fir
103 = PIAL/PICO	whitebark pine/lodgepole pine
104 = ABLA2/LALY	subalpine fir/subalpine larch
105 = PSME/ABGR	Douglas-fir/grand fir
106 = ABGR/ABLA2	grand fir/subalpine fir
107 = ABGR/PIEN	grand fir/Engelmann spruce

Notes: An overstory can exist without and understory. However, an understory cannot exist without an overstory. Recording an understory tree species implies more than one canopy layer (cnpy_lyrs > 1), and an overstory canopy closure less than total crown closure (OS_CC + US_CC = TOTL_CC). BA/ac = (TPA * DBH^2 * .005454)

S. Dead Trees / Snags.	Dead tree and snag abundance are estimated. <u>Dead tree/snag options:</u> 1 = none apparent 2 = < 10% of trees dead or snags 3 = 10 to 39% of trees dead or snags 4 = 40 to 70% of trees dead or snags 5 = > 70% of trees dead or snags

T. Elevation Belt-Nonforested Type.

	Options:
1 = colline	Below lower timberline
2 = lower montane	Adjacent forest vegetation where applicable with PIPO or PSME and below subalpine forest types, e.g., ABLA, PIEN, TSME, ABAM, and/or ABMA
3 = upper montane	Adjacent forest vegetation where applicable with ABLA, TSME, PIEN, ABAM, and/or ABMA and below continuous forest upper timberline.
4 = subalpine	Above upper timberline but with trees as islands or krummholz.
5 = alpine	Above upper timberline.

U. Nonforest Overstory Species.

<u>Options:</u>

1 = native bunchgrasses (wildrye, bluebunch wheatgrass, idaho fescue, alkali grass, bottlebrush squirreltail, others - *key distinguishing features: fine grain, random pattern*)

2 = annual grasses (cheatgrass, medusahead - *key distinguishing features: very fine grain, lighter tones*)

3 = seeded wheatgrasses (crested wheatgrass, other seeded dryland grasses - *key distinguishing features: fine grain uniform regular pattern*)

4 = exotic forbs (spotted knapweed, yellowstar thistle, leafy spurge, others - *key distinguishing features: fine grain darker tones, mottled or variegated appearance*)

5 = native moist site herbs (sedges, rushes, moist site grasses, forbs, others - *key distinguishing features: very fine grain, smooth texture, darker tones*)

6 = low sagebrush (black sage, low sage, salt desert shrub, others - *key distinguishing features: medium texture, random pattern, darker tones*)

7 = low shrub alpine (meadow heathers, others - *key distinguishing features: medium textures, darker tones*)

8 = big sagebrush/bitterbrush (basin big sage, Wyoming sage, mountain big sage, silver sage, bitterbrush, rabbitbrush, others - *key distinguishing features: coarse texture, darker tones, random pattern*)

9 = mahogany (mountain and curlleaf mahoganies - *key distinguishing features: coarse texture, darker tones, random pattern, tall stature*)

10 = mountain shrubs (serviceberry, rose, snowberry, mountain maple, Scouler's willow, buffaloberry, chokeberry, bittercherry, others - *key distinguishing features: coarse texture, darker tones, random pattern, tall stature*)

11 = wet site shrubs (willow, alder, bog birch, dogwood, others - *key distinguishing features: coarse texture, darker tones, dense cover, clumped pattern, medium to tall stature*)

12 = Beargrass <u>Xerophyllum tenax</u> (Xete)

13 = Herbaceous cover...combine codes: (#1) native bunchgrasses, (#2) annual grasses, and (#4) exotic forbs where they can't be distinguished. **ONLY USE THIS CODE ON HISTORICAL PHOTOGRAPHY AND ONLY AS A LAST RESORT.**

14 = Sagebrush/bitterbrush cover...combine codes (#6) low sagebrush and (#8) big sagebrush/bitterbrush where they can't be distinguished. **ONLY USE THIS CODE ON HISTORICAL PHOTOGRAPHY AND ONLY AS A LAST RESORT.**

V. Overstory Canopy Cover Nonforest Types. Estimate overstory canopy cover to the nearest 1/3 cover for each nonforested polygon. A new polygon is drawn according to overstory canopy cover alone when two adjacent polygons are similar for all attributes, but the difference in average overstory canopy cover for the two polygons is > 33%.

<u>Options:</u>
~~1 = less than 33% canopy cover.~~ **DON'T USE**
2 = 33 to 66% canopy cover
3 = more than 67% canopy cover
4 = 0 to 15% canopy cover
5 = 16 to 33% canopy cover

W. Tree Cover-Grassland or Shrubland Types. When option 36 (shrubland) or 42 (grassland) is selected in column K, nonforest type, indicate whether the shrubland or grassland polygon has tree cover present. Remember that nonforest types have < 10% total tree crown closure.

	Options:
Tree cover present?	1 = yes;
	2 = no.

Additional Caveats:

In the **overstory column** the following codes should be interpreted as follows:

5 = Abgr/Abco...This should be used to code either grand fir or white fire or the combination of both where the ranges come together.

7 = Abla/Pien...This should be used to code either subalpine fir or Englemann spruce or the combination of both.

8 = Tshe/Thpl...This should be used to code either western hemlock fir or western redcedar or the combination of both.

10 = Pial/Laly...This should be used code either whitebark pine or subalpine larch or the combination of both.

11 = Pimo/Pila...This should be used to code either western white pine or sugar pine or the combination of both where the ranges come together.

In the **understory column** the following codes should be interpreted as follows:

21 = Laoc/Pico...This should be used to code either western larch or combination of both western larch and lodgepole pine.

22 = Psme/Abgr/Abco/Abam...This should be used to code either any one of these species (singularly) or the combination of any of these species.

23 = Tshe/Thpl...This should be used to code either western hemlock fir or western redcedar or the combination of both.

25 = Abla/Pien...This should be used to code either subalpine fir or Englemann spruce or the combination of both.

Appendix 2: Generate Forest Cover Type Macro

```
# Name: R. Brion Salter                                    #
# USDA Forest Service, PNW Research Station                       #
# Date: 07/16/2009                                    #
# Last Revision: 07/16/2009                                    #
# Purpose: This script will derive SAF Cover Types from photo-interpreted data.#
#       Adapted from "gencover.aml"                              #
#***************************************************************************
*#
# Import system modules
import arcgisscripting, string, sys, os, time, traceback
# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
timestamp = time.clock()
try:
  gp.AddMessage("\nMonty Python Quote:\
  \nNOBODY expects the Spanish Inquisition!\n")
  # Local variables...
  gp.OverWriteOutput = 1
  inFC = gp.GetParameterAsText(0)
  # Generate a list of Fields in the Feature Class
  FieldListObj = gp.ListFields(inFC)
  FieldNameList = []
  for VegField in FieldListObj:
      FieldName = VegField.Name
      FieldNameList.append(FieldName)
  # Check for the existance of the 'COVER' and CT Fields and add if necessary
  FieldName = "COVER"
  if not FieldName in FieldNameList:
    gp.AddMessage('\tAdding the field "'+FieldName+'" to '+inFC)
    gp.AddField(inFC,FieldName,"TEXT","","","25")
  FieldName = "CT"
  if not FieldName in FieldNameList:
    gp.AddMessage('\tAdding the field "'+FieldName+'" to '+inFC)
    gp.AddField(inFC,FieldName,"SHORT")
  # Add temporary fields
  FieldName = "COUNTER"
  if not FieldName in FieldNameList:
    gp.AddMessage('\tAdding the field "'+FieldName+'" to '+inFC)
    gp.AddField(inFC,FieldName,"SHORT")
  # Create a Feature Layer from the input Feature Class
  if gp.Exists("inLayer"):
    gp.Delete_management("inLayer")
  gp.MakeFeatureLayer_management(inFC, "inLayer")
  # Clear the COVER, CT, and COUNT Fields
```

```
 gp.AddMessage("\tClearing the COVER, CT and COUNT fields\n")
 gp.SelectLayerByAttribute_management("inLayer","CLEAR_SELECTION")
 gp.CalculateField_management("inLayer","COVER","''")
 gp.CalculateField_management("inLayer","CT","0")
 gp.CalculateField_management("inLayer","COUNTER","0")
 # Define the Select and Calc function
 def Select_and_Calc(Query, Type, Code):
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",Query)
  CountSel = gp.GetCount_management("inLayer").GetOutput(0)
  gp.AddMessage("\t"+str(CountSel)+"\t("+str(Code)+")\t"+string.upper(Type))
  if int(CountSel) > 0:
   gp.CalculateField_management("inLayer","COVER","'"+Type+"'")
   gp.CalculateField_management("inLayer","CT",Code)
   CounterExpression = '[COUNTER] + 1'
   gp.CalculateField_management("inLayer","COUNTER",CounterExpression)
 # Print Report Header to StdOut
 gp.AddMessage("\tCount\t CT\tCOVER TYPE")
 gp.AddMessage("\t---------------------------------------------")
#******************************************************************************
*#
# Attribute Forest COVER based solely on SPP_OS                    #
#******************************************************************************
*#
 CovCall_OS = '("OS_CC" >= 30 OR ("OS_CC" < 30 AND "US_CC" <= 20))'
 CovCall_US = '"OS_CC" < 30 AND "US_CC" > 20'
 # PIPO
************************************************************************#
 CoverType = "pipo"
 CoverCode = "10"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (1,17)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (20,33)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # LAOC
************************************************************************#
 CoverType = "laoc"
 CoverCode = "11"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (2,53,68,69,70,71)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" = 21'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PICO
************************************************************************#
 CoverType = "pico"
 CoverCode = "12"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (3,19,74)'
```

```
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (31,32,38,100)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PSME
********************************************************************#
 CoverType = "psme"
 CoverCode = "13"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (4,54,65,73,75,78)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (22,41,43,85,105)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ABGR/ABCO
***************************************************************#
 CoverType = "abgr/abco"
 CoverCode = "14"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (5,66,77,91,92,93) OR \
 ("SPP_OS" = 52 AND "SPP_US" IN (22,44))'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (34,49,106,107)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ABAM
********************************************************************#
 CoverType = "abam"
 CoverCode = "15"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (6,14)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" = 87'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ABLA2/PIEN
**************************************************************#
 CoverType = "abla2/pien"
 CoverCode = "16"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (7,51,67,72,90,97)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (25,44,88,102)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # TSHE/THPL
**************************************************************#
 CoverType = "tshe/thpl"
 CoverCode = "17"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" = 8'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (23,101)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # TSME
********************************************************************#
```

```
 CoverType = "tsme"
 CoverCode = "18"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (9,18,50) OR \
 ("SPP_OS" = 52 AND "SPP_US" IN (24,35,36))'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (24,35,36,37)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PIAL/LALY
****************************************************************#
 CoverType = "pial/laly"
 CoverCode = "19"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (10,95,96,98)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (39,89,103,104)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PILA/PIMO
****************************************************************#
 CoverType = "pila/pimo"
 CoverCode = "20"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (11,16)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" = 42'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ASPEN/COTTONWOOD-WIL
*****************************************************#
 CoverType = "aspen/cottonwood-wil"
 CoverCode = "21"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (12,59,60,61,62,79)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (26,80,81,82,83)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # JUOC/JUSC
****************************************************************#
 CoverType = "juoc/jusc"
 CoverCode = "22"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" = 13'
 US_CoverQuery = CovCall_US+' AND "SPP_US" = 27'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ABMA
*********************************************************************#
 CoverType = "abma"
 CoverCode = "23"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" = 15'
 US_CoverQuery = CovCall_US+' AND "SPP_US" = 40'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
```

```
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PIFL
********************************************************************#
 CoverType = "pifl"
 CoverCode = "24"
 OS_CoverQuery = CovCall_OS+' AND "SPP_OS" IN (55,63,76)'
 US_CoverQuery = CovCall_US+' AND "SPP_US" IN (45,84)'
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PIED  *******************************************************************#


 # PIMO2/JUSC
**************************************************************#
 CoverType = "pimo2/jusc"
 CoverCode = "26"
 OS_CoverQuery = '"SPP_OS" IN (57,64)'
 US_CoverQuery = OS_CoverQuery
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # RUSSIAN OLIVE
***********************************************************#
 CoverType = "russian olive"
 CoverCode = "27"
 OS_CoverQuery = '"SPP_OS" = 94'
 US_CoverQuery = OS_CoverQuery
 CoverQuery = '('+OS_CoverQuery+') OR ('+US_CoverQuery+')'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
#***************************************************************************
*#
# The following is for classifying covertype where non_frst covertype          #
# classes use the codes from section K of the PI key.                          #
#***************************************************************************
*#

 # ROCK
********************************************************************#
 CoverType = "rock"
 CoverCode = "28"
 CoverQuery = '"NON_FRST" = 30 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # WATER
*******************************************************************#
 CoverType = "water"
 CoverCode = "29"
```

```
 CoverQuery = '"NON_FRST" = 31 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # WET MEADOW/MARSH
*****************************************************************#
 CoverType = "wet meadow/marsh"
 CoverCode = "30"
 CoverQuery = '"NON_FRST" = 32 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # ALPINE MEADOW
********************************************************************#
 CoverType = "alpine meadow"
 CoverCode = "31"
 CoverQuery = '"NON_FRST" = 33 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # DRY MEADOW/GRASSLAND
************************************************************#
 CoverType = "dry meadow/grassland"
 CoverCode = "32"
 CoverQuery = '"NON_FRST" = 34 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # SHRUBLAND
*************************************************************************#
 CoverType = "shrubland"
 CoverCode = "33"
 CoverQuery = '"NON_FRST" = 36 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # BG/ROADCUT
************************************************************************#
 CoverType = "bg/roadcut"
 CoverCode = "34"
 CoverQuery = '"NON_FRST" = 44 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # BARE GROUND
***********************************************************************#
 CoverType = "bare ground"
 CoverCode = "35"
 CoverQuery = '"NON_FRST" = 49 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
```

```
 # PL - BG/BURNED
*******************************************************************#
 CoverType = "pl - bg/burned"
 CoverCode = "36"
 CoverQuery = '"NON_FRST" = 37 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PL - BG/SLUMPS-EROSION
**********************************************************#
 CoverType = "pl - bg/slumps-erosion"
 CoverCode = "37"
 CoverQuery = '"NON_FRST" = 38 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PL - GRASS/FORB STAGE
************************************************************#
 CoverType = "pl - grass/forb stage"
 CoverCode = "38"
 CoverQuery = '"NON_FRST" = 35 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # STREAM/FLOODPLAIN
****************************************************************#
 CoverType = "stream/floodplain"
 CoverCode = "39"
 CoverQuery = '"NON_FRST" = 45 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PF - GRASS/FORB
******************************************************************#
 CoverType = "pf - grass/forb"
 CoverCode = "40"
 CoverQuery = '"NON_FRST" = 46 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # SAND DUNE
*************************************************************************#
 CoverType = "sand dune"
 CoverCode = "41"
 CoverQuery = '"NON_FRST" = 47 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # GLACIER
***************************************************************************#
 CoverType = "glacier"
 CoverCode = "42"
```

```
 CoverQuery = '"NON_FRST" = 48 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # CROPLAND
************************************************************************#
 CoverType = "cropland"
 CoverCode = "43"
 CoverQuery = '"NON_FRST" = 39 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # URBAN/RURAL
********************************************************************#
 CoverType = "urban/rural"
 CoverCode = "44"
 CoverQuery = '"NON_FRST" = 40 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # PASTURE
*************************************************************************#
 CoverType = "pasture"
 CoverCode = "45"
 CoverQuery = '"NON_FRST" = 41 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # GRASSLAND
***********************************************************************#
 CoverType = "grassland"
 CoverCode = "46"
 CoverQuery = '"NON_FRST" = 42 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # WOODLAND
************************************************************************#
 CoverType = "woodland"
 CoverCode = "47"
 CoverQuery = '"NON_FRST" = 43 AND "NON_FRST_SPP_OS" = 0 AND
"NON_FRST_TCC" = 0'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
#/***********************************************************************************
*#
#/* Non-forest cover type group classification                    #
#/***********************************************************************************
*#

 # NON_FRST1_1
********************************************************************#
```

```
 CoverType = "non_frst1_1"
 CoverCode = "48"
 CoverQuery = '"NON_FRST_SPP_OS" IN (1,13) AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST1_2
***************************************************************#
 CoverType = "non_frst1_2"
 CoverCode = "49"
 CoverQuery = '"NON_FRST_SPP_OS" IN (1,13) AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST1_3
***************************************************************#
 CoverType = "non_frst1_3"
 CoverCode = "50"
 CoverQuery = '"NON_FRST_SPP_OS" IN (1,13) AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST2_1
***************************************************************#
 CoverType = "non_frst2_1"
 CoverCode = "51"
 CoverQuery = '"NON_FRST_SPP_OS" IN (2,3,4) AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST2_2
***************************************************************#
 CoverType = "non_frst2_2"
 CoverCode = "52"
 CoverQuery = '"NON_FRST_SPP_OS" IN (2,3,4) AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST2_3
***************************************************************#
 CoverType = "non_frst2_3"
 CoverCode = "53"
 CoverQuery = '"NON_FRST_SPP_OS" IN (2,3,4) AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST3_1
***************************************************************#
 CoverType = "non_frst3_1"
 CoverCode = "54"
 CoverQuery = '"NON_FRST_SPP_OS" = 5 AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST3_2
***************************************************************#
 CoverType = "non_frst3_2"
 CoverCode = "55"
 CoverQuery = '"NON_FRST_SPP_OS" = 5 AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
```

```
 # NON_FRST3_3
***************************************************************#
 CoverType = "non_frst3_3"
 CoverCode = "56"
 CoverQuery = '"NON_FRST_SPP_OS" = 5 AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST4_1
***************************************************************#
 CoverType = "non_frst4_1"
 CoverCode = "57"
 CoverQuery = '"NON_FRST_SPP_OS" IN (6,8,14) AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST4_2
***************************************************************#
 CoverType = "non_frst4_2"
 CoverCode = "58"
 CoverQuery = '"NON_FRST_SPP_OS" IN (6,8,14) AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST4_3
***************************************************************#
 CoverType = "non_frst4_3"
 CoverCode = "59"
 CoverQuery = '("NON_FRST_SPP_OS" = 7 AND "ELEV_BELT" IN (3,4,5)) OR '\
 '"NON_FRST_SPP_OS" = 8 AND "ELEV_BELT" IN (4,5) '
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST5_1
***************************************************************#
 CoverType = "non_frst5_1"
 CoverCode = "60"
 CoverQuery = '"NON_FRST_SPP_OS" = 9 AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST5_2
***************************************************************#
 CoverType = "non_frst5_2"
 CoverCode = "61"
 CoverQuery = '"NON_FRST_SPP_OS" = 9 AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST5_3
***************************************************************#
 CoverType = "non_frst5_3"
 CoverCode = "62"
 CoverQuery = '"NON_FRST_SPP_OS" = 9 AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST6_1
***************************************************************#
 CoverType = "non_frst6_1"
```

```
 CoverCode = "63"
 CoverQuery = '"NON_FRST_SPP_OS" = 10 AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST6_2
*************************************************************#
 CoverType = "non_frst6_2"
 CoverCode = "64"
 CoverQuery = '"NON_FRST_SPP_OS" = 10 AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST6_3
*************************************************************#
 CoverType = "non_frst6_3"
 CoverCode = "70"
 CoverQuery = '"NON_FRST_SPP_OS" = 10 AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST1_1
*************************************************************#
 CoverType = "non_frst7_1"
 CoverCode = "65"
 CoverQuery = '"NON_FRST_SPP_OS" = 11 AND "ELEV_BELT" = 1'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST1_2
*************************************************************#
 CoverType = "non_frst7_2"
 CoverCode = "66"
 CoverQuery = '"NON_FRST_SPP_OS" = 11 AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST1_3
*************************************************************#
 CoverType = "non_frst7_3"
 CoverCode = "67"
 CoverQuery = '"NON_FRST_SPP_OS" = 11 AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST8_2
*************************************************************#
 CoverType = "non_frst8_2"
 CoverCode = "68"
 CoverQuery = '"NON_FRST_SPP_OS" = 12 AND "ELEV_BELT" IN (2,3)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
 # NON_FRST8_3
*************************************************************#
 CoverType = "non_frst8_3"
 CoverCode = "69"
 CoverQuery = '"NON_FRST_SPP_OS" = 12 AND "ELEV_BELT" IN (4,5)'
 Select_and_Calc(CoverQuery,CoverType,CoverCode)
```

```
#***************************************************************************#
  # Potential Classification Errors                                         #

#***************************************************************************#
  gp.AddMessage("\n")
  # Get the count of polygons where count = 0
  CountQuery = '"COUNTER" < 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CountQuery)
  ZeroCount = int(gp.GetCount_management("inLayer").GetOutput(0))
  ZeroWarning = str(ZeroCount)+" polygons remain unclassified."
  # Get the count of polygons where count > 1
  CountQuery = '"COUNTER" > 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CountQuery)
  MultiCount = int(gp.GetCount_management("inLayer").GetOutput(0))
  MultiWarning = str(MultiCount)+" polygons were classified by more than one rule."
  # Warn of potential erros if there are polygons with count <> 1
  if ZeroCount > 0 or MultiCount > 0:
    if ZeroCount > 0:
      gp.AddMessage("Error:\t"+ZeroWarning)
    if MultiCount > 0:
      gp.AddMessage("Warning:\t"+MultiWarning)
    gp.AddMessage("TEMPORARY FIELDS WILL NOT BE DELETED!!!")
  # Delete the temporary fields if potential errors are not flagged.
  else:
    gp.AddMessage("Deleting Temporary Fields...")
    DelFieldList = '"COUNTER"'
    gp.DeleteField_management(inFC,DelFieldList)
  gp.Delete_management("inLayer")
# ** PLAY A VICTORY TUNE
*******************************************************#
  gp.AddMessage("\n")
  file='ding.wav'##'tada.wav'
  from winsound import PlaySound, SND_FILENAME, SND_ASYNC
  audiocount = 2
  i = 0
  while i < audiocount:
    PlaySound(file, SND_FILENAME|SND_ASYNC)
    time.sleep(0.25)
    i = i + 1
#***************************************************************************
*#
except:
  # get the traceback object
  tb = sys.exc_info()[2]
  # tbinfo contains the line number that the code failed on and the code from that line
```

```
  tbinfo = traceback.format_tb(tb)[0]
  # concatenate information together concerning the error into a message string
  seperator = "***********************************************************************\
  *****************"
  pymsg = "PYTHON ERRORS:\nTraceback Info:\n" + tbinfo + "\nError Info:\n    " \
  + str(sys.exc_type)+ ": " + str(sys.exc_value)
  # generate a message string for any geoprocessing tool errors
  msgs = seperator + "\nGP ERRORS:\n" + gp.GetMessages(2)
  # return gp messages for use with a script tool
  gp.AddError(msgs)
  gp.AddError(pymsg)
  # print messages for use in Python/PythonWin
  gp.AddMessage(msgs)
##  print msgs
  gp.AddMessage(pymsg)
##  print pymsg
  gp.AddMessage("\nSCRIPT FAILED...")
  print "\nSCRIPT FAILED..."
  #Play wav file to let me know it has failed!
  file='Windows XP Error.wav'
  from winsound import PlaySound, SND_FILENAME, SND_ASYNC
  PlaySound(file, SND_FILENAME|SND_ASYNC)
```

Appendix 3: Generate Forest Structural Class Macro and Dichotomy Key

```
# Name: R. Brion Salter                                    #
# USDA Forest Service, PNW Research Station                #
# Date: 07/21/2009                                         #
# Last Revision: 07/21/2009                                #
# Purpose: This script will derive Structural Class from photo-interpreted     #
#       data, based on a dichotomized rule set.                       #
#       The dichotomy was produced by implimenting the intent of            #
#       Tables 5 and 6 of PNW-GTR-458 by tailoring the classification to    #
#       the ICBEMP midscale database structure.                       #
#       Following on the Latham et. al.                          #
#***************************************************************************
*#
# Import system modules
import arcgisscripting, string, sys, os, time, traceback
# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
timestamp = time.clock()
try:
  gp.AddMessage("\nMonty Python Quote:\tConfess! Confess! Confess!\n")
  # Local variables...
  inFC = gp.GetParameterAsText(0)
  # Generate a list of Fields in the Feature Class
  FieldListObj = gp.ListFields(inFC)
  FieldNameList = []
  for VegField in FieldListObj:
      FieldName = VegField.Name
      FieldNameList.append(FieldName)
  # Check for the "SERIES" field (needed for WOODLAND classification)
  # Check for the existance of the STRUCTURE and SS Fields and add if necessary
  TextFieldList = ["STRUCTURE","STRUCT_RULE"]
  for FieldName in TextFieldList:
    if not FieldName in FieldNameList:
      gp.AddMessage('\tAdding the field "'+FieldName+'" to '+inFC)
      gp.AddField(inFC,FieldName,"TEXT","","","10")
  # Add integer fields
  IntFieldList = ["SS","COUNTER","SS_CC","P_CC","S_CC","M_CC","L_CC",\
  "PSM_CC","LPSM_CC"]
  for FieldName in IntFieldList:
    if not FieldName in FieldNameList:
      gp.AddMessage('\tAdding the field "'+FieldName+'" to '+inFC)
      gp.AddField(inFC,FieldName,"SHORT")
  # Create a Feature Layer from the input Feature Class
  if gp.Exists("inLayer"):
    gp.Delete_management("inLayer")
```

```
  gp.MakeFeatureLayer_management(inFC, "inLayer")
  # Reset Values or remove "NULL"
  gp.AddMessage('\tInitializing the Field values.\n')
  for FieldName in TextFieldList:
    gp.CalculateField_management("inLayer",FieldName,"''")
  for FieldName in IntFieldList:
    gp.CalculateField_management("inLayer",FieldName,"0")
#**************************************************************************
*#
# Calculate Tree Size CC Fields                                  #
#**************************************************************************
*#

  # Seed/Sap Crown Cover
  FieldName = "SS_CC"
  CC_Query = '"SIZE_OS" = 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
  CC_Query = '"SIZE_US" = 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  Expression = '['+FieldName+']'+' + [US_CC]'
  gp.CalculateField_management("inLayer",FieldName,Expression)
  # Pole Crown Cover
  FieldName = "P_CC"
  CC_Query = '"SIZE_OS" = 2'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
  CC_Query = '"SIZE_US" = 2'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  Expression = '['+FieldName+']'+' + [US_CC]'
  gp.CalculateField_management("inLayer",FieldName,Expression)
  # Small Crown Cover
  FieldName = "S_CC"
  CC_Query = '"SIZE_OS" = 3'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
  CC_Query = '"SIZE_US" = 3'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  Expression = '['+FieldName+']'+' + [US_CC]'
  gp.CalculateField_management("inLayer",FieldName,Expression)
  # Medium Crown Cover
  FieldName = "M_CC"
  CC_Query = '"SIZE_OS" = 4'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
  gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
  CC_Query = '"SIZE_US" = 4'
```

```
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
Expression = '['+FieldName+']'+' + [US_CC]'
gp.CalculateField_management("inLayer",FieldName,Expression)
# Pole/Small/Medium Crown Cover
FieldName = "PSM_CC"
CC_Query = '"SIZE_OS" IN (2,3,4)'
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
CC_Query = '"SIZE_US" IN (2,3,4)'
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
Expression = '['+FieldName+']'+' + [US_CC]'
gp.CalculateField_management("inLayer",FieldName,Expression)
# Large Crown Cover
FieldName = "L_CC"
CC_Query = '"SIZE_OS" = 5'
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
# Pole/Small/Medium/Large Crown Cover
FieldName = "LPSM_CC"
CC_Query = '"SIZE_OS" IN (2,3,4,5)'
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
gp.CalculateField_management("inLayer",FieldName,'[OS_CC]')
CC_Query = '"SIZE_US" IN (2,3,4)'
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CC_Query)
Expression = '['+FieldName+']'+' + [US_CC]'
gp.CalculateField_management("inLayer",FieldName,Expression)
# Define the Select and Calc function
def Select_and_Calc(Query, Type, Code):
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",Query)
  CountSel = gp.GetCount_management("inLayer").GetOutput(0)
  if int(CountSel) > 0:
    gp.CalculateField_management("inLayer","STRUCTURE",'"'+Type+'"')
    gp.CalculateField_management("inLayer","SS",Code)
    CounterExpression = '[COUNTER] + 1'
    gp.CalculateField_management("inLayer","COUNTER",CounterExpression)
    RuleExpression = '[STRUCT_RULE]'+'&"'+Rule+'"'
    gp.CalculateField_management("inLayer","STRUCT_RULE",RuleExpression)
def Select_and_Report(Query, Type):
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",Query)
  CountSel = gp.GetCount_management("inLayer").GetOutput(0)
  gp.AddMessage("\t"+str(CountSel)+"\t"+string.upper(Type))
def PrintHeader():
  gp.AddMessage("\n\tCount\tSTRUCTURE CLASS")
  gp.AddMessage("\t-------------------------------------------")
#**************************************************************************
*#
```

```
# Classify Forest Structure                                    #
#****************************************************************************
*#
  gp.AddMessage("\tClassifying Forest Structure...\n")
  # C1 - Old Forest Multi-Story **********************************************#
  Rule = "C1"
  StructClass = "ofms"
  StructCode = "15"
  StructQuery = '"L_CC" >= 30 AND "US_CC" > 20'
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # C2 - Old Forest Single-Story *********************************************#
  Rule = "C2"
  StructClass = "ofss"
  StructCode = "16"
  StructQuery = '"L_CC" >= 30 AND "US_CC" <= 20'
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # D1
*************************************************************************#
  Rule = "D2"
  StructClass = "si"
  StructCode = "10"
  StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "SS_CC" >= 10'
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # G1
*************************************************************************#
  Rule = "G1"
  StructClass = "secc"
  StructCode = "12"
  StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" > 70 AND '\
  '("S_CC" >= 10 OR "M_CC" >= 10) AND "CNPY_LYRS" = 2'
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # G2
*************************************************************************#
  Rule = "G2"
  StructClass = "yfms"
  StructCode = "14"
  StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" > 70 AND '\
  '("S_CC" >= 10 OR "M_CC" >= 10) AND "CNPY_LYRS" > 2'
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # H1
*************************************************************************#
  Rule = "H1"
  StructClass = "secc"
  StructCode = "12"
  StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" > 70 AND '\
  '"P_CC" >= 10 AND "CNPY_LYRS" = 2'
```

```
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # H2
*****************************************************************************#
 Rule = "H2"
 StructClass = "ur"
 StructCode = "13"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" > 70 AND '\
 '"P_CC" >= 10 AND "CNPY_LYRS" > 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # J1 *****************************************************************************#
 Rule = "J1"
 StructClass = "seoc"
 StructCode = "11"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" <= 70 AND '\
 '"PSM_CC" < 30 AND "SS_CC" = 0 AND "CNPY_LYRS" <= 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # J2 *****************************************************************************#
 Rule = "J2"
 StructClass = "ur"
 StructCode = "13"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" <= 70 AND '\
 '"PSM_CC" < 30 AND "SS_CC" = 0 AND "CNPY_LYRS" > 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # K1
*****************************************************************************#
 Rule = "K1"
 StructClass = "seoc"
 StructCode = "11"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" <= 70 AND '\
 '"PSM_CC" >= 30 AND "P_CC" >= 10'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # L1
*****************************************************************************#
 Rule = "L1"
 StructClass = "ur"
 StructCode = "13"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" <= 70 AND '\
 '"PSM_CC" >= 30 AND ("S_CC" >= 10 OR "M_CC" >= 10) AND "CNPY_LYRS" = 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # L2
*****************************************************************************#
 Rule = "L2"
 StructClass = "yfms"
 StructCode = "14"
 StructQuery = '"L_CC" > 0 AND "L_CC" < 30 AND "LPSM_CC" <= 70 AND '\
 '"PSM_CC" >= 30 AND ("S_CC" >= 10 OR "M_CC" >= 10) AND "CNPY_LYRS" > 2'
```

```
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # O1
************************************************************************#
 Rule = "O1"
 StructClass = "secc"
 StructCode = "12"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" > 70 AND "SS_CC" = 0 AND '\
 '"CNPY_LYRS" = 1'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # P1
************************************************************************#
 Rule = "P1"
 StructClass = "secc"
 StructCode = "12"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" > 70 AND "M_CC" = 0 AND '\
 '"SS_CC" = 0 AND "CNPY_LYRS" >= 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # Q1
************************************************************************#
 Rule = "Q1"
 StructClass = "ur"
 StructCode = "13"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" > 70 AND "S_CC" < 10 AND '\
 '"M_CC" >= 10 AND "SS_CC" = 0 AND "CNPY_LYRS" >= 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # Q2
************************************************************************#
 Rule = "Q2"
 StructClass = "yfms"
 StructCode = "14"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" > 70 AND "S_CC" >= 10 AND '\
 '"M_CC" >= 10 AND "SS_CC" = 0 AND "CNPY_LYRS" >= 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # R1
************************************************************************#
 Rule = "R1"
 StructClass = "seoc"
 StructCode = "11"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" < 40 AND "SS_CC" = 0 AND '\
 '"CNPY_LYRS" > 0'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # S1
************************************************************************#
 Rule = "S1"
 StructClass = "seoc"
 StructCode = "11"
```

```
StructQuery = '"L_CC" = 0 AND "PSM_CC" <= 70 AND "PSM_CC" >= 40 AND '\
'"SS_CC" = 0 AND "CNPY_LYRS" < 2'
Select_and_Calc(StructQuery, StructClass, StructCode)
# T1
************************************************************************#
Rule = "T1"
StructClass = "ur"
StructCode = "13"
StructQuery = '"L_CC" = 0 AND "PSM_CC" <= 70 AND "PSM_CC" >= 40 AND '\
'"M_CC" = 0 AND "SS_CC" = 0 AND "CNPY_LYRS" >= 2'
Select_and_Calc(StructQuery, StructClass, StructCode)
# T2
************************************************************************#
Rule = "T2"
StructClass = "yfms"
StructCode = "14"
StructQuery = '"L_CC" = 0 AND "PSM_CC" <= 70 AND "PSM_CC" >= 40 AND '\
'"M_CC" > 0 AND "SS_CC" = 0 AND "CNPY_LYRS" >= 2'
Select_and_Calc(StructQuery, StructClass, StructCode)
# U1
************************************************************************#
Rule = "U1"
StructClass = "si"
StructCode = "10"
StructQuery = '"L_CC" = 0 AND "PSM_CC" < 10 AND "SS_CC" >= 10'
Select_and_Calc(StructQuery, StructClass, StructCode)
# V1
************************************************************************#
Rule = "V1"
StructClass = "ur"
StructCode = "13"
StructQuery = '"L_CC" = 0 AND "PSM_CC" > 60 AND "SS_CC" >= 10'
Select_and_Calc(StructQuery, StructClass, StructCode)
# W1
************************************************************************#
Rule = "W1"
StructClass = "seoc"
StructCode = "11"
StructQuery = '"L_CC" = 0 AND "PSM_CC" >= 10 AND "PSM_CC" < 40 AND '\
'"SS_CC" >= 10 AND "SS_CC" < "PSM_CC" AND "CNPY_LYRS" >= 2'
Select_and_Calc(StructQuery, StructClass, StructCode)
# W2
************************************************************************#
Rule = "W2"
StructClass = "si"
StructCode = "10"
```

```
 StructQuery = '"L_CC" = 0 AND "PSM_CC" >= 10 AND "PSM_CC" < 40 AND '\
 '"SS_CC" >= "PSM_CC" AND "CNPY_LYRS" >= 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # X1
*********************************************************************#
 Rule = "X1"
 StructClass = "ur"
 StructCode = "13"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" <= 60 AND "PSM_CC" >= 40 AND '\
 '"SS_CC" >= 10 AND "CNPY_LYRS" = 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # X2
*********************************************************************#
 Rule = "X2"
 StructClass = "yfms"
 StructCode = "14"
 StructQuery = '"L_CC" = 0 AND "PSM_CC" <= 60 AND "PSM_CC" >= 40 AND '\
 '"SS_CC" >= 10 AND "CNPY_LYRS" > 2'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 #------------------------------------------------------------------------#
 # Report Forest Structure Type Classification Results                    #
 #------------------------------------------------------------------------#
 PrintHeader()
 ForestStructList = ["si","seoc","secc","ur","yfms","ofms","ofss"]
 for ForestStruct in ForestStructList:
   StructQuery = '"STRUCTURE" = '+"'"+ForestStruct+"'"
   Select_and_Report(StructQuery, ForestStruct)
#**************************************************************************
*#
# Classify Herbland, Shrubland, and other Nonforest Structure              #
#**************************************************************************
*#
 gp.AddMessage("\n\tClassifying Herbland, Shrubland, and other Nonforest \
 Structures...\n")
 Rule = "NF"
 # HERBLAND - OPEN
*****************************************************#
 StructClass = "oh"
 StructCode = "17"
 StructQuery = '"NON_FRST_TCC" IN (1,2,4,5) AND \
 "NON_FRST_SPP_OS" IN (1,2,3,4,5,13)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # HERBLAND - CLOSED
***************************************************#
 StructClass = "ch"
 StructCode = "18"
```

```
 StructQuery = '"NON_FRST_TCC" = 3 AND "NON_FRST_SPP_OS" IN (1,2,3,4,5,13)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # SHRUBLAND - OPEN LOW
*****************************************************#
 StructClass = "ols"
 StructCode = "20"
 StructQuery = '"NON_FRST_TCC" IN (1,2,4,5) \
 AND "NON_FRST_SPP_OS" IN (6,7,8,12,14)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # SHRUBLAND - CLOSED LOW
***************************************************#
 StructClass = "cls"
 StructCode = "21"
 StructQuery = '"NON_FRST_TCC" = 3 AND "NON_FRST_SPP_OS" IN (6,7,8,12,14)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # SHRUBLAND - OPEN TALL
****************************************************#
 StructClass = "ots"
 StructCode = "22"
 StructQuery = '"NON_FRST_TCC" IN (1,2,4,5) AND "NON_FRST_SPP_OS" IN (9,10,11)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # SHRUBLAND - CLOSED TALL
**************************************************#
 StructClass = "cts"
 StructCode = "23"
 StructQuery = '"NON_FRST_TCC" = 3 AND "NON_FRST_SPP_OS" IN (9,10,11)'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 # NONFOREST/NONRANGE
******************************************************#
 StructClass = "nf"
 StructCode = "24"
 StructQuery = '"NON_FRST" > 0 AND "NON_FRST_SPP_OS" = 0'
 Select_and_Calc(StructQuery, StructClass, StructCode)
 #-------------------------------------------------------------------------#
 # Report Forest Structure Type Classification Results                  #
 #-------------------------------------------------------------------------#
 PrintHeader()
 ForestStructList = ["oh","ch","ols","cls","ots","cts","nf"]
 for ForestStruct in ForestStructList:
   StructQuery = '"STRUCTURE" = '+"'"+ForestStruct+"'"
   Select_and_Report(StructQuery, ForestStruct)
#**************************************************************************
*#
# Classify Woodland Structure                                   #
#**************************************************************************
*#
```

```
gp.AddMessage("\n\tClassifying Woodland Structure...\n")
WoodlandQuery = '"TOTL_CC" > 0 AND "SERIES" IN '+"('quga') OR "+\
'"COVER" IN '+"('juoc/jusc'))"
gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",WoodlandQuery)
CountSel = gp.GetCount_management("inLayer").GetOutput(0)
if int(CountSel) > 0:
  Rule = "Woodland"
  # Woodland - Stand Initiation ********************************************#
  StructClass = "w_si"
  StructCode = "25"
  StructQuery = '"SS_CC" >= 10 AND "PSM_CC" = 0 AND "L_CC" = 0 AND '\
  '("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # Woodland - Stem Exclusion **********************************************#
  StructClass = "w_se"
  StructCode = "26"
  StructQuery = '"SS_CC" = 0 AND "PSM_CC" >= 10 AND "L_CC" = 0 AND '\
  '("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # Woodland - Understory Reinitiation *************************************#
  StructClass = "w_ur"
  StructCode = "27"
  StructQuery = '"SS_CC" >= 10 AND "PSM_CC" >= 10 AND "L_CC" = 0 AND '\
  '("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # Woodland - Young Multi-Story *******************************************#
  StructClass = "w_yms"
  StructCode = "28"
  StructQuery = '"SS_CC" >= 10 AND ("S_CC" >= 10 OR "M_CC" >=0) AND '\
  '"P_CC" >= 10 AND "L_CC" = 0 '\
  'AND ("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # Woodland - Old Multi-Story *********************************************#
  StructClass = "w_oms"
  StructCode = "29"
  StructQuery = '("SS_CC" >= 10 OR "PSM_CC" >= 10) AND "L_CC" >= 10 AND '\
  '("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
  # Woodland - Old Single-Story ********************************************#
  StructClass = "w_oss"
  StructCode = "30"
  StructQuery = '"SS_CC" = 0 AND "PSM_CC" = 0 AND "L_CC" >= 10 AND '\
  '("SERIES" IN '+"('quga') OR "+'"COVER" IN '+"('juoc/jusc'))"
  Select_and_Calc(StructQuery, StructClass, StructCode)
#-------------------------------------------------------------------------#
# Report Woodland Structure Type Classification Results                    #
```

```
  #----------------------------------------------------------------------------#
  PrintHeader()
  ForestStructList = ["w_si","w_se","w_ur","w_yms","w_oms","w_oss"]
  for ForestStruct in ForestStructList:
    StructQuery = '"STRUCTURE" = '+"'"+ForestStruct+"'"
    Select_and_Report(StructQuery, ForestStruct)

#****************************************************************************#
  # Potential Classification Errors                                #

#****************************************************************************#
  gp.AddMessage("\n")
  # Get the count of polygons where count = 0
  CountQuery = '"COUNTER" < 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CountQuery)
  ZeroCount = int(gp.GetCount_management("inLayer").GetOutput(0))
  ZeroWarning = str(ZeroCount)+" polygons remain unclassified."
  # Get the count of polygons where count > 1
  CountQuery = '"COUNTER" > 1'
  gp.SelectLayerByAttribute_management("inLayer","NEW_SELECTION",CountQuery)
  MultiCount = int(gp.GetCount_management("inLayer").GetOutput(0))
  MultiWarning = str(MultiCount)+" polygons were classified by more than one rule."
  # Warn of potential erros if there are polygons with count <> 1
  if ZeroCount > 0 or MultiCount > 0:
    if ZeroCount > 0:
      gp.AddMessage("Error:\t"+ZeroWarning)
    if MultiCount > 0:
      gp.AddMessage("Warning:\t"+MultiWarning)
    gp.AddMessage("TEMPORARY FIELDS WILL NOT BE DELETED!!!")
  # Delete the temporary fields if potential errors are not flagged.
  else:
    gp.AddMessage("Deleting Temporary Fields...")
    DelFieldList =
'COUNTER;SS_CC;P_CC;S_CC;M_CC;L_CC;LPSM_CC;PSM_CC;STRUCT_RULE'
    gp.DeleteField_management(inFC,DelFieldList)
  gp.Delete_management("inLayer")
  # ** PLAY A VICTORY TUNE
****************************************************#
  gp.AddMessage("\n")
  file='ding.wav'##'tada.wav'
  from winsound import PlaySound, SND_FILENAME, SND_ASYNC
  audiocount = 2
  i = 0
  while i < audiocount:
    PlaySound(file, SND_FILENAME|SND_ASYNC)
    time.sleep(0.25)
```

```
    i = i + 1
#*****************************************************************************
*#
except:
  # get the traceback object
  tb = sys.exc_info()[2]
  # tbinfo contains the line number that the code failed on and the code from that line
  tbinfo = traceback.format_tb(tb)[0]
  # concatenate information together concerning the error into a message string
  seperator =
"*****************************************************************************
***"
  pymsg = "PYTHON ERRORS:\nTraceback Info:\n" + tbinfo + "\nError Info:\n    " +
str(sys.exc_type)+ ": " + str(sys.exc_value)
  # generate a message string for any geoprocessing tool errors
  msgs = seperator + "\nGP ERRORS:\n" + gp.GetMessages(2)
  # return gp messages for use with a script tool
  gp.AddError(msgs)
  gp.AddError(pymsg)
  # print messages for use in Python/PythonWin
  gp.AddMessage(msgs)
##  print msgs
  gp.AddMessage(pymsg)
##  print pymsg
  gp.AddMessage("\nSCRIPT FAILED...")
  print "\nSCRIPT FAILED..."
  #Play wav file to let me know it has failed!
  file='Windows XP Error.wav'
  from winsound import PlaySound, SND_FILENAME, SND_ASYNC
  PlaySound(file, SND_FILENAME|SND_ASYNC)
```

Dichotomy Key

C:\Shared_Files\Documents\Veg-Docs\Structure_Key_2010.doc

- A1. large tree cover ≥ 10%
  - B1. large tree cover ≥ 30%
    - C1. seedlings/saplings, poles, small, or medium trees > 20% — OFMS
    - C2. seedlings/saplings, poles, small, or medium trees ≤ 20% — OFSS
  - B2. large tree cover >0% and < 30
    - D1. seedling/sapling cover ≥ 10% — SI
    - D2. seedling/sapling cover < 10%
      - E1. large tree cover plus poles, small, or medium tree cover > 70%
        - F1. small or medium tree cover ≥ 10%
          - G1. canopy layers = 2 — SECC
          - G2. canopy layers > 2 — YFMS
        - F2. small or medium tree cover < 10%
          - H1. canopy layers = 2 — SECC
          - H2. canopy layers > 2 — UR
      - E2. large tree cover plus poles, small, or medium tree cover ≤ 70%
        - I1. pole, small, or medium tree cover < 30%
          - J1. canopy layers ≤ 2 — SEOC
          - J2. canopy layers > 2 — UR
        - I2. pole, small, or medium tree cover ≥ 30%
          - K1. small or medium tree cover < 10% — SEOC
          - K2. small or medium tree cover ≥ 10%
            - L1. canopy layers = 2 — UR
            - L2. canopy layers > 2 — YFMS

A2. large tree cover < 10%	
M1. seedling/sapling cover < 10%	
N1. pole, small, and/or medium tree cover > 70%	
O1. canopy layers < 2	SECC
O2. canopy layers ≥ 2	
P1. medium tree cover < 10%	SECC
P2. medium tree cover ≥ 10%	
Q1. small tree cover < 10%	UR
Q2. small tree cover ≥ 10%	YFMS
N2. pole, small, and/or medium tree cover ≤ 70%	
R1. pole, small, and/or medium tree cover < 40%	SEOC
R2. pole, small, and/or medium tree cover ≥ 40%	
S1. canopy layers < 2	SEOC
S2. canopy layers ≥ 2	
T1. medium tree cover < 10%	UR
T2. medium tree cover ≥ 10%	YFMS
M2. seedling/sapling cover ≥ 10%	
U1. pole, small, or medium tree cover < 10%	SI
U2. pole, small, or medium tree cover ≥ 10%	
V1. pole, small, or medium tree cover > 60%	UR
V2. pole, small, or medium tree cover ≤ 60%	
V1. pole, small, or medium tree cover < 40%	
W1. seedling/sapling cover < pole, small, or medium tree cover	SEOC
W2. seedling/sapling cover ≥ pole, small, or medium tree cover	SI
V2. pole, small, or medium tree cover ≥ 40%	
X1. canopy layers = 2	UR
Y2. canopy layers > 2	YFMS

Appendix 4: Yakama Nation Continuous Forest Inventory Protocol

INDIAN AFFAIRS MANUAL

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8.1 Purpose. This chapter documents the policies, standards, and responsibilities applicable to the collection, analysis and use of scientifically based data for monitoring and management of resources on Indian forest lands (see 53 IAM 1).

8.2 Guidance. Handbooks, directives and other guides may be issued and revised as necessary. In addition to standard guides identified in 53 IAM 1.3 and the *Indian Forest Management Handbook, Volume 8*, titled, *Inventory and Monitoring*, a project specific "Forest Inventory Field Procedures Guide" will be developed for all inventories.

8.3 Scope. The directives contained in this chapter apply to all Federal agencies and programs participating in the management, accountability, or protection of Indian forest resources. Regardless of the means of program execution, the appropriate Federal official shall assure that the standards prescribed herein are met.

8.4 Policy. Sound forest inventory and analysis shall be the basis for approval and implementation of decisions relative to the management and protection of Indian forest resources.

8.5 Inventory Standards. The national inventory standards described herein are tiered to the Reservation Prioritization Categories defined in 53 IAM 2.8.A. Inventory design shall be correlated with the basic purpose and need for data collection. The BIA recognizes the following inventory types:

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A. Forest Inventory for Management Planning & Trust Monitoring (Planning Inventory). The purpose of the Planning Inventory, also known as the Continuous Forest Inventory (CFI) system on Category 1 Reservations, is accountability of the Indian forest resource and scientific basis for long-term planning. Planning Inventories must meet or exceed the following national standards.

	Category 1	Category 2	Category 3	Category 4
Scheduling	15-years or less	15-years or less	15-years or less	As necessary for plan
Design	Permanent fixed-area plot for entire timberland ownership on a systematic grid with 100% of plots measured, & Category 3 standards applied on woodland areas.	Temporary plot for entire timberland ownership on a systematic grid with 100% of plots measured, & Category 3 standards applied on woodland areas.	Forest-wide inventory based on Regional Discretion	Forest-wide inventory based on Regional Discretion
Mapping Requirements	Ownership, Forest Land Classification, Cover Type, Stratum Boundaries, Plot Location	Ownership, Forest Land Classification, Cover Type, Stratum Boundaries	Ownership, Forest Land Classification, Cover Type	Ownership, Forest Land Classification, Cover Type
Accuracy of Inventory and Trust Monitoring **(Sampling Error at 1 Standard Deviation)**	TIMBERLAND: ≤ 5% for BA Comm. Timberland Stratified: ≤ 5% for pooled strata for primary unit of volume and ≤ 15% per stratum Unstratified: ≤ 5% for primary unit of volume WOODLAND: Cat. 3 standards.	TIMBERLAND: ≤ 10% for BA Comm. Timberland Stratified: ≤ 10% for pooled strata for primary unit of volume and ≤ 15% per stratum Unstratified: ≤ 10% for primary unit of volume WOODLAND: Cat. 3 standards.	Comm. Woodland: 20% for BA	At Regional Discretion
Data	Acres, Species, Frequency, Diameter, Height, Tree Condition, Plot Description, Regeneration	Same as Category 1.	Same as Category 1.	Same as Category 1.
Analysis	See 53 IAM 8.6.	See 53 IAM 8.6.	See 53 IAM 8.6.	See 53 IAM 8.6.
Quality Control	10% plot verification, Crew qualifications as per Forest Inventory Field Procedure Guide.	Same as Category 1.	Same as Category 1.	At Regional Discretion.
Document Retention	Data & Approved FIA archived in Central Office	Same as Category 1.	Same as Category 1.	Same as Category 1.

Trust Standards are not specified for Category 5 reservations, as they are non-trust.

B. **Forest Inventory for Timber Product Sales (Cruise).** The purpose of the Cruise is to accurately estimate the timber products and volume of the forest resources. Cruise design will vary depending upon product values, extent of the resource, harvest policies, etc. However, the Cruise standards below shall be met as a minimum and further constrained as necessary by the Regional Office to fulfill the Secretary's trust obligations.

	All Categories
Scheduling	Within 2-years of advertisement of predetermined volume sale and within 5-years of advertisement of estimated volume sales. This will occur as detailed in the Forest Management Plan (FMP) harvest schedule.
Design	As Regionally required.
Accuracy (Sampling Error at 1 Standard Deviation)	Estimated Volume Sale of Timber: 15% for volume and value. Pre-determined Volume Sale of Timber: 5% for volume and value.
Data	Acres, Species, Products, Volume and Value Variables
Analysis	Sample Compilation with summary statistics Sample Expansion using spatial data
Quality Control	Standards will be set by Regional Directors.
Document Retention	Consistent with BIA *Files and Maintenance Handbook*.

C. **Forest Inventory for Other Forest Product Sales (Other Products Inventory).** The purpose of the Other Products Inventory is to accurately estimate the other forest products and their volume from the forest resources. Design standards will vary depending upon product values, extent of the resource, harvest policies, etc., and will be determined by the Regional Director to fulfill the Secretary's trust obligations.

D. **Forest Inventory for Real Estate Values (Realty Cruise).** Timber is part of the "Real Property" and thus a trust resource under the protection and care of the Secretary. The fair market value of the timber must be accounted for as a part of a Realty appraisal. A Realty Cruise will be performed to the standards determined by the Regional Director to fulfill the Secretary's trust obligations.

E. **Forest Inventory for Stand Management (Stand Exam).** The purpose of this type of inventory is to collect site-specific forest data and other information for silvicultural and other forest management purposes. All stand level inventories shall be based upon site specific data acquired by the Stand Exam, consistent with procedures defined in the *Indian Forest Management Handbook, Volume 8*. Stand Exams will be performed to the standards determined by the Regional Director to fulfill the Secretary's trust obligations.

F. Forest Inventory for Trespass Investigation (Trespass Inventory). When unauthorized use or damage of the resource is reported, a determination of extent and value is to be made using Trespass Inventory methods to substantiate claims for compensation. The nature of the damage and the physical evidence present will influence the design (refer to 53 IAM Chapter 7. A Trespass Inventory shall be performed to the standards below.

	For All Occurrences
Scheduling	Promptly upon reported detection.
Design	100% sample; or utilize a sampling method regionally approved for the specific incident.
Accuracy	5% Sampling Error at 1 standard deviation if using regionally approved sampling method.
Data	All physical evidence will be mapped and photographically documented. All measurements necessary to yield quantity and value will be recorded.
Analysis	Full documentation of quantity and value calculations, cost of site rehabilitation, and loss of intrinsic values.
Quality Control	Regional Discretion.
Document Retention	Consistent with BIA file maintenance plans.

G. Forest Inventory for Ecosystem Management. Ecosystem management is recognized as an integration of resources, values, and activities over a very broad area. Ecosystem inventory is more than simple measurement of physical characteristics of trees. The standard required is that of adequate documentation of forest related data collected in all types of inventory, so as to facilitate its use by other disciplines. This type of inventory could be used in addressing forest health, adaptive management and landscape issues. Standards are determined by the Regional Director.

H. Forest Inventory for Research (Research Inventory). BIA research studies are designed to demonstrate and understand local forest potentials. Research Inventories for stocking study blocks shall meet the standards in the *Indian Forest Management Handbook, Volume 8*. Research Inventories for other purposes, such as genetic improvement, shall have applicable scientifically based procedures established and record analysis maintained.

8.6 Minimum Content Standards for a Forest Inventory Analysis (FIA). The analysis of Planning Inventory data shall be documented by a Forest Inventory Analysis report approved by the Regional Director. The substance of the functional elements will be unique to the resource and its beneficial owners' aspirations for management. Prior to approval, the FIA shall meet or exceed the following content standards according to Reservation Prioritization Categories defined in 53 IAM 2.8.A. The identified basic elements within each function shall be addressed with sufficient detail for clarity and understanding of the data. For examples of Forest Inventory Analysis outline formats, refer to *Indian Forest Management Handbook, Volume 8*.

	Category 1	Category 2	Category 3	Category 4
APPROVAL	Required	Required	Required	Required
PREFACE	Required	Required	Required	Required
SYNOPSIS	Required	Required	Required	Required
DESCRIPTION OF FOREST	Required	Required	Required	Required
SUMMARY OF RESULTS	Previous Inventories Current Inventory Sample Methods Area and Volume Growth Forest Condition Forest Trends Cut Calculations Indicated Annual Cut Regulated Annual Cut Comparative Analysis	Previous Inventories (if any) Current Inventory Sample Methods Area and Volume Growth Forest Condition Cut Calculations Indicated Annual Cut Regulated Annual Cut Comparative Analysis	Regional discretion	Regional discretion
COMPILATION AND ANALYSIS OF DATA	Forest Strata Description. Statistical Analysis Method of Forest Regulation Volume and Growth Cutting Cycle / Rotation Age Planning Period Objectives Present Forest Objectives Indicated Annual Cut Regulated Annual Cut	Same As Category 1	Regional discretion	Regional discretion
RECOMMEN-DATIONS	See *Indian Forest Management Handbook, Volume 8*	Same As Category 1	Same As Category 1	Regional discretion
APPENDIX	FIMP&TM Field Proc Guide Volume Reference & Tables Regression Coefficients and Equations, Site Index Curves/Equations Inventory Cost Data	Same As Category 1	Same As Category 1	Regional discretion

Trust Standards are not specified for Category 5 reservations, as they are non-trust.

8.7 Responsibilities. In addition to the responsibilities identified in 53 IAM 1.7, the following are directly associated with forest inventory.

A. Director, Bureau of Indian Affairs.

(1) Develop national inventory and trust monitoring policies, standards and procedures.

(2) Provide national forest inventory program direction, oversight, and guidance.

(3) Assure state-of-the-art forest inventories are implemented, maintained and analyzed for forest management planning and trust monitoring purposes.

(4) Maintain data and document archive for all forest lands in trust.

(5) Annually compile and publish the *"Status of Forest Management Inventories and Planning Report"* and the *"Catalog of Forest Acres"*.

(6) Approve regional inventory guidelines for program implementation.

B. Regional Director.

(1) Develop regional inventory guidelines for program implementation within the scope of this manual and in compliance with all other national policies, directions and standards.

(2) Assure national and regional trust monitoring standards, policies and procedures are met and followed.

(3) Assure national and regional inventory policies, standards and procedures are met and followed.

(4) Provide regional forest inventory program direction, oversight and guidance within the scope of this manual and in compliance with all other national policies, directions and standards.

(5) Approve each project "Forest Inventory Field Procedures Guide" prior to project initiation.

(6) Approve each "Forest Inventory Analysis" report.

C. Agency Superintendent.

(1) Plan and budget for field inventory events.

(2) Organize and conduct field inventory activities.

(3) Develop project "Forest Inventory Field Procedures Guide".

(4) Analyze inventory data and develop "Forest Inventory Analysis" report.

(5) Assure inventory quality control.

Appendix 5: Yakama Nation Timber Type Key

Program	File Name	Class Name	Class Number	Abbreviation Label
Forest Cover Types	**for_tty**			Overstory
Forest Feature Types, Cover types, & Overstory types are Labeled as cover type/feature type/overstory type i.e. PP53, Ponderosa Pine-large saw timber-41% - 60% canopy cover				
All Programs	for_tty	All Hemlock Species		HEM
All Programs	for_tty	Brush		B
All Programs	for_tty	Douglas Fir		DF
All Programs	for_tty	Grass		G
All Programs	for_tty	Hardwoods		D
All Programs	for_tty	Lodgepole Pine		LP
All Programs	for_tty	Meadow		M
All Programs	for_tty	Mixed Conifer		MC
All Programs	for_tty	Oak Conifer		OC
All Programs	for_tty	Oak Conifer Light		OCL
All Programs	for_tty	Open rocky, Water, etc		O
All Programs	for_tty	Oregon Oak		OO
All Programs	for_tty	Pine-Fir		PF
All Programs	for_tty	Ponderosa Pine		PP
All Programs	for_tty	Subalpine Fir		SAF
All Programs	for_tty	True Fir-Mt. Hemlock		FM
All Programs	for_tty	Whitebark Pine		WBP
Forested area Maps are shaded by Overstory Timber Type				**Understory**
Forest Feature Types, Cover types, & Overstory types are Labeled as cover type/feature type/overstory type i.e. PP53, Ponderosa Pine-large saw timber-41% - 60% canopy cover				
All Programs	for_tty	All Hemlock		HEM
All Programs	for_tty	Brush		B
All Programs	for_tty	Douglas Fir		DF
All Programs	for_tty	Grass		G
All Programs	for_tty	Hardwoods		D
All Programs	for_tty	Lodgepole Pine		LP
All Programs	for_tty	Oak Conifer		OC
All Programs	for_tty	Oak Conifer Light		OCL
All Programs	for_tty	Open rocky, Water, etc		O
All Programs	for_tty	Oregon Oak		OO
All Programs	for_tty	Pine-Fir		PF
All Programs	for_tty	Ponderosa Pine		PP
All Programs	for_tty	Subalpine		SAF
All Programs	for_tty	True Fir-Mt. Hemlock		FM

Program	File Name	Class Name	Class Number	Abbreviation Label
FOREST FEATURE TYPES		**Tree Size**		
Forest Feature Types, Cover types, & Overstory types are Labeled as cover type/feature type/overstory type i.e. PP53, Ponderosa Pine-large saw timber-41% - 60% canopy cover				
All Programs		Seedlings & Saplings	1	
All Programs		Small Pole Timber	2	
All Programs		Large Pole	3	
All Programs		Small Sawtimber	4	
All Programs		Large Sawtimber	5	
All Programs		Forested Areas		
All Programs		Valley-Range Area		
All Programs		No Maps Available		
FOREST OVERSTORY TYPES		**Canopy Cover**		
Forest Feature Types, Cover types, & Overstory types are Labeled as cover type/feature type/overstory type i.e. PP53, Ponderosa Pine-large saw timber-41% - 60% canopy cover				
All Programs		0% - 20% cc	1	
All Programs		21% - 40% cc	2	
All Programs		41% - 60% cc	3	
All Programs		61% - 80% cc	4	
All Programs		81% - 100% cc	5	

<u>Timberland</u>

OC Oak-Conifer: mainly Oregon oak; conifers make up > 10% of the overstory canopy cover.
PP Ponderosa Pine: Ponderosa pine makes up > 75% of the overstory canopy cover.
PF Pine-Fir: Ponderosa pine makes up 40 to 75% of the overstory canopy cover; the remainder is made up of mixed conifer species.
DF Douglas-fir: Douglas-fir makes up > 75% of the overstory canopy cover.
MC Mixed Conifer: Over 60% of the overstory canopy cover consists of any combination of Douglas-fir, grand fir, or western larch.
LP Lodgepole Pine: Lodgepole pine makes up > 75% of the overstory canopy cover.
FM True fir – Mountain hemlock: Over 60% of the overstory canopy cover consists of any combination of Pacific silver fir, subalpine fir, mountain hemlock, western hemlock (*Tsuga heterophylla*), Engelmann spruce, or western white pine.
HEM Hemlock: hemlock species make up > 75% of the overstory canopy cover.
SAF Subalpine Fir: High-elevation (5500 feet +) subalpine fir.

Appendix 6: FRAGSTATS Class Metrics

1

Mean Patch Area

$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$	MN (Mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type. MN is given in the same units as the corresponding patch metric.

2

(C4) Percentage of Landscape	
$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).
Description	PLAND equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, PLAND equals the percentage the landscape comprised of the corresponding patch type. Note, total landscape area (A) includes any internal background present.
Units	Percent
Range	$0 < PLAND \leq 100$ PLAND approaches 0 when the corresponding patch type (class) becomes increasingly rare in the landscape. PLAND = 100 when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch.
Comments	*Percentage of landscape* quantifies the proportional abundance of each patch type in the landscape. Like total class area, it is a measure of landscape composition important in many ecological applications. However, because PLAND is a relative measure, it may be a more appropriate measure of landscape composition than class area for comparing among landscapes of varying sizes.

3

(C5) Number of Patches	
$NP = n_i$	n_i = number of patches in the landscape of patch type (class) i.
Description	NP equals the number of patches of the corresponding patch type (class).
Units	None
Range	$NP \geq 1$, without limit. NP = 1 when the landscape contains only 1 patch of the corresponding patch type; that is, when the class consists of a single patch.
Comments	*Number of patches* of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. Although the number of patches in a class may be fundamentally important to a number of ecological processes, often it has limited interpretive value by itself because it conveys no information about area, distribution, or density of patches. Of course, if total landscape area and class area are held constant, then number of patches conveys the same information as patch density or mean patch size and may be a useful index to interpret. Number of patches is probably most valuable, however, as the basis for computing other, more interpretable, metrics. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.

4

(C6) Patch Density	
$PD = \frac{n_i}{A}(10{,}000)(100)$	n_i = number of patches in the landscape of patch type (class) i. A = total landscape area (m^2).
Description	PD equals the number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). Note, total landscape area (A) includes any internal background present.
Units	Number per 100 hectares
Range	PD > 0, constrained by cell size. PD is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch. Therefore, ultimately cell size will determine the maximum number of patches per unit area. However, the maximum density of patches of a single class is attained when every other cell is of that focal class (i.e., in a checker board manner; because adjacent cells of the same class would be in the same patch).
Comments	*Patch density* is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. Of course, if total landscape area is held constant, then patch density and number of patches convey the same information. Like number of patches, patch density often has limited interpretive value by itself because it conveys no information about the sizes and spatial distribution of patches. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.

5

(C8) Edge Density	
$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10{,}000)$$	e_{ik} = total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i. A = total landscape area (m^2).
Description	ED equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares). If a landscape border is present, ED includes landscape boundary segments involving the corresponding patch type and representing 'true' edge only (i.e., abutting patches of different classes). If a landscape border is absent, ED includes a user-specified proportion of landscape boundary segments involving the corresponding patch type. Regardless of whether a landscape border is present or not, ED includes a user-specified proportion of internal background edge segments involving the corresponding patch type. Note, total landscape area (A) includes any internal background present.
Units	Meters per hectare
Range	ED ≥ 0, without limit. ED = 0 when there is no class edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of the corresponding patch type and the user specifies that none of the landscape boundary and background edge be treated as edge.
Comments	*Edge density* at the class level has the same utility and limitations as Total Edge (see Total Edge description), except that edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.

6

(C9) Landscape Shape Index	
$$LSI = \frac{e_i}{\min e_i}$$	e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i = minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces (see below).
Description	LSI equals the total length of edge (or perimeter) involving the corresponding class, given in number of cell surfaces, divided by the minimum length of class edge (or perimeter) possible for a maximally aggregated class, also given in number of cell surfaces, which is achieved when the class is maximally clumped into a single, compact patch. If a_i is the area of class i (in terms of number of cells)[note, this is equivalent to the sum of patch areas across all patches of class i] and n is the side of the largest integer square smaller than a_i (denoted $\text{int}\sqrt{a_i}$) and $m = a_i - n^2$, then the minimum edge or perimeter of class i, min-e_i, will take one of the three forms (Milne 1991, Bogaert et al. 2000): min-e_i = 4n, when m = 0, or min-e_i = 4n + 2, when $n^2 < a_i \le n(1+n)$, or min-e_i = 4n + 4, when $a_i > n(1+n)$.
Units	None
Range	LSI ≥ 1, without limit. LSI = 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases without limit as the patch type becomes more disaggregated (i.e., the length of edge within the landscape of the corresponding patch type increases).
Comments	*Landscape shape index* provides a simple measure of class aggregation or clumpiness and, as such, is very similar to the Aggregation index. The differences lie in whether aggregation is measured via class edge (or perimeter) surfaces (as in LSI) or via internal like adjacencies (as in AI). Since these surface counts are inversely related to each other (i.e., holding area constant, as the perimeter count increases, the internal adjacency count must decrease, and vice versa), these metrics largely measure the same thing. Note, previous versions of FRAGSTATS used a slightly different definition of LSI; hence, the results will differ from previous runs.

7

(C10) Largest Patch Index	
$$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$$	a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).
Description	LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percentage of the landscape comprised by the largest patch. Note, total landscape area (A) includes any internal background present.
Units	Percent
Range	0 < LPI ≤ 100 LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; that is, when the largest patch comprises 100% of the landscape.
Comments	*Largest patch index* at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.

8

(C114) Percentage of Like Adjacencies	
$PLADJ = \left(\frac{g_{ii}}{\sum_{k=1}^{m} g_{ik}} \right)(100)$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *double-count* method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method.
Description	PLADJ equals the number of like adjacencies involving the focal class, divided by the total number of cell adjacencies involving the focal class; multiplied by 100 (to convert to a percentage). In other words, the percentage of cell adjacencies involving the corresponding patch type that are like adjacencies. All background edge segments are included in the sum of all adjacencies involving the focal class, including landscape boundary segments if a border is not provided. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved, at least for all internal adjacencies (i.e., involving cells on the inside of the landscape). If a landscape border is present, adjacencies on the landscape boundary are counted only once, as are all adjacencies with background.
Units	Percent
Range	$0 \le PLADJ \le 100$ PLADJ equals 0 when the corresponding patch type is maximally disaggregated (i.e., every cell is a different patch) and there are no like adjacencies. This occurs when the class is subdivided into one cell patches. Note, this condition can only be achieved when the proportion of the landscape comprised of the focal class (P_i) is ≤ 0.5. When $P_i = 0.5$, this occurs only when the class is distributed as a perfect checkerboard. When $P_i > 0.5$, the checkerboard begins to fill in and there will exist like adjacencies. PLADJ increases as the corresponding patch type becomes increasingly aggregated such that the proportion of like adjacencies increases. PLADJ = 100 when the landscape consists of single patch and all adjacencies are between the same class, and the landscape contains a border comprised entirely of the same class. If the landscape consists of single patch but does not contain a border, PLADJ will be less than 100 due to the background edge segments in the tally of adjacencies involving the focal class. Finally, PLADJ is undefined and reported as "N/A" in the "basename".class file if the class consists of a single cell.
Comments	*Percentage of like adjacencies* is calculated from the adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map. PLADJ measures the degree of aggregation of the focal patch type. Thus, it is a measure of class-specific contagion. Regardless of how much of the landscape is comprised of the focal class (P_i), this index will be minimum if the patch type is maximally dispersed (or disaggregated), and it will be maximum if the patch type is maximally contagious. However, this index does not account for the fact that the percentage of like adjacencies for a random distribution equals P_i. If the percentage of like adjacencies is less than P_i, then the patch type is more dispersed than expected of a random landscape. Conversely, if the percentage of like adjacencies is greater than P_i, then the patch type is contagiously distributed. Note, this metric measures only dispersion and not interspersion, and thus may be a useful index of fragmentation of the focal class when interpreted in conjunction with P_i.

9

(C116) Aggregation Index	
$AI = \left[\frac{g_{ii}}{max \to g_{ii}} \right](100)$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type (class) i (see below) based on the *single-count* method.
Description	AI equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100 (to convert to a percentage). If a_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than a_i, and $m = a_i - n^2$, then the largest number of shared edges for class i, max-g_{ii} will take one of the three forms: max-$g_{ii} = 2n(n-1)$, when $m = 0$, or max-$g_{ii} = 2n(n-1) + 2m - 1$, when $m \le n$, or max-$g_{ii} = 2n(n-1) + 2m - 2$, when $m > n$. Note, because of the design of the metric, like adjacencies are tallied using the *single-count* method, and all landscape boundary edge segments are ignored, even if a border is provided.
Units	Percent
Range	$0 \le AI \le 100$ Given any P_i , AI equals 0 when the focal patch type is maximally disaggregated (i.e., when there are no like adjacencies); AI increases as the focal patch type is increasingly aggregated and equals 100 when the patch type is maximally aggregated into a single, compact patch. AI is undefined and reported as "N/A" in the "basename".class file if the class consists of a single cell. Note, AI is closely related to the Landscape Shape Index (LSI), only the latter is based on perimeter surfaces as opposed in internal like adjacencies. Both metrics can be normalized to reflect the fact the minimum and maximum values vary depending on P_i; the range of possible values is greatest when $P_i = 0.5$. The normalized versions of LSI and AI are completely redundant; thus, FRAGSTATS only computes the normalized LSI (nLSI) metric.
Comments	*Aggregation index* is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map. Aggregation index takes into account only the like adjacencies involving the focal class, not adjacencies with other patch types. In addition, in contrast to all of the other metrics based on adjacencies, the aggregation index is based on like adjacencies tallied using the *single-count* method, in which each cell side is counted only once. Consequently, the tallies given in the "basename".adj output file are not correct for this metric. Further, because of the design of the metric, landscape boundary edge segments are ignored, even if a border is provided FRAGSTATS handles this case by distinguishing between internal like adjacencies (i.e., like adjacencies involving cells *inside* the landscape) and external like adjacencies (i.e., like adjacencies between cells *inside* the landscape and those in the border). Only internal like adjacencies are used in the calculation of this metric; a landscape border has no affect on this metric. The aggregation index is scaled to account for the maximum possible number of like adjacencies given any P_i. The maximum aggregation is achieved when the patch type consists of a single, compact patch, which is not necessarily a square patch.

10

(C117) Interspersion and Juxtaposition Index	
$$IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\right]}{\ln(m-1)}(100)$$	e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k. m = number of patch types (classes) present in the landscape, including the landscape border, if present.
Description	IJI equals minus the sum of the length (m) of each unique edge type involving the corresponding patch type divided by the total length (m) of edge (m) involving the same type, multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types minus 1; multiplied by 100 (to convert to a percentage). In other words, the observed interspersion over the maximum possible interspersion for the given number of patch types. Note, IJI considers all patch types present on an image, including any present in the landscape border, if present. All background edge segments are ignored, as are landscape boundary segments if a border is not provided, because adjacency information for these edge segments is not available and the intermixing of the focal class with background is assumed to be irrelevant.
Units	Percent
Range	$0 < IJI \le 100$ IJI approaches 0 when the corresponding patch type is adjacent to only 1 other patch type and the number of patch types increases. IJI = 100 when the corresponding patch type is equally adjacent to all other patch types (i.e., maximally interspersed and juxtaposed to other patch types). IJI is undefined and reported as "N/A" in the "basename".class file if the number of patch types is less than 3.
Comments	*Interspersion and juxtaposition index* is based on *patch* adjacencies, not *cell* adjacencies like the contagion index. As such, it does not provide a measure of class aggregation like the contagion index, but rather isolates the interspersion or intermixing of patch types.

11

(C121) Patch Cohesion Index	
$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \cdot (100)$$	p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. A = total number of cells in the landscape.
Description	COHESION equals 1 minus the sum of patch perimeter (in terms of number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage. Note, total landscape area (A) excludes any internal background present.
Units	None
Range	$0 \le COHESION < 100$ COHESION approaches 0 as the proportion of the landscape comprised of the focal class decreases and becomes increasingly subdivided and less physically connected. COHESION increases monotonically as the proportion of the landscape comprised of the focal class increases until an asymptote is reached near the percolation threshold (see background discussion). COHESION is given as 0 if the landscape consists of a single non-background cell.
Comments	*Patch cohesion index* measures the physical connectedness of the corresponding patch type. Below the percolation threshold, patch cohesion is sensitive to the aggregation of the focal class. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected. Above the percolation threshold, patch cohesion does not appear to be sensitive to patch configuration (Gustafson 1998).

Appendix 7: FRAGSTATS Landscape Metrics

1
Mean Patch Area

$MN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}}{N}$	MN (Mean) equals the sum, across all patches in the landscape, of the corresponding patch metric values, divided by the total number of patches. MN is given in the same units as the corresponding patch metric.

2

(L5) Number of Patches	
$NP = N$	N = total number of patches in the landscape.
Description	NP equals the number of patches in the landscape. Note, NP does not include any internal background patches (i.e., within the landscape boundary) or any patches at all in the landscape border, if present.
Units	None
Range	NP ≥ 1, without limit. NP = 1 when the landscape contains only 1 patch.
Comments	*Number of patches* often has limited interpretive value by itself because it conveys no information about area, distribution, or density of patches. Of course, if total landscape area is held constant, then number of patches conveys the same information as patch density or mean patch size and may be a useful index to interpret. Number of patches is probably most valuable, however, as the basis for computing other, more interpretable, metrics. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.

3

(L6) Patch Density	
$PD = \frac{N}{A}(10{,}000)(100)$	N = total number of patches in the landscape. A = total landscape area (m^2).
Description	PD equals the number of patches in the landscape, divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). Note, PD does not include background patches or patches in the landscape border, if present. However, total landscape area (A) includes any internal background present.
Units	Number per 100 hectares
Range	PD > 0, constrained by cell size. PD is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch.
Comments	*Patch density* is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. Of course, if total landscape area is held constant, then patch density and number of patches convey the same information. Like number of patches, patch density often has limited interpretive value by itself because it conveys no information about the sizes and spatial distribution of patches. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.

4

(L8) Edge Density	
$ED = \frac{E}{A}(10{,}000)$	E = total length (m) of edge in landscape. A = total landscape area (m^2).
Description	ED equals the sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares). If a landscape border is present, ED includes landscape boundary segments representing 'true' edge only (i.e., abutting patches of different classes). If a landscape border is absent, ED includes a user-specified proportion of the landscape boundary. Regardless of whether a landscape border is present or not, ED includes a user-specified proportion of internal background edge. Note, total landscape area (A) includes any internal background present.
Units	Meters per hectare
Range	ED ≥ 0, without limit. ED = 0 when there is no edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of a single patch and the user specifies that none of the landscape boundary and background edge be treated as edge.
Comments	*Edge density* has the same utility and limitations as Total Edge (see Total Edge description), except that edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.

5

(L9) Landscape Shape Index	
$LSI = \frac{E}{\min E}$	E = total length of edge in landscape in terms of number of cell surfaces; includes all landscape boundary and background edge segments. min E = minimum total length of edge in landscape in terms of number of cell surfaces (see below).
Description	LSI equals the total length of edge in the landscape, given in number of cell surfaces, divided by the minimum total length of edge possible, also given in number of cell surfaces, which is achieved when the landscape consists of a single patch. If A is the landscape area, including all internal background (in terms of number of cells), and n is the side of the largest integer square smaller than A (denoted $\text{int}\sqrt{A}$) and $m = A - n^2$, then the minimum edge or perimeter of the landscape, min-E, will take one of the three forms (Milne 1991, Bogaert et al. 2000): min-E = 4n, when m = 0, or min-E = 4n + 2, when $n^2 < A \leq n(1+n)$, or min-E = 4n + 4, when $A > n(1+n)$.
Units	None
Range	LSI ≥ 1, without limit. LSI = 1 when the landscape consists of a single square (or almost square) patch; LSI increases without limit as landscape shape becomes more irregular and/or as the length of edge within the landscape increases.
Comments	*Landscape shape index* provides a standardized measure of total edge or edge density that adjusts for the size of the landscape. Because it is standardized, it has a direct interpretation, in contrast to total edge, for example, that is only meaningful relative to the size of the landscape. LSI can also be interpreted as a measure of patch aggregation or disaggregation, similar to the class-level interpretation. Specifically, as LSI increases, the patches become increasingly disaggregated.

6

(L10) Largest Patch Index	
$LPI = \frac{\max(a_{ij})}{A}(100)$	a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).
Description	LPI equals the area (m^2) of the largest patch in the landscape divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percent of the landscape that the largest patch comprises. Note, total landscape area (A) includes any internal background present.
Units	Percent
Range	0 < LPI ≤ 100 LPI approaches 0 when the largest patch in the landscape is increasingly small. LPI = 100 when the entire landscape consists of a single patch; that is, when the largest patch comprises 100% of the landscape.
Comments	*Largest patch index* quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.

7

(L115) Contagion Index	
$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\cdot\left[\ln(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right](100)$	
P_i =proportion of the landscape occupied by patch type (class) i. g_{ik} =number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method. m =number of patch types (classes) present in the landscape, including the landscape border if present.	
Description	CONTAG equals minus the sum of the proportional abundance of each patch type multiplied by the proportion of adjacencies between cells of that patch type and another patch type, multiplied by the logarithm of the same quantity, summed over each unique adjacency type and each patch type; divided by 2 times the logarithm of the number of patch types; multiplied by 100 (to convert to a percentage). In other words, the observed contagion over the maximum possible contagion for the given number of patch types. Note, CONTAG considers all patch types present on an image, including any present in the landscape border, if present, and considers like adjacencies (i.e., cells of a patch type adjacent to cells of the same type). All background edge segments are ignored, as are landscape boundary segments if a border is not provided, because adjacency information for these edge segments is not available and the intermixing of the classes with background is assumed to be irrelevant. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved, at least for all internal adjacencies (i.e., involving cells on the inside of the landscape). If a landscape border is present, adjacencies on the landscape boundary are counted only once as are all adjacencies with background. Note, P_i is based on the total landscape area (A) excluding any internal background present.
Units	Percent
Range	0 < CONTAG ≤ 100 CONTAG approaches 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of all pairwise adjacencies). CONTAG = 100 when all patch types are maximally aggregated; i.e., when the landscape consists of single patch. CONTAG is undefined and reported as "N/A" in the "basename".land file if the number of patch types is less than 2, or all classes consist of one cell patches adjacent to only background.
Comments	*Contagion* is inversely related to edge density. When edge density is very low, for example, when a single class occupies a very large percentage of the landscape, contagion is high, and vice versa. In addition, note that contagion is affected by both the dispersion and interspersion of patch types. Low levels of patch type dispersion (i.e., high proportion of like adjacencies) and low levels of patch type interspersion (i.e., inequitable distribution of pairwise adjacencies results in high contagion, and vice versa.

8

9

(L116) Aggregation Index	
$$AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{\max \to g_{ii}} \right) P_i \right] (100)$$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type (class) i (see below) based on the *single-count* method. P_i = proportion of landscape comprised of patch type (class) i.
Description	AI equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch, multiplied the proportion of the landscape comprised of the corresponding class, summed over all classes and multiplied by 100 (to convert to a percentage). If A_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than A_i, and $m = A_i - n^2$, then the largest number of shared edges for class i, max-g_{ii} will take one of the three forms: max-$g_{ii} = 2n(n-1)$, when $m = 0$, max-$g_{ii} = 2n(n-1) + 2m - 1$, when $m \le n$, or max-$g_{ii} = 2n(n-1) + 2m - 2$, when $m > n$. Note, because of the design of the metric, like adjacencies are tallied using the *single-count* method, and all landscape boundary edge segments are ignored, even if a border is provided. Also, P_i is based on the total landscape area (A) excluding any background present.
Units	Percent
Range	$0 \le AI \le 100$ Given any P_i, AI equals 0 when the patch types are maximally disaggregated (i.e., when there are no like adjacencies); AI increases as the landscape is increasingly aggregated and equals 100 when the landscape consists of a single patch. AI is undefined and reported as "N/A" in the "basename".land file if each class consists of a single cell (and hence is undefined).
Comments	*Aggregation index* is calculated from an adjacency matrix at the class level (see class-level AI comments). At landscape level, the index is computed simply as an area-weighted mean class aggregation index, where each class is weighted by its proportional area in the landscape. The index is scaled to account for the maximum possible number of like adjacencies given any landscape composition.

(L117) Interspersion and Juxtaposition Index	
$$IJI = \frac{-\sum_{i=1}^{m} \sum_{k=i+1}^{m} \left[\left(\frac{e_{ik}}{E} \right) \cdot \ln \left(\frac{e_{ik}}{E} \right) \right]}{\ln(0.5[m(m-1)])} (100)$$	e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k. E = total length (m) of edge in landscape, excluding background. m = number of patch types (classes) present in the landscape, including the landscape border, if present.
Description	IJI equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage). In other words, the observed interspersion over the maximum possible interspersion for the given number of patch types. Note, IJI considers all patch types present on an image, including any present in the landscape border, if present. All background edge segments are ignored, as are landscape boundary segments if a border is not provided, because adjacency information for these edge segments is not available and the intermixing of classes with background is assumed to be irrelevant.
Units	Percent
Range	$0 < IJI \le 100$ IJI approaches 0 when the distribution of adjacencies among unique patch types becomes increasingly uneven. IJI = 100 when all patch types are equally adjacent to all other patch types (i.e., maximum interspersion and juxtaposition). IJI is undefined and reported as "N/A" in the "basename".land file if the number of patch types is less than 3.
Comments	*Interspersion and juxtaposition index* is based on patch adjacencies, not cell adjacencies like the contagion index. As such, it does not provide a measure of class aggregation like the contagion index, but rather isolates the interspersion or intermixing of patch types.

10

(L121) Patch Cohesion Index	
$$COHESION = \left[1 - \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij} \sqrt{a_{ij}}} \right] \left[1 - \frac{1}{\sqrt{A}} \right]^{-1} \cdot (100)$$	p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. A = total number of cells in the landscape.
Description	COHESION equals 1 minus the sum of patch perimeter (in terms of number of cells) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for all patches in the landscape, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage. Note, total landscape area (A) excludes any internal background present.
Units	None
Range	The behavior of this metric at the landscape level has not yet been evaluated.
Comments	*Patch cohesion index* at the class level measures the physical connectedness of the corresponding patch type. However, at the landscape level, the behavior of this metric has not yet been evaluated.

11

(L127) Shannon's Diversity Index	
$SHDI = -\sum_{i=1}^{m} (P_i * \ln P_i)$	P_i = proportion of the landscape occupied by patch type (class) i.
Description	SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion. Note, P_i is based on total landscape area (A) excluding any internal background present.
Units	Information
Range	SHDI ≥ 0, without limit SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SHDI increases as the number of different patch types (i.e., patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equitable.
Comments	*Shannon's diversity index* is a popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index.

12

(L128) Simpson's Diversity Index	
$SIDI = 1 - \sum_{i=1}^{m} P_i^2$	P_i = proportion of the landscape occupied by patch type (class) i.
Description	SIDI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared. Note, P_i is based on total landscape area (A) excluding any internal background present.
Units	None
Range	0 ≤ SIDI < 1 SIDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SIDI approaches 1 as the number of different patch types (i.e., patch richness, PR) increases and the proportional distribution of area among patch types becomes more equitable.
Comments	*Simpson's diversity index* is another popular diversity measure borrowed from community ecology. Simpson's index is less sensitive to the presence of rare types and has an interpretation that is much more intuitive than Shannon's index. Specifically, the value of Simpson's index represents the probability that any 2 pixels selected at random would be different patch types.

Appendix 8: Spatial Autocorrelation (Global Moran's I)

The Spatial Autocorrelation (Global Moran's I) tool measures spatial autocorrelation based on both feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. The Spatial Autocorrelation tool returns five values: Observed Moran's I Index, Expected Index, Variance, z-score, and p-value. The tool calculates the Moran's I Index value and both a z-score and p-value to evaluate the significance of that Index. P-values are numerical approximations of the area under the curve for a known distribution, limited by the test statistic. Z-scores are simply standard deviations.

The tool computes the mean and variance for the attribute being evaluated. Then, for each feature value, it subtracts the mean, creating a *deviation from the mean*. Deviation values for all neighboring features (features within the specified distance band, for example) are multiplied together to create a *cross-product*. Notice that the numerator for the Global Moran's I statistic includes these summed cross-products. Suppose features A and B are neighbors, and the mean for all feature values is 10. Notice the range of possible cross-product results:

Feature values		Deviations		Cross-products
A=50	B=40	40	30	1200
A= 8	B=6	-2	-4	8
A=20	B=2	10	-8	-80

When values for neighboring features are either both larger than the mean or both smaller than the mean, the cross-product will be positive. When one value is smaller than the mean and the other is larger than the mean, the cross-product will be negative. In all cases, the larger the deviation from the mean, the larger the cross-product result. If the values in the dataset tend to cluster spatially (high values cluster near other high values; low values cluster near other low values), the Moran's Index will be positive. When high values repel other high values, and tend to be near low values, the Index will be negative. If positive cross-product values balance negative cross-product values, the Index will be near zero. The numerator is normalized by the variance so that Index values fall between -1.0 and +1.0 (see the FAQ section below for exceptions).

After the Spatial Autocorrelation (Global Moran's I) tool computes the Index value, it computes the Expected Index value. The Expected and Observed Index values are then compared. Given the number of features in the dataset and the variance for the data values overall, the tool computes a z-score and p-valueindicating whether this difference is statistically significant or not. Index values cannot be interpreted directly; they can only be interpreted within the context of the null hypothesis.

Interpretation

The Spatial Autocorrelation (Global Moran's I) tool is an inferential statistic, which means that the results of the analysis are always interpreted within the context of its null hypothesis. For the

Global Moran's I statistic, the null hypothesis states that the attribute being analyzed is randomly distributed among the features in your study area; said another way, the spatial processes promoting the observed pattern of values is random chance. Imagine that you could pick up the values for the attribute you are analyzing and throw them down onto your features, letting each value fall where it may. This process (picking up and throwing down the values) is an example of a random chance spatial process.

When the p-value returned by this tool is statistically significant, you can reject the null hypothesis. The table below summarizes interpretation of results:

The p-value is *not* statistically significant.	You cannot reject the null hypothesis. It is quite possible that the spatial distribution of feature values is the result of random spatial processes. The observed spatial pattern of feature values could very well be one of many, many possible versions of complete spatial randomness (CSR).
The p-value *is* statistically significant, and the z-score is positive.	You may reject the null hypothesis. The spatial distribution of high values and/or low values in the dataset is more spatially clustered than would be expected if underlying spatial processes were random.
The p-value *is* statistically significant, and the z-score is negative.	You may reject the null hypothesis. The spatial distribution of high values and low values in the dataset is more spatially dispersed than would be expected if underlying spatial processes were random. A dispersed spatial pattern often reflects some type of competitive process—a feature with a high value repels other features with high values; similarly, a feature with a low value repels other features with low values.

The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where z_i is the deviation of an attribute for feature i from its mean $(x_i - \bar{X})$, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features, and S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad (2)$$

The z_I-score for the statistic is computed as:

$$z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}} \quad (3)$$

where:

$$\mathrm{E}[I] = -1/(n-1) \quad (4)$$

$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2 \quad (5)$$

Additional calculations are as follows:

$$\mathrm{E}[I^2] = \frac{A - B}{C} \quad (6)$$

$$A = n\left[(n^2 - 3n + 3)S_1 - nS_2 + 3S_0^2\right] \quad (7)$$

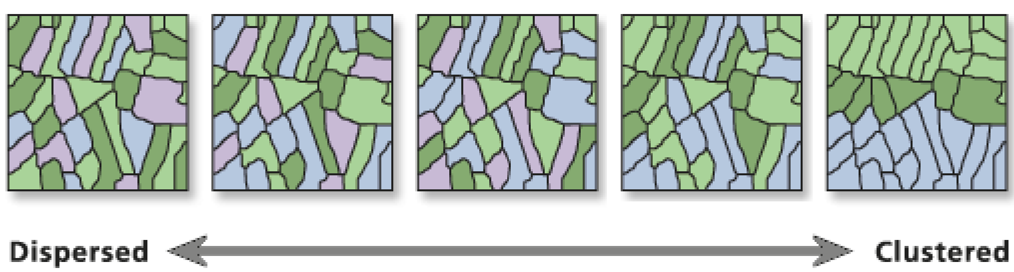
$$B = D\left[(n^2 - n)S_1 - 2nS_2 + 6S_0^2\right] \quad (8)$$

$$C = (n-1)(n-2)(n-3)S_0^2 \quad (9)$$

$$D = \frac{\sum_{i=1}^{n} z_i^4}{\left(\sum_{i=1}^{n} z_i^2\right)^2} \quad (10)$$

$$S_1 = (1/2)\sum_{i=1}^{n}\sum_{j=1}^{n}(w_{i,j} + w_{j,i})^2 \quad (11)$$

$$S_2 = \sum_{i=1}^{n}\left(\sum_{j=1}^{n} w_{i,j} + \sum_{j=1}^{n} w_{j,i}\right)^2 \quad (12)$$



Appendix 9: High/Low Clustering (Getis-Ord General G)

The High/Low Clustering tool measures the degree of clustering for either high values or low values using the Getis-Ord General G statistic. The High/Low Clustering tool returns five values: Observed General G, Expected General G, Variance, z-score, and p-value. The tool calculates the General G Index value and both a z-score and p-value to evaluate the significance of that Index. P-values are numerical approximations of the area under the curve for a known distribution, limited by the test statistic. Z-scores are simply standard deviations.

The High/Low Clustering tool measures the concentration of high or low values for a given study area.

Notice that the only difference between the numerator and the denominator is the weighting (wij). High/Low Clustering will only work with positive values. Consequently, if your weights are binary (0/1) or are always less than 1, the range for General G will be between 0 and 1. A binary weighting scheme is recommended for this statistic. Select Fixed Distance Band, Polygon Contiguity, K Nearest Neighbors, or Delaunay Triangulation for the **Conceptualization of Spatial Relationships** parameter. Select None for the **Standardization** parameter.

Interpretation

The High/Low Clustering (Getis-Ord General G) tool is an inferential statistic, which means that the results of the analysis are interpreted within the context of the null hypothesis. The null hypothesis for the High/Low Clustering (General G) statistic states that there is no spatial clustering of feature values. When the p-value returned by this tool is small and statistically significant, the null hypothesis can be rejected (see What is a z-score? What is a p-value?). If the null hypothesis is rejected, then the sign of the z-score becomes important. If the z-score value is positive, the observed General G index is larger than the expected General G index, indicating high values for the attribute are clustered in the study area. If the z-score value is negative, the observed General G index is smaller than the expected index, indicating that low values are clustered in the study area.

The High/Low Clustering (Getis-Ord General G) tool is most appropriate when you have a fairly even distribution of values and are looking for unexpected spatial spikes of high values. Unfortunately, when both the high and low values cluster, they tend to cancel each other out. If you are interested in measuring spatial clustering when both the high values and the low values cluster, use the Spatial Autocorrelation tool.

The null hypothesis for both the High/Low Clustering (Getis-Ord General G) and the Spatial Autocorrelation (Global Moran's I) tool is complete spatial randomness (CSR); values are randomly distributed among the features in the dataset, reflecting random spatial processes at work. However, the interpretation of z-scores for the High/Low Clustering tool is very different from the interpretation of z-scores for the Spatial Autocorrelation (Global Moran's I) tool:

Result	High/Low Clustering	Spatial Autocorrelation
The p-value is **not** statistically significant.	You cannot reject the null hypothesis. It is quite possible that the spatial distribution of feature attribute values is the result of random spatial processes. Said another way, the observed spatial pattern of values could well be one of many, many possible versions of complete spatial randomness.	
The p-value **is** statistically significant, and the z-score is positive.	You may reject the null hypothesis. The spatial distribution of **high** values in the dataset is more spatially clustered than would be expected if underlying spatial processes were truly random.	You may reject the null hypothesis. The spatial distribution of high values and/or low values in the dataset is more spatially clustered than would be expected if underlying spatial processes were truly random.
The p-value **is** statistically significant, and the z-score is negative.	You may reject the null hypothesis. The spatial distribution of **low** values in the dataset is more spatially clustered than would be expected if underlying spatial processes were truly random.	You may reject the null hypothesis. The spatial distribution of high values and low values in the dataset is more spatially **dispersed** than would be expected if underlying spatial processes were truly random. A dispersed spatial pattern often reflects some type of competitive process: a feature with a high value repels other features with high values; similarly, a feature with a low value repels other features with low values.

The General G statistic of overall spatial association is given as:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} x_i x_j}{\sum_{i=1}^{n}\sum_{j=1}^{n} x_i x_j}, \quad \forall j \neq i \qquad (1)$$

where x_i and x_j are attribute values for features i and j, and $w_{i,j}$ is the spatial weight between feature i and j.

The z_G-score for the statistic is computed as:

$$z_G = \frac{G - \mathrm{E}[G]}{\sqrt{\mathrm{V}[G]}} \qquad (2)$$

where:

$$\mathrm{E}[G] = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}}{n(n-1)}, \quad \forall j \neq i \qquad (3)$$

$$\mathrm{V}[G] = \mathrm{E}[G^2] - \mathrm{E}[G]^2 \qquad (4)$$

Additional calculations are as follows:

$$\mathrm{E}[G^2] = \frac{A+B}{C} \quad (5)$$

$$A = D_0\left(\sum_{i=1}^{n} x_i^2\right)^2 + D_1 \sum_{i=1}^{n} x_i^4 + D_2\left(\sum_{i=1}^{n} x_i\right)^2 \sum_{i=1}^{n} x_i^2 \quad (6)$$

$$B = D_3 \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i^3 + D_4\left(\sum_{i=1}^{n} x_i\right)^4 \quad (7)$$

$$C = \left[\left(\sum_{i=1}^{n} x_i\right)^2 - \sum_{i=1}^{n} x_i^2\right]^2 \times n(n-1)(n-2)(n-3) \quad (8)$$

$$D_0 = (n^2 - 3n + 3)S_1 - nS_2 + 3W^2 \quad (9)$$

$$D_1 = -\left[(n^2 - n)S_1 - 2nS_2 + 6W^2\right] \quad (10)$$

$$D_2 = -\left[2nS_1 - (n+3)S_2 + 6W^2\right] \quad (11)$$

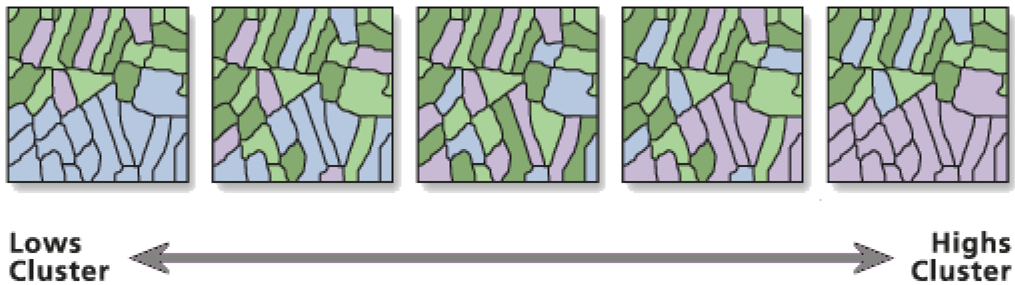
$$D_3 = 4(n-1)S_1 - 2(n+1)S_2 + 8W^2 \quad (12)$$

$$D_4 = S_1 - S_2 + W^2 \quad (13)$$

$$W = \left(\sum_{i=1}^{n} \sum_{j=1, i\neq i}^{n} w_{i,j}\right) \quad (14)$$

$$S_1 = (1/2) \sum_{i=1}^{n} \sum_{j=1, i\neq j}^{n} (w_{i,j} + w_{j,i})^2 \quad (15)$$

$$S_2 = \sum_{i=1}^{n} \left(\sum_{j=1, i\neq j}^{n} w_{i,j} + \sum_{j=1}^{n} w_{i,j}\right)^2 \quad (16)$$



Appendix 10: Tapash Sustainable Forest Collaborative MOU

MEMORANDUM OF UNDERSTANDING
Between
United States Department of Agriculture
Forest Service,
Washington State Department of Natural Resources,
Washington State Department of Fish and Wildlife,
Yakama Nation
And
The Nature Conservancy

This Memorandum of Understanding (MOU) is made and entered into by the UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE (USFS), the WASHINGTON DEPARTMENT OF NATURAL RESOURCES (WDNR), the WASHINGTON STATE DEPARTMENT OF FISH AND WILDLIFE (WDFW), the YAKAMA NATION (YN) and THE NATURE CONSERVANCY (The Conservancy) in achievement of mutual natural resource management goals. The USFS will be represented by its staff on the Okanogan -Wenatchee National Forest. WDNR will be represented by the Southeast Region. WDFW will be represented by Region 3. The Conservancy will be represented by its Washington field offices. This cooperative framework shall be known as “The Tapash Sustainable Forests Collaborative.” This name can be used by the signatories and other cooperators to create an identity for fundraising, publications and public relations.

I. AUTHORITY

This MOU is entered into by the USFS under the authority of the following provisions:
P.L. 86517, Multiple-Use, Sustained-Yield Act (16 U.S.C. §§ 1600 et seq.); P.L. 95-307, Forest and Rangeland Renewable Resources Research Act of 1978 (16 U.S.C. §§ 1641 et seq.); and the Cooperative Forestry Assistance Act of 1978 as amended (16 U.S.C. §§ 2101-2114, P.L. 95-9-313). This MOU will be recorded as Forest Service Agreement No. 06-MU-11061700-211.

This MOU is entered into by the WDFW and the WDNR under the authority of RCW 39.34, and the Interlocal Cooperation Act, also, for the WDNR under the authority of RCW 43.30.700(3) and for WDFW under the authority of RCW 77.12.230.

This MOU is entered into by The Conservancy under the provisions of the by-laws and other governing documents for The Nature Conservancy. This MOU is without prejudice to other existing or potential agreements between the USFS and The Conservancy, including the Master Memorandum of Understanding between The Nature Conservancy and the USDA Forest Service (1991).

II. PURPOSE

The parties recognize that they share common goals on the landscape and, by working together, can achieve more significant and durable outcomes than by working individually.

The purpose of this MOU is to provide a framework for cooperation and coordination. Primarily, this MOU serves as the charter for The Tapash Sustainable Forests Collaborative that over time will restore the dry forest and shrub-steppe zones to a more sustainable species composition and structure within the Tapash Sustainable Forests Collaborative's core planning area in the Naches Ranger District and Oak Creek Wildlife Area on the east slope of the Cascade Range in central Washington. The knowledge gained through that process will be shared to promote dry forest and shrub-steppe restoration on other portions of the east slope of the Cascade Range in central Washington. In addition, The Tapash Sustainable Forests Collaborative recognizes the need for the ongoing use, enjoyment, and environmental education of the public.

The MOU will be used to help achieve mutual goals in the following natural resource related areas. Examples include, but are not limited to:

- Develop strong, effective collaborative planning and implementation processes among the signatories to this MOU as well as interested public agencies and partners.
- Increase shared knowledge within The Tapash Sustainable Forests Collaborative of affected lands and resources (research, inventories, assessments and monitoring results).
- Share the learning gained through program planning and implementation for use by external audiences.
- Protect, preserve and enhance natural resources that are important for the cultural and traditional uses of the Yakama People.
- Manage recreation use to provide opportunities and experiences compatible with conservation and other natural resource management objectives.
- Identify and manage an efficient and environmentally acceptable transportation system across multiple ownerships.
- Restore the use of fire as a tool for achieving ecological objectives.
- Develop and use science-based management tools, including:
    - Stream geomorphic assessments and stream restoration
    - Biological assessments, inventory, and monitoring
    - Conservation planning:
        - WDNR HCP planning
        - Okanogan-Wenatchee National Forest Plan revision
        - Wildlife Area planning
        - The Conservancy's Conservation Action Plan (CAP) methodology
- Forest management, including restoration practices, to sustain seral forest conditions.
- Natural community restoration/exotics and invasives control.
- Land protection (acquisition).
- Recovery planning for federally listed species.

III. STATEMENT OF MUTUAL INTEREST AND BENEFIT

The members of The Tapash Sustainable Forests Collaborative recognize the underlying ecological unity of the landscape that has been divided into administrative ownership boundaries that currently limit the ability to plan and work at the landscape scale. The Tapash Sustainable Forests Collaborative members have an interest in working at the landscape scale and across administrative boundaries to achieve their mutual goals.

This MOU is intended to be the vehicle for encouraging future agreements among The Tapash Collaborative's members, including but not limited to, agreements for the interchange of personnel, equipment, management practices (e.g. utilization of sawtimber and other forest biomass products, implementation of fuels reduction projects, and prescribed fire across administrative boundaries), and information to achieve these goals. Additionally, the parties to this MOU may enter into separate specific cost share agreements when projects will involve an exchange or commitment of funds.

All parties to this MOU, as landowners, have responsibilities and interests in the preservation, conservation, biological diversity, public interests, and management of the dry forest. It is the desire of all parties to cooperate with each other, including the exchange of personnel and other resources, in matters relating to the management and conservation of biological diversity.

The USFS is a natural resource agency dedicated to the sustained management of the nation's natural resources, service to people, and, through federal law and regulations of the Secretary of Agriculture, has major responsibility for the protection and management of biodiversity, fish, wildlife, and plant habitats, including providing special protection for threatened, endangered, and sensitive/rare plant and animal species.

The WDNR provides professional, forward-looking stewardship of Washington state lands, natural resources, and the environment, and provides leadership in creating a sustainable future for the state trusts and all citizens. The Department believes that by entering into this agreement, its ability to act in the best interest of the state trust lands will be furthered and enhanced.

The WDFW serves Washington's citizens by protecting, restoring, and enhancing diverse, healthy fish and wildlife populations and habitats, while providing sustainable fish and wildlife-related recreational and commercial opportunities.

The Yakama Nation is a federally recognized Indian Tribe, under the Treaty of 1855, and has rights and privileges for Usual and Accustom and Ceded Areas, including those areas listed in this agreement.

The Nature Conservancy is a private, non-profit organization incorporated in the District of Columbia whose mission is to preserve the plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive.

The Conservancy is especially interested in promoting conservation of the best examples of representative ecosystems, natural communities, and viable populations of native species.

IV. USFS TASKS. The USFS, consistent with its primary objectives and responsibilities and within the limitations of available funds and personnel, shall:

1. Make National Forest System lands available for the furtherance of The Tapash Sustainable Forests Collaborative, subject to applicable federal law, regulations, Forest Plans, and approval by the appropriate USFS official.

2. Cooperate within The Tapash Sustainable Forests Collaborative in carrying out programs and activities of the National Forest System, including the development and implementation of forest plans, watershed and other ecological assessments, local projects, and heritage programs which provide information for sharing through an interstate data network for conserving biological diversity and conserving and managing wildlife, fish and sensitive/rare plant resources.

3. Enter into specific agreements or contracts to accomplish agreed upon work projects.

4. Consistent with Forest Plans and other USFS direction, provide leadership and share information across landownership boundaries for the landscape assessments and for the planning, implementation, and monitoring of projects or administrative studies undertaken pursuant to this MOU.

5. Make every reasonable effort to secure public and private funds necessary to its performance under the terms of this MOU.

6. Meet at least annually with The Tapash Sustainable Forests Collaborative to monitor progress and to plan jointly for upcoming activities, including grant proposal writing, implementation projects, sub-agreement drafting, public outreach, and cross-ownership public use activities.

V. WDNR TASKS. WDNR, consistent with its fiduciary obligations, state laws, policies of the Board of Natural Resources, and within the limitations of available funds and personnel, shall:

1. Make WDNR managed lands available for the furtherance of The Tapash Sustainable Forests Collaborative, subject to applicable federal, state, and county laws, regulations, Habitat Conservation Plan, and approval by the appropriate WDNR official.

2. Participate within The Tapash Sustainable Forests Collaborative in carrying out programs and activities of the WDNR, including the development and implementation of landscape plans, local projects, and heritage programs.

3. Make every reasonable effort to secure public and private funds necessary to its performance under the terms of this MOU.

4. WDNR will assign appropriate personnel together with facilities and equipment normally considered necessary to their work, to assist in achieving the goals of The Tapash Sustainable Forests Collaborative.

5. Meet at least annually with The Tapash Sustainable Forests Collaborative to monitor progress and to plan jointly for upcoming activities, including grant proposal writing, implementation projects, sub-agreement drafting, public outreach, and cross-ownership public use activities.

VI. WDFW TASKS. WDFW, consistent with its primary objectives and responsibilities and within the limitations of available funds and personnel, shall:

1. Make WDFW managed lands available for the furtherance of this The Tapash Sustainable Forests Collaborative, subject to applicable federal, state, and county laws, regulations, and approval by the appropriate WDFW official.

2. Participate within the Tapash Sustainable Forests Collaborative in carrying out programs and activities of the WDFW, including the development and implementation of ecoregional assessments, wildlife area plans, landscape/watershed plans, local projects, and the heritage database.

3. Make every reasonable effort to secure public and private funds necessary to its performance under the terms of this MOU.

4. Assign appropriate personnel, together with facilities and equipment normally considered necessary to their work, to assist in achieving the goals of The Tapash Sustainable Forests Collaborative.

5. Meet at least annually with The Tapash Sustainable Forests Collaborative to monitor progress and to plan jointly for upcoming activities, including grant proposal writing, implementation projects, sub-agreement drafting, public outreach, and cross-ownership public use activities.

VII. THE YAKAMA NATION TASKS. The Yakama Nation consistent with its primary objectives and responsibilities and within the limitations of available funds and personnel, shall:

1. Cooperate with the agencies and organizations listed in this MOU.

2. Collaboratively work with and actively participate in the development of specific project proposals, including but not limited to Stewardship Contracting, to meet the objects of this agreement.

3. Support the federal and state agencies to secure public and private funds necessary to its performance under the terms of this MOU.

4. Assign appropriate personnel, together with facilities and equipment normally considered necessary to their work, to assist in achieving the goals of this MOU.

VIII. THE NATURE CONSERVANCY TASKS. The Conservancy, consistent with its primary objectives and responsibilities and within the limitations of available funds and personnel, shall:

1. Cooperate fully with the YN, USFS, WDNR, and WDFW in carrying out the projects and other collaboration which the parties thereto provide support.

2. Enter into specific agreements or contracts to accomplish agreed upon work projects.

3. Meet at least annually with The Tapash Sustainable Forests Collaborative to monitor progress and to plan jointly for upcoming activities, including grant proposal writing, implementation projects, sub-agreement drafting, public outreach, and cross-ownership public use activities.

4. As determined by specific agreement, provide support for the implementation of projects that further The Conservancy's mission of conserving biological diversity.

5. Coordinate ecoregional assessments, as defined by the MOU signed by The Conservancy, WDNR, and WDFW titled "To Collaborate In Developing and Applying Ecoregional Conservation Assessments", and Conservation Action Plans (CAPs) to support project implementation within The Tapash Sustainable Forests Collaborative.

6. Provide land for project implementation, and to support the overall goals of The Tapash Sustainable Forests Collaborative.

7. Provide resources, including staff, political support, and funding to the extent possible.

8. Seek to pool resources to leverage the goals of The Tapash Sustainable Forests Collaborative.

IX. GENERAL UNDERSTANDINGS. In connection with their execution of this MOU, the parties commit to the following mutual understandings:

1. FREEDOM OF INFORMATION ACT (FOIA). Any information furnished to the USFS under this MOU is subject to the provisions of FOIA (5 U.S.C. § 552).

2. PUBLIC DISCLOSURE ACT. Any information furnished to the Washington Department of Natural Resources or the Washington Department of Fish and Wildlife under this instrument is subject to the Public Disclosure Act {Chapter 42.17.250-.348 RCW (through 6/30/06), recodified as Chapter 42.56 RCW, effective 7/1/06}.

3. MODIFICATION. Modifications to the scope or terms of this MOU shall be made by mutual consent of the parties through a written modification, signed and dated by all parties.

4. PARTICIPATION IN SIMILAR ACTIVITIES. This instrument in no way restricts The Tapash Sustainable Forests Collaborative members from participating in similar activities with other public or private agencies, organizations, and individuals.

5. COMMENCEMENT/EXPIRATION/TERMINATION. The instrument is executed as of the date of the last signature and is effective through December 31, 2011 at which time it will expire automatically unless extended by a written modification as described in Section VIII. 2.

6. TERMINATION. Any of the parties may terminate its participation in this MOU in whole, or in part, by providing 60 days written notice. The remaining parties may, upon their mutual consent, continue the Collaborative among themselves.

7. PRINCIPAL CONTACTS. The principal contacts for the parties to this MOU are:

USFS Project Contact USFS Administrative Contact
Peter Forbes Rick Edwards
Okanogan and Wenatchee National
Forests, Naches Ranger District
Okanogan & Wenatchee National
Forests
10237 Hwy 12 215 Melody Lane
Naches, WA 98937 Wenatchee, WA 98801-5933
Phone: 509-653-1440 Phone: 509-664-9315
FAX: 509-653-2638 FAX: 509-664-9281
E-Mail: pforbes@fs.fed.us E-Mail: redwards@fs.fed.us

WDNR Project Contact WDNR Administrative Contact
George Shelton
713 Bowers Rd.
Ellensburg, WA 98926-9301
Phone:509-925-8510 Phone:
FAX:509-925-8522 FAX:
E-Mail: george.shelton@wadnr.gov E-Mail:

WDFW Project Contact WDFW Administrative Contact
Ted Clausing
1701 South 24th Avenue
Yakima, WA 98902
Phone: 509-457-9313 Phone:
FAX: 509-575-2474 FAX:
E-Mail: claustac@dfw.wa.gov E-Mail:

YN Project Contact YN Administrative Contact
Philip Rigdon, Deputy Director
YN Division of Natural Resources
P.O. Box 151, 401 Fort Road
Toppenish, WA 98948
Phone: 509-865-5121 x4655 Phone:

FAX: 509-865-6850 FAX:
E-Mail: prigdon@yakama.com E-Mail:

The Conservancy Project Contact The Conservancy Administrative
Contact
Betsy Bloomfield, South Central WA
Program Director
Melinda Milner
The Nature Conservancy The Nature Conservancy
507 S. 5th Ave. 1917 First Avenue
Yakima, WA 98902 Seattle, WA 98101
Phone: 509.248.6672 Phone: 206.343.4344
FAX: 509.248.6697 FAX: 206.343.5608
E-mail: bbloomfield@tnc.org E-mail: amoraes@tnc.org

8. NON-FUND OBLIGATING DOCUMENT: Nothing in this MOU shall obligate either the USFS, WDNR, WDFW, YN or The Conservancy to obligate or transfer any funds. Specific work projects or activities that involve the transfer of funds, services, or property among the various agencies and offices of the USFS, WDNR, WDFW, and The Conservancy will require execution of separate written agreements and shall be contingent upon the availability of appropriated funds. Such activities must be independently authorized by appropriate statutory authority. This MOU does not provide such authority. Negotiation, execution, and administration of each such agreement must comply with all applicable statues and regulations.

9. ESTABLISHMENT OF RESPONSIBILITY. This MOU is not intended to, and does not create, any right, benefit, or trust responsibility, substantive or procedural, enforceable at law or equity, by any of the parties to this MOU or by a party against the United States, its agencies, its officers, or any person.

10. NO ENTITY OR PARTNERSHIP. No party to this MOU is to be considered a partner, agent, or employee of the other party for any purpose, and this MOU shall not create a partnership, joint venture, or any other legal entity or principal-agent relationship between the parties. No party shall have any right, power, or authority to create any obligation, expressed or implied, on behalf of another party.

11. The Yakama Nation does not waive, alter, or otherwise diminish its Sovereign Immunity, whether expressed or implied, by virtue of this MOU for any and all administrative or legal action which may arise directly or indirectly from the same, nor does the Yakama Nation waive, alter, or otherwise diminish their rights, privileges, remedies or services guaranteed by the Treaty of 1855.

IN WITNESS WHEREOF, each of the parties has caused this agreement to be executed by an authorized representative on the day and year set forth opposite their signature.

By: ___________________________________ Date: _______________
Linda Goodman, Regional Forester, USFS Region 6
United States Forest Service

By: ___________________________________ Date: _______________
Rebecca Lockett Heath, Forest Supervisor, USFS Region 6
Okanogan and Wenatchee National Forests

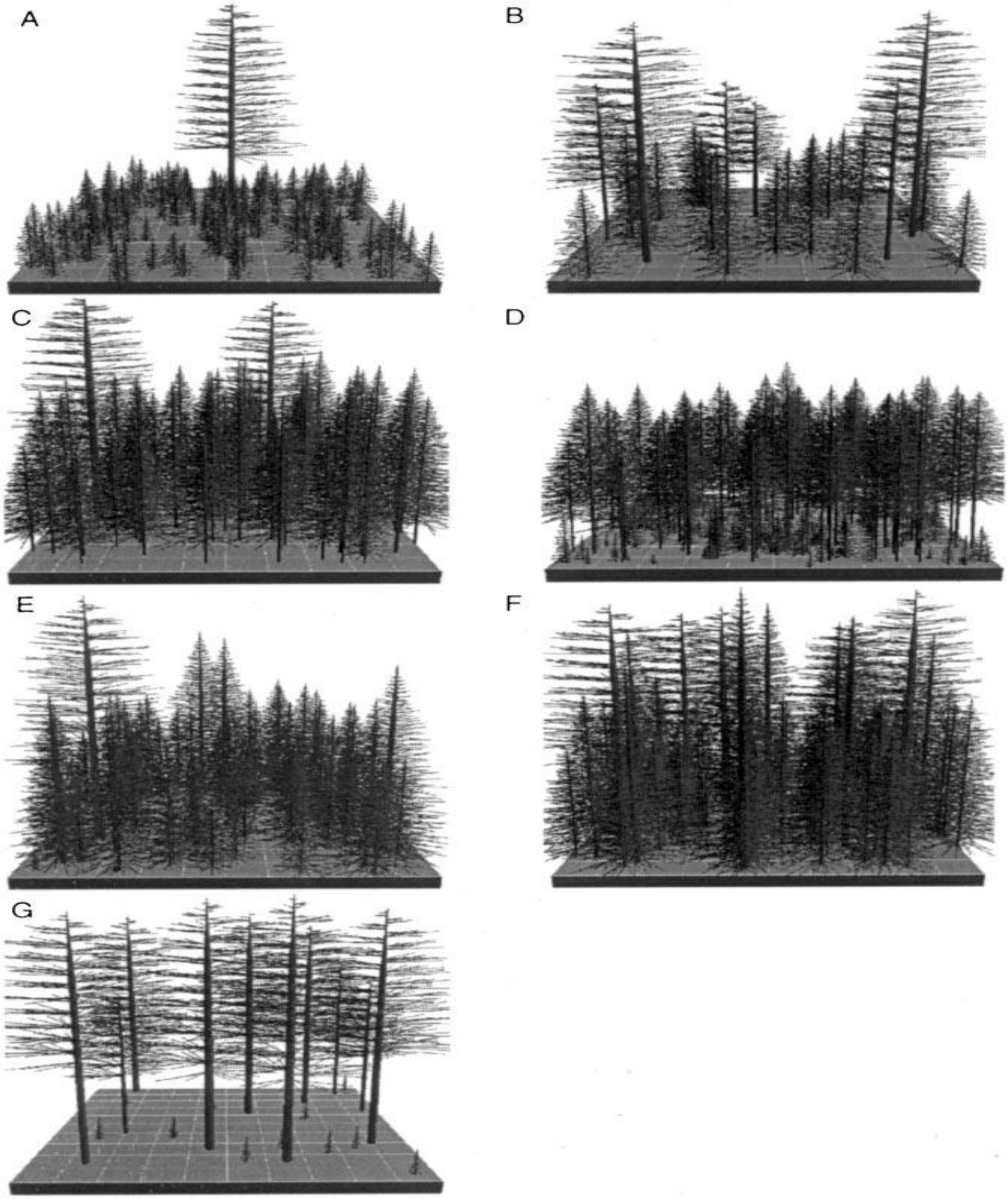
By: ___________________________________ Date: _______________
Doug Sutherland, Commissioner of Public Lands
Washington Department of Natural Resources

By: ___________________________________ Date: _______________
Jeffrey P. Koenings, Director
Washington Department of Fish and Wildlife

By: ___________________________________ Date: _______________
Lavina Washines, Chairperson
Yakama Nation Tribal Council

By: ___________________________________ Date: _______________
David H. Weekes, Washington State Director
The Nature Conservancy

Appendix 11: Visual Representation of Forest Structural Classes



Graphical representation of forest structural classes used in the mid-scale assessment of the interior Columbia River basin; (A) stand initiation, (B) open stem exclusion, (C) closed stem exclusion, (D) understory reinitiation, (E) young multi-story forest, (F) old multi-story forest, (G) old single story forest. (Hessburg et al. 2000).

Appendix 12: Descriptive Key for LANDFIRE, Cover Type, and Structure Classes

LANDFIRE Code Numeric		LANDFIRE Code Name
Environmental Site Potential	Biophysical Settings	
11	11	Open Water
12	12	Perrennial Ice/Snow
31	31	Barren-Rock/Sand/Clay
1018	721	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland
1037	724	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest
1038	725	North Pacific Maritime Mesic Subalpine Parkland
1041	—	North Pacific Mountain Hemlock Forest
1042	729	North Pacific Mesic Western Hemlock-Silver Fir Forest
1045	730	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
1046	731	Northern Rocky Mountain Subalpine Woodland and Parkland
1053	—	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
1055	733	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
1056	734	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland
1060	735	East Cascades Oak-Ponderosa Pine Forest and Woodland
1068	738	North Pacific Dry and Mesic Alpine Dwarf-Shrubland or Fell-field or Meadow
1124	745	Columbia Plateau Low Sagebrush Steppe
1125	746	Inter-Mountain Basins Big Sagebrush Steppe
1126	747	Inter-Mountain Basins Montane Sagebrush Steppe
1139	—	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland
1154	749	Inter-Mountain Basins Montane Riparian Systems
1156	750	North Pacific Lowland Riparian Forest and Shrubland
1157	—	North Pacific Swamp Systems
1158	—	North Pacific Montane Riparian Woodland and Shrubland
1167	755	Rocky Mountain Poor-Site Lodgepole Pine Forest
1171	756	North Pacific Alpine and Subalpine Dry Grassland

1174	758	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
—	719	Rocky Mountain Alpine/Montane Sparsely Vegetated Systems
—	720	North Pacific Oak Woodland
—	727	North Pacific Mountain Hemlock Forest - Wet
—	728	North Pacific Mountain Hemlock Forest - Xeric
—	732	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna - Mesic
—	737	Columbia Plateau Scabland Shrubland
—	740	North Pacific Avalanche Chute Shrubland
—	741	North Pacific Montane Shrubland
—	742	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
—	744	Columbia Plateau Steppe and Grassland
—	748	North Pacific Montane Grassland
—	752	North Pacific Montane Riparian Woodland and Shrubland - Wet
—	753	North Pacific Montane Riparian Woodland and Shrubland - Dry

Cover Type Code Name	**Cover Type Code Numeric**	**Cover Type Common Name**
pipo	10	Ponderosa Pine
laoc	11	Western Larch
pico	12	Lodgepole Pine
psme	13	Douglas-Fir
abgr/abco	14	Grand Fir / White Fir
abam	15	Pacific Silver Fir
abla2/pien	16	Subalpine Fir / Engelmann spruce
tsme	18	Mountain Hemlock
pial/laly	19	Whitebark Pine / Subalpine Larch
pila/pimo	20	Sugar Pine / Western White Pine
aspen/cottonwood-wil	21	aspen/cottonwood-willow
rock	28	Rock
water	29	Water
bg/roadcut	34	Bare Ground / Roadcut
bare ground	35	Bare Ground
cropland	43	Cropland
urban/rural	44	Urban / Rural
pasture	45	Pasture

woodland	47	Woodland
non_frst1_2	49	native bunchgrasses
non_frst1_3	50	native bunchgrasses
non_frst2_2	52	annual grasses, seeded wheatgrasses, exotic forb
non_frst3_2	55	native moist site herb
non_frst3_3	56	native moist site herb
non_frst4_2	58	low sagebrush, big sagebrush/bitterbrush
non_frst5_3	62	mahogany
non_frst6_2	64	mountain shrub
non_frst7_2	66	wet site shrub
non_frst6_3	70	mountain shrub

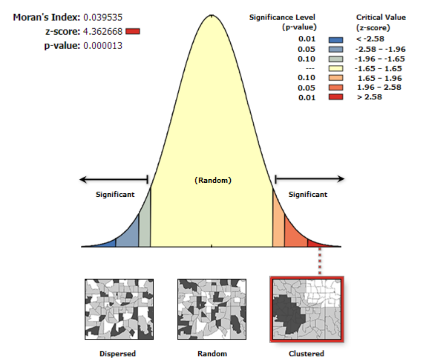
Structure Class Code Name	**Structure Class Code Numeric**	**Structure Class Common Name**
si	10	Stand Initiation
seoc	11	Stem Exclusion Open Canopy
secc	12	Stem Exclusion Closed Canopy
ur	13	Understory Reinitiation
yfms	14	Young Forest Multi-Story
ofms	15	Old Forest Multi-Story
ofss	16	Old Forest Single Story
oh	17	Open Herbland
ch	18	Closed Herbland
ols	20	Open Low Shrubland
cts	23	Closed Tall Shrubland
ots	22	Open Tall Shrubland
nf	24	Non-Forest / Non-Range

Appendix 13: ArcGIS Spatial Statistic Outputs

LANDFIRE Potential Vegetation

Environmental Site Potential

Spatial Autocorrelation Report



Given the z-score of 4.36, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

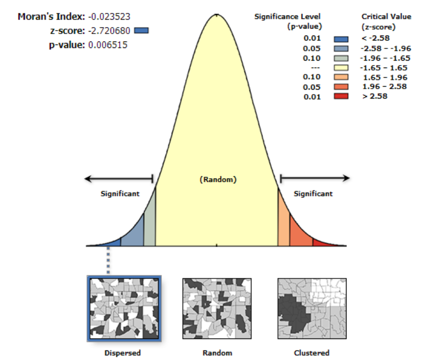
Global Moran's I Summary

Moran's Index:	0.039535
Expected Index:	-0.000151
Variance:	0.000083
z-score:	4.362668
p-value:	0.000013

Dataset Information

Input Feature Class:	nachesesp
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Spatial Autocorrelation Report



Given the z-score of -2.72, there is a less than 1% likelihood that this dispersed pattern could be the result of random chance.

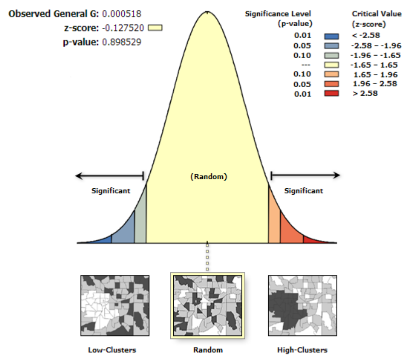
Global Moran's I Summary

Moran's Index:	-0.023523
Expected Index:	-0.000119
Variance:	0.000074
z-score:	-2.720680
p-value:	0.006515

Dataset Information

Input Feature Class:	Yakama_ESP
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -0.13, the pattern does not appear to be significantly different than random.

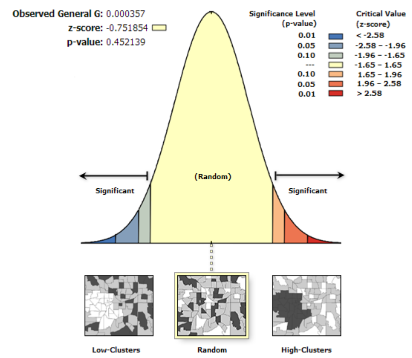
General G Summary

Observed General G:	0.000518
Expected General G:	0.000521
Variance:	0.000000
z-score:	-0.127520
p-value:	0.898529

Dataset Information

Input Feature Class:	nachesesp
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -0.75, the pattern does not appear to be significantly different than random.

General G Summary

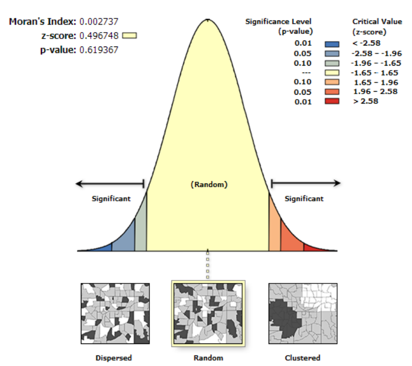
Observed General G:	0.000357
Expected General G:	0.000362
Variance:	0.000000
z-score:	-0.751854
p-value:	0.452139

Dataset Information

Input Feature Class:	Yakama_ESP
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Biophysical Settings

Spatial Autocorrelation Report



Given the z-score of 0.50, the pattern does not appear to be significantly different than random.

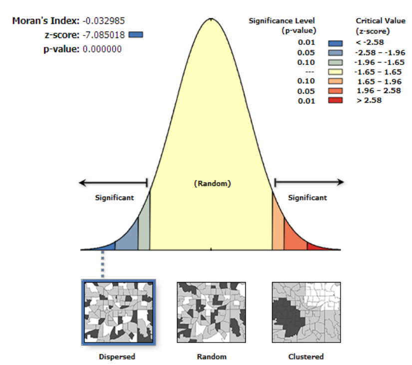
Global Moran's I Summary

Moran's Index:	0.002737
Expected Index:	-0.000059
Variance:	0.000032
z-score:	0.496748
p-value:	0.619367

Dataset Information

Input Feature Class:	nachesbps
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Spatial Autocorrelation Report



Given the z-score of -7.09, there is a less than 1% likelihood that this dispersed pattern could be the result of random chance.

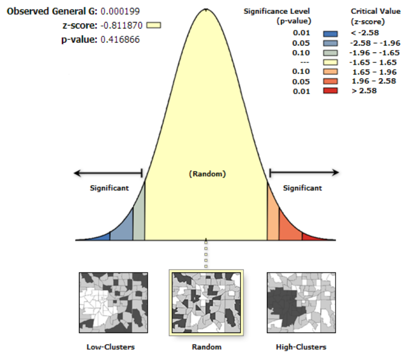
Global Moran's I Summary

Moran's Index:	-0.032985
Expected Index:	-0.000041
Variance:	0.000022
z-score:	-7.085018
p-value:	0.000000

Dataset Information

Input Feature Class:	yakamabps
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -0.81, the pattern does not appear to be significantly different than random.

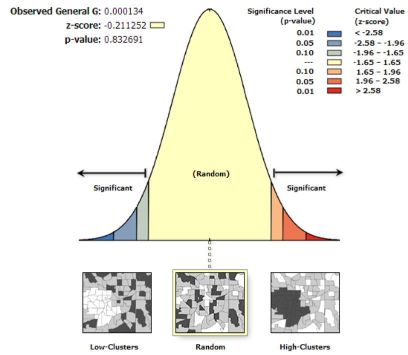
General G Summary

Observed General G:	0.000199
Expected General G:	0.000202
Variance:	0.000000
z-score:	-0.811870
p-value:	0.416866

Dataset Information

Input Feature Class:	nachesbps
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -0.21, the pattern does not appear to be significantly different than random.

General G Summary

Observed General G:	0.000134
Expected General G:	0.000134
Variance:	0.000000
z-score:	-0.211252
p-value:	0.832691

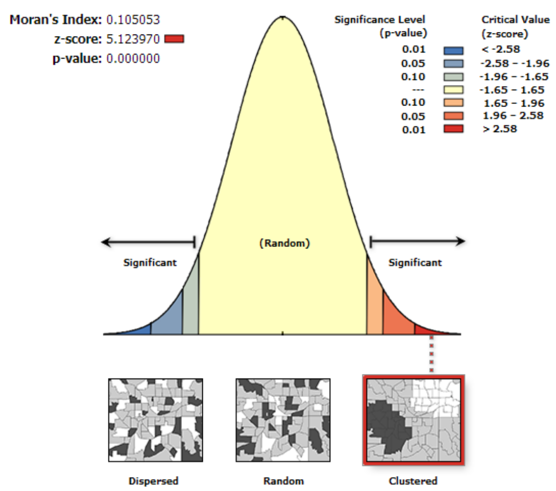
Dataset Information

Input Feature Class:	yakamabps
Input Field:	GRIDCODE
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Vegetation Mapping Units

Cover Type

Spatial Autocorrelation Report



Given the z-score of 5.12, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

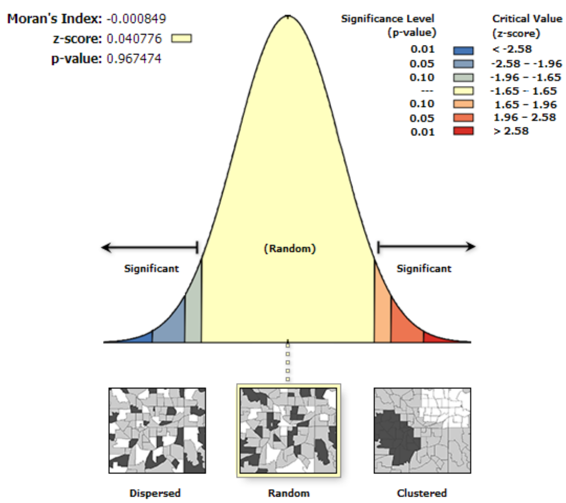
Global Moran's I Summary

Moran's Index:	0.105053
Expected Index:	-0.001174
Variance:	0.000430
z-score:	5.123970
p-value:	0.000000

Dataset Information

Input Feature Class:	Naches
Input Field:	CT
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Spatial Autocorrelation Report



Given the z-score of 0.04, the pattern does not appear to be significantly different than random.

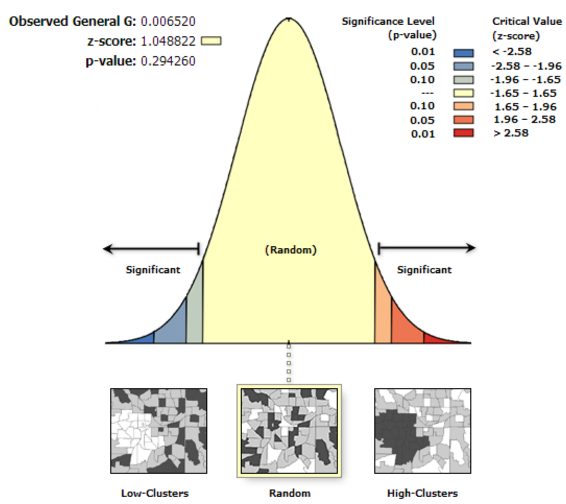
Global Moran's I Summary

Moran's Index:	-0.000849
Expected Index:	-0.001972
Variance:	0.000759
z-score:	0.040776
p-value:	0.967474

Dataset Information

Input Feature Class:	Yakama
Input Field:	CT
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of 1.05, the pattern does not appear to be significantly different than random.

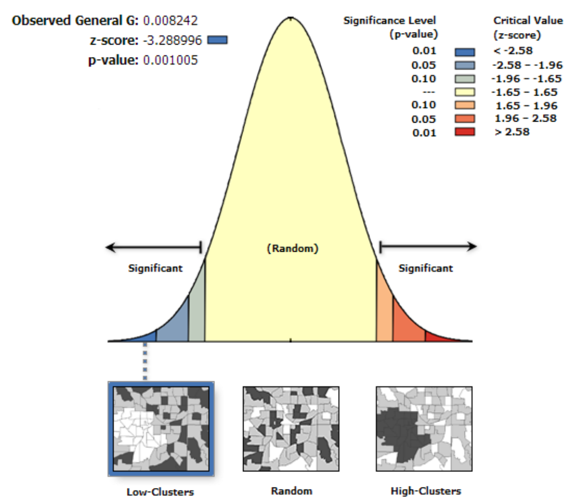
General G Summary

Observed General G:	0.006520
Expected General G:	0.006288
Variance:	0.000000
z-score:	1.048822
p-value:	0.294260

Dataset Information

Input Feature Class:	Naches
Input Field:	CT
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -3.29, there is a less than 1% likelihood that this low-clustered pattern could be the result of random chance.

General G Summary

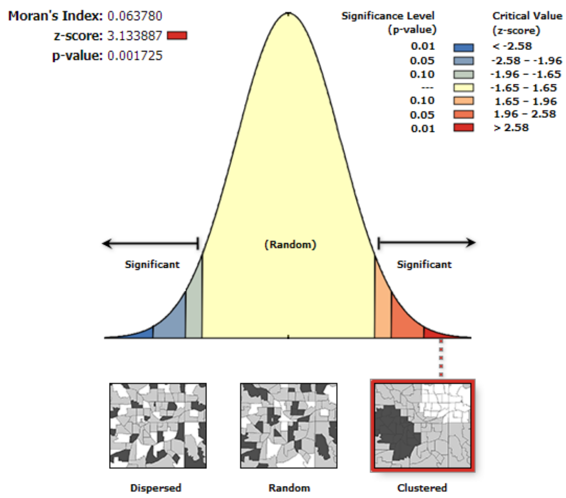
Observed General G:	0.008242
Expected General G:	0.010017
Variance:	0.000000
z-score:	-3.288996
p-value:	0.001005

Dataset Information

Input Feature Class:	Yakama
Input Field:	CT
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Structure Class

Spatial Autocorrelation Report



Given the z-score of 3.13, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

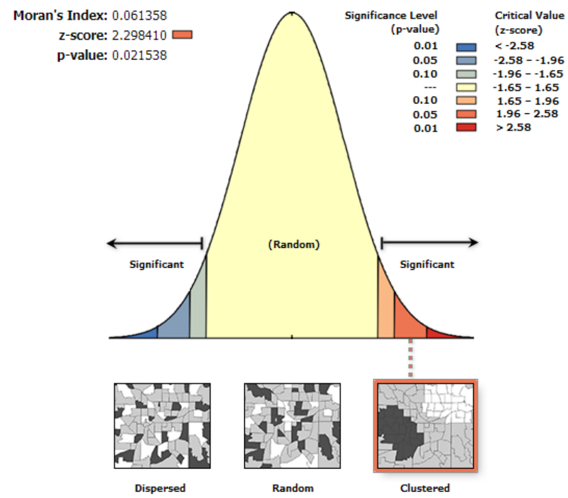
Global Moran's I Summary

Moran's Index:	0.063780
Expected Index:	-0.001174
Variance:	0.000430
z-score:	3.133887
p-value:	0.001725

Dataset Information

Input Feature Class:	Naches
Input Field:	SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Spatial Autocorrelation Report



Given the z-score of 2.30, there is a less than 5% likelihood that this clustered pattern could be the result of random chance.

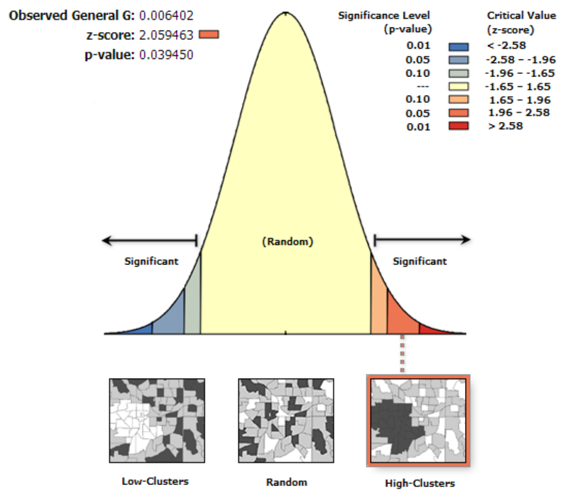
Global Moran's I Summary

Moran's Index:	0.061358
Expected Index:	-0.001972
Variance:	0.000759
z-score:	2.298410
p-value:	0.021538

Dataset Information

Input Feature Class:	Yakama
Input Field:	SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of 2.06, there is a less than 5% likelihood that this high-clustered pattern could be the result of random chance.

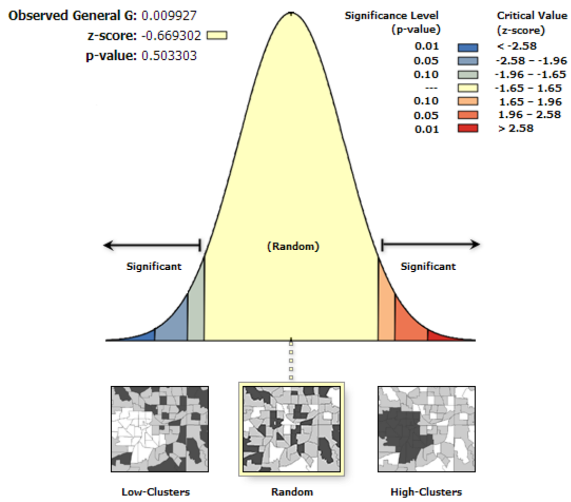
General G Summary

Observed General G:	0.006402
Expected General G:	0.006288
Variance:	0.000000
z-score:	2.059463
p-value:	0.039450

Dataset Information

Input Feature Class:	Naches
Input Field:	SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -0.67, the pattern does not appear to be significantly different than random.

General G Summary

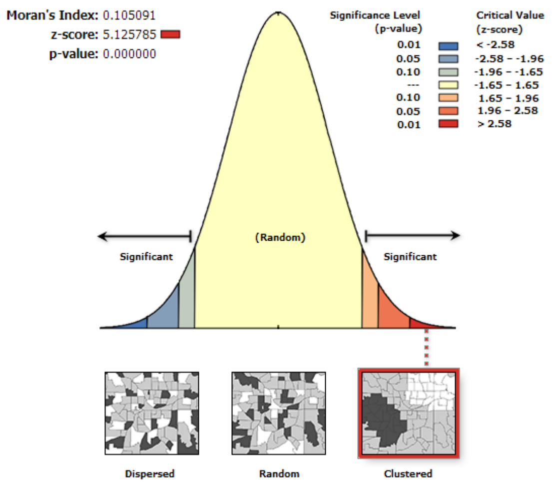
Observed General G:	0.009927
Expected General G:	0.010017
Variance:	0.000000
z-score:	-0.669302
p-value:	0.503303

Dataset Information

Input Feature Class:	Yakama
Input Field:	SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Cover Structure Composite Class

Spatial Autocorrelation Report



Given the z-score of 5.13, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

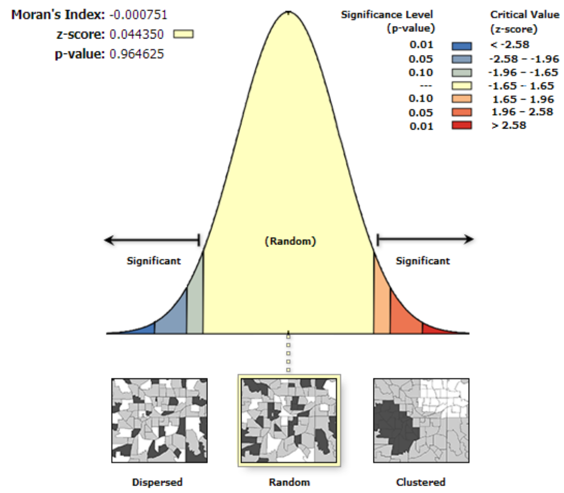
Global Moran's I Summary

Moran's Index:	0.105091
Expected Index:	-0.001174
Variance:	0.000430
z-score:	5.125785
p-value:	0.000000

Dataset Information

Input Feature Class:	Naches
Input Field:	CT_SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Spatial Autocorrelation Report



Given the z-score of 0.04, the pattern does not appear to be significantly different than random.

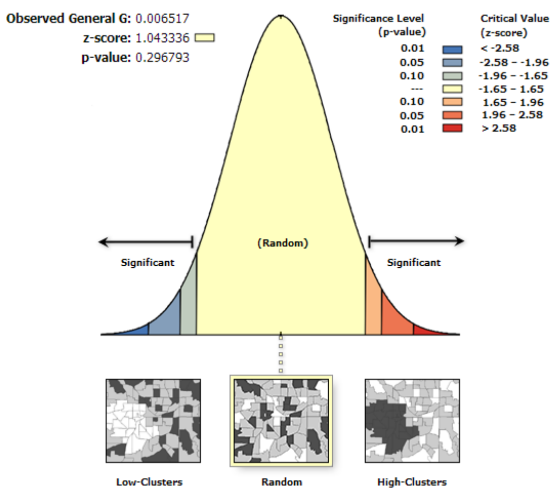
Global Moran's I Summary

Moran's Index:	-0.000751
Expected Index:	-0.001972
Variance:	0.000759
z-score:	0.044350
p-value:	0.964625

Dataset Information

Input Feature Class:	Yakama
Input Field:	CT_SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of 1.04, the pattern does not appear to be significantly different than random.

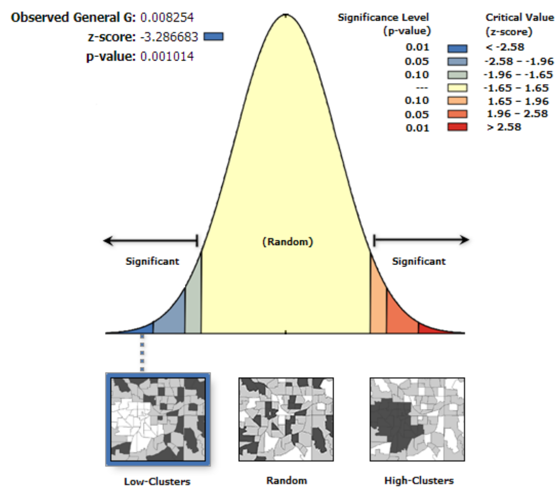
General G Summary

Observed General G:	0.006517
Expected General G:	0.006288
Variance:	0.000000
z-score:	1.043336
p-value:	0.296793

Dataset Information

Input Feature Class:	Naches
Input Field:	CT_SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

High-Low Clustering Report



Given the z-score of -3.29, there is a less than 1% likelihood that this low-clustered pattern could be the result of random chance.

General G Summary

Observed General G:	0.008254
Expected General G:	0.010017
Variance:	0.000000
z-score:	-3.286683
p-value:	0.001014

Dataset Information

Input Feature Class:	Yakama
Input Field:	CT_SS
Conceptualization:	CONTIGUITY_EDGES_ONLY
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold.:	None
Weights Matrix File:	None

Appendix 14: Permutational Multivariate Analysis of Variance (PERMANOVA) Outputs

LANDFIRE Models

RGui (64-bit) - [R Console]

File Edit View Misc Packages Windows Help

```
> ESP.perm<- adonis(ESP.bcd~ Ownership, data= ESP.expln)
> ESP.perm

Call:
adonis(formula = ESP.bcd ~ Ownership, data = ESP.expln)

          Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership  1     0.308 0.30753 0.62674 0.00684  0.992
Residuals 91    44.652 0.49068         0.99316
Total     92    44.959                 1.00000
> ESP.perm<- adonis(ESP.bcd~ Watershed, data= ESP.expln)
> ESP.perm

Call:
adonis(formula = ESP.bcd ~ Watershed, data = ESP.expln)

          Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Watershed  5     1.459 0.29185  0.5837 0.03246      1
Residuals 87    43.500 0.50000         0.96754
Total     92    44.959                 1.00000
> ESP.perm<- adonis(ESP.bcd~ Ownership+Watershed, data= ESP.expln)
> ESP.perm

Call:
adonis(formula = ESP.bcd ~ Ownership + Watershed, data = ESP.expln)

          Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership  1     0.308 0.30753 0.61505 0.00684  0.993
Watershed  4     1.152 0.28793 0.57586 0.02562  1.000
Residuals 87    43.500 0.50000         0.96754
Total     92    44.959                 1.00000
> ESP.perm<- adonis(ESP.bcd~ Ownership:Watershed, data= ESP.expln)
```

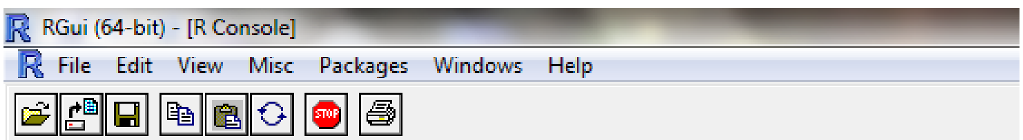
```
> ESP.perm<- adonis(ESP.bcd~ Ownership:Watershed, data= ESP.expln)
> ESP.perm

Call:
adonis(formula = ESP.bcd ~ Ownership:Watershed, data = ESP.expln)

                    Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership:Watershed  5     1.459 0.29185  0.5837 0.03246      1
Residuals           87    43.500 0.50000         0.96754
Total               92    44.959                 1.00000
> ESP.perm<- adonis(ESP.bcd~ Ownership+Watershed + Ownership:Watershed, data= ESP.expln)
> ESP.perm

Call:
adonis(formula = ESP.bcd ~ Ownership + Watershed + Ownership:Watershed,      data = ESP.expln)

          Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership  1     0.308 0.30753 0.61505 0.00684  0.991
Watershed  4     1.152 0.28793 0.57586 0.02562  1.000
Residuals 87    43.500 0.50000         0.96754
Total     92    44.959                 1.00000
```




```
> BPS.perm<- adonis(BPS.bcd~ Ownership, data= BPS.expln)
> BPS.perm

Call:
adonis(formula = BPS.bcd ~ Ownership, data = BPS.expln)

           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership   1     0.301 0.30129 0.61108 0.00498  0.999
Residuals 122    60.153 0.49306         0.99502
Total     123    60.454                 1.00000
> BPS.perm<- adonis(BPS.bcd~ Watershed, data= BPS.expln)
> BPS.perm

Call:
adonis(formula = BPS.bcd ~ Watershed, data = BPS.expln)

           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Watershed   5     1.454 0.29081 0.58161 0.02405      1
Residuals 118    59.000 0.50000         0.97595
Total     123    60.454                 1.00000
> BPS.perm<- adonis(BPS.bcd~ Ownership+Watershed, data= BPS.expln)
> BPS.perm

Call:
adonis(formula = BPS.bcd ~ Ownership + Watershed, data = BPS.expln)

           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership   1     0.301 0.30129 0.60259 0.00498      1
Watershed   4     1.153 0.28818 0.57637 0.01907      1
Residuals 118    59.000 0.50000         0.97595
Total     123    60.454                 1.00000
> BPS.perm<- adonis(BPS.bcd~ Ownership:Watershed, data= BPS.expln)
```

```
> BPS.perm<- adonis(BPS.bcd~ Ownership:Watershed, data= BPS.expln)
> BPS.perm

Call:
adonis(formula = BPS.bcd ~ Ownership:Watershed, data = BPS.expln)

                     Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership:Watershed   5     1.454 0.29081 0.58161 0.02405      1
Residuals           118    59.000 0.50000         0.97595
Total               123    60.454                 1.00000
> BPS.perm<- adonis(BPS.bcd~ Ownership+Watershed + Ownership:Watershed, data= BPS.expln)
> BPS.perm

Call:
adonis(formula = BPS.bcd ~ Ownership + Watershed + Ownership:Watershed,      data = BPS.expln)

           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership   1     0.301 0.30129 0.60259 0.00498  0.999
Watershed   4     1.153 0.28818 0.57637 0.01907  1.000
Residuals 118    59.000 0.50000         0.97595
Total     123    60.454                 1.00000
```

Vegetation Mapping Units Models

```
> N.Cover.respn.perm<- adonis(N.Cover.respn.bcd~ SUBWATERSHED + ESP_nam
> N.Cover.respn.perm

Call:
adonis(formula = N.Cover.respn.bcd ~ SUBWATERSHED + ESP_name +      LOG

                       Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED            2     18.63  9.3169 27.0693 0.05300   0.01 **
ESP_name               11     22.12  2.0113  5.8436 0.06293   0.01 **
LOG_TYPE_code           4      6.51  1.6282  4.7305 0.01853   0.01 **
Elev_class             29     22.40  0.7724  2.2441 0.06372   0.01 **
BPS_name               15      7.08  0.4717  1.3706 0.02013   0.01 **
SUBWATERSHED:ESP_name   9      5.66  0.6288  1.8268 0.01610   0.01 **
Residuals             782    269.16  0.3442         0.76560
Total                 852    351.56                 1.00000
```

```
>
> Y.Cover.respn.perm<- adonis(Y.Cover.respn.bcd~ SUBWATERSHED + LOG_TYPE_co
> Y.Cover.respn.perm

Call:
adonis(formula = Y.Cover.respn.bcd ~ SUBWATERSHED + LOG_TYPE_code +      El

                           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED                2     4.580 2.28988  5.8326 0.02088   0.01 **
LOG_TYPE_code               4     3.449 0.86237  2.1966 0.01573   0.01 **
Elev_class                 22    16.550 0.75226  1.9161 0.07545   0.01 **
Slope_code                 57    25.590 0.44895  1.1435 0.11666   0.01 **
SUBWATERSHED:LOG_TYPE_code  7     4.741 0.67727  1.7251 0.02161   0.01 **
SUBWATERSHED:Elev_class    25    11.335 0.45338  1.1548 0.05167   0.03 *
Residuals                 390   153.114 0.39260         0.69801
Total                     507   219.359                 1.00000
```

```
> Cover.respn.perm<- adonis(Cover.respn.bcd~ Ownership + SUBWATERSHED + Elev_class +
> Cover.respn.perm

Call:
adonis(formula = Cover.respn.bcd ~ Ownership + SUBWATERSHED +      Elev_class + LOG_T

                                   Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership                           1      6.15  6.1518 17.1177 0.01066   0.01 **
SUBWATERSHED                        4     23.21  5.8034 16.1483 0.04023   0.01 **
Elev_class                         29     50.17  1.7301  4.8142 0.08695   0.01 **
LOG_TYPE_code                       4      5.08  1.2695  3.5326 0.00880   0.01 **
BPS_name                           18      8.39  0.4660  1.2966 0.01454   0.03 *
Slope_code                         76     30.76  0.4047  1.1261 0.05330   0.03 *
Ownership:LOG_TYPE_code             4      2.73  0.6820  1.8977 0.00473   0.02 *
Ownership:BPS_name                  9      4.50  0.5005  1.3928 0.00781   0.04 *
SUBWATERSHED:Elev_class            88     35.89  0.4078  1.1348 0.06219   0.01 **
SUBWATERSHED:LOG_TYPE_code         12      6.72  0.5601  1.5586 0.01165   0.01 **
Ownership:Elev_class:LOG_TYPE_code 91     35.46  0.3896  1.0842 0.06144   0.04 *
Residuals                        1024    368.01  0.3594         0.63771
Total                            1360    577.07                 1.00000
```

```
> N.Strctr.respn.perm<- adonis(N.Strctr.respn.bcd~ SUBWATERSHED + LOG_TYPE_code + BPS_nam
> N.Strctr.respn.perm

Call:
adonis(formula = N.Strctr.respn.bcd ~ SUBWATERSHED + LOG_TYPE_code +      BPS_name + SUBW

                            Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED                 2      3.86 1.93027  4.8465 0.01077   0.01 **
LOG_TYPE_code                4      8.65 2.16372  5.4327 0.02415   0.01 **
BPS_name                    17     12.73 0.74911  1.8809 0.03554   0.01 **
SUBWATERSHED:LOG_TYPE_code   5      4.93 0.98645  2.4768 0.01376   0.01 **
Residuals                  824    328.18 0.39828         0.91578
Total                      852    358.36                 1.00000
```

```
> Y.Strctr.respn.perm<- adonis(Y.Strctr.respn.bcd~ SUBWATERSHED + LOG_TYPE_code + BPS
> Y.Strctr.respn.perm

Call:
adonis(formula = Y.Strctr.respn.bcd ~ SUBWATERSHED + LOG_TYPE_code +      BPS_name +

                                     Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED                          2     3.928 1.96385  4.7590 0.01754   0.01 **
LOG_TYPE_code                         4     7.921 1.98037  4.7990 0.03538   0.01 **
BPS_name                             10     5.822 0.58215  1.4107 0.02600   0.01 **
SUBWATERSHED:LOG_TYPE_code            7     4.245 0.60642  1.4695 0.01896   0.01 **
SUBWATERSHED:BPS_name                 9     4.754 0.52827  1.2801 0.02124   0.02 *
SUBWATERSHED:LOG_TYPE_code:BPS_name  19     9.023 0.47488  1.1508 0.04030   0.05 *
Residuals                           456   188.174 0.41266         0.84056
Total                               507   223.867                 1.00000
```

```
> Strctr.respn.perm<- adonis(Strctr.respn.bcd~ Ownership + LOG_TYPE_code + SUBWATERSHE
> Strctr.respn.perm

Call:
adonis(formula = Strctr.respn.bcd ~ Ownership + LOG_TYPE_code +      SUBWATERSHED + BP

                                      Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership                              1      9.39  9.3861 23.3290 0.01587   0.01 **
LOG_TYPE_code                          4      9.77  2.4426  6.0711 0.01651   0.01 **
SUBWATERSHED                           4      8.21  2.0518  5.0997 0.01387   0.01 **
BPS_name                              18     13.87  0.7705  1.9149 0.02344   0.01 **
Elev_class                            29     14.27  0.4922  1.2232 0.02412   0.02 *
Ownership:LOG_TYPE_code                4      6.11  1.5283  3.7987 0.01033   0.01 **
LOG_TYPE_code:SUBWATERSHED            12      9.45  0.7872  1.9566 0.01597   0.01 **
LOG_TYPE_code:SUBWATERSHED:BPS_name   61     26.89  0.4408  1.0956 0.04545   0.05 *
Residuals                           1227    493.66  0.4023         0.83443
Total                               1360    591.62                 1.00000
```

```
> N.CTSS.respn.perm<- adonis(N.CTSS.respn.bcd~ SUBWATERSHED + LOG_TYPE_code
> N.CTSS.respn.perm

Call:
adonis(formula = N.CTSS.respn.bcd ~ SUBWATERSHED + LOG_TYPE_code +      ESP_

                            Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED                 2      7.19  3.5935  8.1073 0.01775   0.01 **
LOG_TYPE_code                4      7.14  1.7850  4.0272 0.01764   0.01 **
ESP_name                    11     11.77  1.0698  2.4137 0.02907   0.01 **
Elev_class                  29     17.76  0.6123  1.3814 0.04386   0.01 **
BPS_name                    15      7.44  0.4959  1.1188 0.01837   0.03 *
SUBWATERSHED:LOG_TYPE_code   5      4.43  0.8860  1.9989 0.01094   0.01 **
SUBWATERSHED:ESP_name        9      4.71  0.5232  1.1805 0.01163   0.03 *
Residuals                  777    344.40  0.4432         0.85073
Total                      852    404.83                 1.00000
```

```
> Y.CTSS.respn.perm<- adonis(Y.CTSS.respn.bcd~ SUBWATERSHED + LOG_TYPE_code
> Y.CTSS.respn.perm

Call:
adonis(formula = Y.CTSS.respn.bcd ~ SUBWATERSHED + LOG_TYPE_code +      BPS_

                            Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
SUBWATERSHED                 2     2.954 1.47725  3.2357 0.01208   0.01 **
LOG_TYPE_code                4     4.319 1.07980  2.3652 0.01766   0.01 **
BPS_name                    10     7.032 0.70323  1.5403 0.02875   0.01 **
Elev_class                  21    11.413 0.54348  1.1904 0.04666   0.01 **
SUBWATERSHED:LOG_TYPE_code   7     4.461 0.63732  1.3960 0.01824   0.01 **
SUBWATERSHED:BPS_name        9     4.822 0.53573  1.1734 0.01971   0.01 **
LOG_TYPE_code:BPS_name      14     7.223 0.51591  1.1300 0.02953   0.01 **
LOG_TYPE_code:Elev_class    42    20.674 0.49225  1.0782 0.08452   0.04 *
Residuals                  398   181.704 0.45654         0.74285
Total                      507   244.603                 1.00000
```

```
> CTSS.respn.perm<- adonis(CTSS.respn.bcd~ Ownership + SUBWATERSHED + LOG_TYP
> CTSS.respn.perm

Call:
adonis(formula = CTSS.respn.bcd ~ Ownership + SUBWATERSHED +      LOG_TYPE_co

                             Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
Ownership                     1      3.69  3.6923  8.1913 0.00565   0.01 **
SUBWATERSHED                  4     10.14  2.5354  5.6247 0.01553   0.01 **
LOG_TYPE_code                 4      6.60  1.6488  3.6578 0.01010   0.01 **
ESP_name                     13     13.01  1.0006  2.2198 0.01992   0.01 **
Elev_class                   29     20.85  0.7191  1.5952 0.03193   0.01 **
BPS_name                     17      9.26  0.5445  1.2079 0.01417   0.02 *
Ownership:LOG_TYPE_code       4      4.35  1.0870  2.4114 0.00666   0.01 **
Ownership:ESP_name            5      2.69  0.5381  1.1938 0.00412   0.04 *
SUBWATERSHED:LOG_TYPE_code   12      8.87  0.7388  1.6391 0.01357   0.01 **
SUBWATERSHED:ESP_name        16      7.97  0.4979  1.1046 0.01220   0.04 *
Residuals                  1255    565.71  0.4508         0.86616
Total                      1360    653.12                 1.00000
```

Appendix 15: Background Information

2. Background

2.1 Environmental History

The Cordilleran ice sheet maximum extent reached from the Puget Lowland up the Cascade Range and Coast Mountains of British Columbia to the mountains of coastal south and southeast Alaska and east to the Columbia Plateau connecting the Puget and Okanogan lobes on its way to northwestern Montana (Easterbrook 1979, Booth et al. 2003). The Cordilleran ice sheet maximum extent coincides with the last Pleistocene glacial peak between 25,000 and 18,000 years before present (Roberts 1998). After 18,000 years before present (BP) the world's ice sheets began to retreat and thin due to temporal variations in Earth's orbital eccentricity/ obliquity/ precession, ice-ocean-climate interactions, and greenhouse-gas concentrations (Berger 1992, Roberts 1998, Huybers and Wunsch 2005, Lisiecki 2010). Following the late Pleistocene glacial terminations, general vegetation succession patterns initiated with increased grass and sedge biomass giving way to secondary colonizers, predominately shrubs such as *Juniperus*, *Salix*, and *Empetrum* (Roberts 1998). Scrubland and shrubland persisted in some areas or moved to savanna, woodland, or forestland depending on biophysical conditions (Roberts 1998).

As early as 18,000 years BP, regions around the Puget and Okanogan lobes developed habitats that included: subalpine parkland; tundra; spruce, fir, lodgepole pine and other conifer subalpine, moist, and mesic forestland; haploxylon and diploxylon pines forestland; *Artemisia* shrubland; grasslands; and steppe (Mack et al. 1979, Barnosky 1984, Whitlock 1992, Aikens 1993, Robbins and Wolf 1994, Lian et al. 2001). Along the Cascade Range, vegetation on opposite sides became dissimilar as early as 17,000 years BP, but this trend was accentuated during the late glacial and early Holocene transition (Barnosky 1984). The height of postglacial warming in the Pacific Northwest occurred in the early Holocene between 12,000 and 6,000 years BP and the Cascade and Olympic Mountain Ranges became important precipitation divides (Barnosky 1984). However, major patterns of vegetation change at individual sites responded to large-scale changes in the climate system that affected the entire region (Barnosky 1984, Whitlock 1992, Sea and Whitlock 1995).

In the Okanogan Highlands and Channeled Scablands, increased summer drought was evident beginning between 10,000 and 9,000 years BP, inferred from increasing pollen percentages of *Pinus* (attributed to either *P. contorta or P. ponderosa*), grass, and *Artemisia* (Mack et al 1978, Nickmann and Leopold 1985, Whitlock 1992). These assemblages resembled modern pollen spectra from the steppe vegetation in the Columbia Basin, suggesting that the forest/steppe ecotone lay at least 100 kilometers north of its present position in the early Holocene (Mack et al. 1978, Whitlock 1992). Prior to 12,000 years BP, conditions were cooler than at present thus the Cascade Range was colonized by subalpine forests of *Pinus*, *Picea*, and *Tsuga* and open meadows and the tree line lay 500 to 1000 m below its modern elevation (Sea and Whitlock 1995). Between 12,000 and 4,500 years BP, the pollen record implies warmer and drier climate conditions than present, a rise in the tree line, and *Abies, Pinus*, *Pseudotsuga*, *Alnus*, and *Quercus* becoming more abundant in forests (Mack et al. 1979, Barnosky 1984, Whitlock 1992, Sea and Whitlock 1995).

After 6,000 - 5,000 years BP, summer drought was less intense because of decreased temperatures and increased precipitation than before; these conditions carried into the late Holocene, beginning 4,000 - 4,500 years BP (Whitlock 1992, Sea and Whitlock 1995). The response of vegetation to a large-scale climate change to cooler, wetter conditions varied by location and individual species and populations, but modern vegetation assemblages were established by the late Holocene (Minore 1979, Whitlock 1992, Sea and Whitlock 1995, Gugger and Sugita 2010).

> In eastern Washington, early Holocene communities with abundant *Artemisia* and grass shifted to *Pinus* parkland and then mixed forest in response to cooler wetter conditions in the late Holocene (Mack et al. 1978a, b, c, d, 1979; Nickmann 1979; Nickmann and Leopold 1985). In the western Columbia Basin, this transition occurred quite early, between 8.5 and 7 ka, when steppe vegetation was rather dramatically replaced by *Pinus ponderosa* parkland (Barnosky 1985b; Leopold and Nickmann 1985). In the last 4,000 years, *Pinus* forest has been invaded by mesophytic conifers (e.g., *Pseudotsuga/Larix*, *Abies*, *Tsuga*, *Picea*) and in some places by *Quercus* (Barnosky 1985b). Some sites from the Okanogan Highland indicate a brief cooling between 3.5 and 1.7 ka when pollen percentages of Picea and Abies increased (Fig. 4). In general, however, modern forests dominated by Pseudotsuga, Abies, Tsuga heterophylla, and Picea were established in the Okanogan Highlands after 2.5—1.7 ka. (Whitlock 1992)

Large-scale climate change and vegetation responses have been fundamental in shaping Pacific Northwest vegetation over the Pleistocene and Holocene epochs, however, numerous disturbance events have additionally influenced modern vegetation assemblages. After concluding the Channeled Scabland's origin, by cataclysmic outburst flooding from glacial Lake Missoula, research since the 1960’s has focused on details of flood magnitudes, frequency, routing, and number and time of events (Baker and Bunker 1985). Correlating ash beds associated with young flood deposits of the Channeled Scablands, Mullineaux et al. (1978)

determined the last of the major Lake Missoula floods crossed the scabland about 13,000 years before present. Cataclysmic volcanic explosions like Mount Mazama approximately 6,000 years BP and Mount St. Helens in 1980 have also had large-scale effects on modern vegetation (Smathers and Mueller-Dombois 1974, Means et al. 1982, Agee 1993, Robbins and Wolf 1994). Large infrequent disturbances are strong modifiers of Pacific Northwest environments, but fire is a far more frequent and equally influential disturbance in the region east of the Cascade Range.

Fire is by no means a recent phenomenon (Agee1993) and is the keystone ecological disturbance in Earth's terrestrial ecosystems (Clark et al. 1997, Pyne 2001, Lavorel et al. 2005, Rupp et al 2007). The most ancient fossil charcoal dates back 420 to 360 million years BP to the early Devonian, before that time Earth lacked land plants suitable in characteristics or abundance to burn regularly or vigorously (Pyne 2001). Fire influences ecosystem, community, and population structures and changes resources, substrate availability, and the physical environment, proving a strong selective force that guides evolution, organizes biotas, and bonds the physical world to the biological (Agee 1993, Pyne 2001). While the literature supports that fires were probably more frequent in the Pacific Northwest during the early Holocene warm/dry period than they are today, evidence shows that fires continue to be influential drivers of vegetation in the region.

Lightning is the primary natural source of forest fires in the world (Agee 1993). Agee (1993) stated, "As many as 44,000 thunderstorms occur daily over the earth (Trewartha 1968), and up to 1,800 such storms may be in progress at one time (Taylor 1974)." Fifty-seven percent of ignitions in the Rocky Mountains and 37 percent of ignitions in the Pacific states originate from lightning due to low precipitation accompanying thunderstorm events (Taylor 1974, Agee 1993). Lightning-ignited fires have resulted in landscape vegetation spatial patterns that have complex interactions with other forest disturbances, processes, functions, and health conditions, notably in dry and mesic mixed-conifer forests (Agee 1993, Agee 1994, Hessburg et al. 1994, Lehmkuhl et al. 1994, Hessburg et al. 2000, Hessburg et al. 2005).

Pinus ponderosa forests are widely distributed in eastern Oregon and Washington occupying a narrow band approximately 15 to 30 km wide on the eastern flanks of the entire Cascade Range (Franklin and Dyrness 1973). At their upper limits, *Pinus ponderosa* forests may grade into forests of *Pseudotsuga menziesii*, *Abies grandis*, or *A. concolor* depending on the locale and at lower elevation limits into either grassland or *Artemisia* steppe (Franklin and Dyrness 1973). Prior to Euro-American settlement, dry *Pinus ponderosa* and mixed conifer forests of the Inland Northwest burned with frequent low- or mixed-severity fires of variable spatial and temporal extent (Agee 1993, Agee 1994, Agee 2003, Hessburg and Agee 2003, Hessburg et al. 2005). Temporal and spatial variation of fire events were important controls on forest and fuels species composition and structure (stand, landscape, region), landscape vegetation spatial patterns, and insect and pathogen distribution and abundance (Agee 2003, Hessburg et al. 2000, Hessburg et al. 2005).

Low- and mixed-severity fires influenced forest structure and species composition by maintaining variable tree densities through consuming seedling, saplings, and pole-sized trees and favoring shade-intolerant, fire-tolerant species (Weaver 1943, Camp 1999, Harrod 1999, Hessburg et al. 2005). Periodic exposure of bare mineral soil due to low- and mixed-severity fires favored an ongoing, uneven aged regeneration of fire-tolerant trees, cycled nutrients from consumed biomass to the soil, and promoted the growth and development of low and patchy understory shrub and herb vegetation (Weaver 1943, Weaver 1955, Hessburg et al. 2005). Fire-tolerant forest structures with reduced crown fire potential were maintained by elevating crown base heights, consuming understory biomass, and reducing competition for site resources among surviving trees, shrubs, and herbs (Weaver 1943, Kauffman 1990, Hessburg et al. 2005). At the landscape level, spatial patterns of dry and mixed conifer forest structure and composition favored low- or mixed-severity fires by maintaining a semi-predictable mosaic, which spatially isolated conditions that supported high-severity fires (Hessburg et al. 2005). The western pine beetle and mountain beetle variably thinned densely stocked areas missed by fire, and killed trees injured by fire, wind, or weather, or weakened by root disease, dwarf mistletoe, other insects, or advanced age (Weaver 1943, Hessburg et al. 1994). Historical effects of insects and pathogens were mostly beneficial and integral to fire-adapted ecosystems because of their contribution to animal and plant habitat development, biomass and nutrient recycling, and patch and landscape diversity (Hessburg et al. 1994). While the importance of environmental influences on modern vegetation composition, structure, and spatial pattern has been the main consideration in the manuscript to this point, any dialog of this nature is incomplete without a review of cultural influences on Pacific Northwest landscapes.

2.2 The First Peoples

The probable birthplace of humankind lies in East Africa, around 5 million years before present (BP), but establishing precise dates at which hominid populations reached particular parts of Earth's surface is problematic, due in part to new discoveries constantly pushing dates and locations back in time (Roberts 1998). It is perhaps safer then to consider the latest agreed rather than the earliest possible dates of arrival, and using this approach the main human population expansion into the Americas is shown to have taken place between 14,000 – 13,000 years BP (Roberts 1998). This period of expansion is supported by the archeological record, including finds like Fort Rock Cave, Oregon on the periphery of the Great Basin, indicating that humans first arrived in the greater Pacific Northwest during the late Pleistocene (Cressman 1962, Borden 1979, Robbins and Wolf 1994). Over the next several millennia human diets, migratory patterns, languages, spiritualism, hunting/fishing/gathering practices, water- and land-use practices, sociopolitical interactions, commerce, etc. (hereafter, "cultures") developed in the Pacific Northwest were strongly shaped by variable climate, biological organisms and communities present, and the aforementioned disturbances and their patterns (Borden 1979, Hunn 1990, Whitlock and Knox 2002). By the advent of modern climate conditions and vegetation assemblages between 6,000 – 5,000 years BP (Barnosky 1984, Whitlock 1992), human cultures were well established throughout the Pacific Northwest and surrounding regions (Borden 1979, Hunn 1990, Robbins and Wolf 1994).

Skeptics maintain that much of the western North America was not significantly altered by prehistoric peoples and vegetation at the time of European contact was more natural than humanized (Vale 2002). However, the following dialog builds off the large body of literature supporting extensive manipulation of natural environments through the agency of indigenous burning. The cumulative effects of indigenous modifications were so extensive it may be said the general consequence of the Indian occupation of the New World was to replace forested land with grassland or savannah, or, where the forest persisted, to open it up and free it from underbrush (Pyne 1982). Numerous scientific studies have used lake sediment, archeological, and dendrochronological data to quantify and reconstruct natural and cultural fire regimes in the Pacific Northwest. Historical documents and scientific findings from the region verify a landscape modified by extensive Indian burning in grassland, shrub, and forest ecosystems, beyond a frequency and distribution that would be created from lightning fires alone (Barrett and

Arno 1982, Robbins and Wolf 1994, Stewart 2002). While some evidence indicates that Pleistocene hunters in the Northwest used burning thousands of years ago (Robbins and Wolf 1994), this document focuses on the importance of anthropogenic ignitions in certain forest, shrub, and grassland types of the Pacific Northwest in the context of modern climate conditions and vegetation assemblages, and more specifically, of the last 500 years.

Fire is the essential ecological ingredient for the formation and maintenance of grasslands, and Indian burning practices established, or at least maintained, grasslands appears to be true beyond question (Stewart 2002). Common objectives of Indian burning for grassland vegetation management included: autumn burning to improve grass species production the following spring (Jackson and Spence 1970, Robbins and Wolf 1994), frequent burning to prevent or reduce encroachment from shrub and tree species (Johannessen 1971, Shinn 1980, Stewart 2002), and burning to increase forb, seed, root, bulb, and tuber abundance, richness, growth, and yield (Boyd 1999, Kimmerer and Lake 2001, Williams 2003). Grassland were also burned to improved forage to attract large ungulates and other game (Kimmerer and Lake 2001, Lewis 1973), drive and harvest game (e.g. ungulates, small mammals, insects) (Stewart 2002, Williams 2003), and improved forage for large horse herds developed from Spanish horses acquired during the 17th century (Hunn 1990, Robbins and Wolf 1994, Hessburg and Agee 2003).

While inland Pacific Northwest tribes burned to encourage and utilize grasslands and accompanying resources, promoting shrub communities was equally advantageous in many situations. Riparian areas were commonly burned to attract ungulates, small mammals, and waterfowl to the new grass, shrub, and tree sprouts at locations conducive to harvesting regimes (Kimmerer and Lake 2001, Williams 2003). Fire was widely used to manage distribution, abundance, and growth form of riparian and upland shrub species vital to production of storage/carrying baskets, clothing, and building materials (Kimmerer and Lake 2001, Williams 2003). Enhanced production and yield of berries was also a key objective of Indian burning in subalpine and montane shrubland glades and forest shrub layers (Robbins and Wolf 1994, Hessburg and Agee 2003, Williams 2003). Shrub steppe ecosystems, which depended on fire to maintain stable shrub-grass-forb composition dynamics (Daubenmire 1970, Shinn 1980), were, to some extent, burned by Indians to promote production and yield of seed, forb, and root plants, suitable ungulate and small mammal habitat, and to drive and harvest game (Shinn, 1980, Stewart 2002, Williams 2003).

Grass and shrub lands modified by Indian burning provided many resources vital to tribal cultures. Forest ecosystems in the inland Pacific Northwest were also often rich in biological diversity and characterized the most complex fuel structures in the region. Diversity and complexity of forest ecosystems initiated most local tribes developing inherently complex interactions with these ecosystems, dependent on respective forest types. The most common forest types of the Pacific Northwest modified by Indian burning were dry and mesic mixed-conifer forests (Barrett and Arno 1982, Stewart 2002, Hessburg and Agee 2003) chiefly composed of *P. ponderosa* (ponderosa pine), *Pseudotsuga menziesii* (Douglas-fir), and *Larix occidentalis* (western larch) (Whitlock 1992, Wright and Agee 2004).

Common management objectives of Indian burning in dry and mesic mixed-conifer forests included: suppress understory regeneration and shrubs to maintain stand structure, composition, and vigor (Weaver 1943, Williams 2003), promote and maintain a good balance between pasture and timber (Stewart 2002, Williams 2003), create and maintain glades and promote diversity and stability of food and medicinal plants within glades (Hunn 1990, Kimmerer and Lake 2001, William 2003), and enhance production and yield of fruit-bearing shrubs and forbs (e.g. huckleberries, strawberries) (Robbins and Wolf 1994, Hessburg and Agee 2003, Williams 2003). Forests were also burned to improve forage to attract large ungulates and other game (Hunn 1990, Kimmerer and Lake 2001, Lewis 1973), remove tree moss favored by deer forcing them to locations conducive to hunting (Williams 2003), drive and harvest game (e.g. ungulates, small mammals, insects) (Stewart 2002, Williams 2003), and improve forage for large horse herds developed from Spanish horses acquired during the 17th century (Hunn 1990, Robbins and Wolf 1994, Hessburg and Agee 2003). Fire was also used by inland Pacific Norwest tribes in forest and shrub lands to maintain travel corridors, fell trees for fuel and building materials, construct canoes, improve visibility for hunting and safety from predators (e.g. wolves, bears, and cougars) and enemies, communicate, and in warfare (offensive and defensive) (Lewis 1973, Williams 2003).

Individually, grassland, shrub, and forest ecosystems provided a wide range of resources, but tribes throughout the inland Pacific Northwest practiced seminomadic migratory patterns dependent on resource availability that fluctuated due to seasonality and variable climate conditions. Thus, cultures of inland Pacific Northwest tribes were enhanced by intentionally burning to creating a mosaic of habitat patches that promoted food security by ensuring a diverse and productive landscape (Lewis 1985, Williams 2000, Kimmerer and Lake 2001). Quantifying the spatial extent and patterns of area influenced by intentional Indian burning is difficult due to fire and vegetation reconstruction techniques, discerning between lightning and human ignitions, and lack of record in pretreatment period to base estimates of Indian burning contribution (Hessburg and Agee 2003). However, American Indians had three powerful technologies: fire, the ability to work wood into useful objects, and the bow and arrow (Botkin 1995). To claim that people with these technologies did not or could not create major changes in natural ecosystems should be regarded as Western civilization's ignorance, chauvinism, and prejudice against different cultures and their practices — the noble but dumb savage (Botkin 1995). In addition, by the time Euro-Americans began to interact with tribes and note the condition of western landscapes, two centuries of disease had already dramatically reduced indigenous populations. Explanations for reduced Indian burning are presented in the following sections, nevertheless the practice of broadcast burning remained useful to tribal cultures and persisted into the early 20th century (Robbins and Wolf 1994, Williams 2004).

2.3 The Second Peoples

Indigenous population’s collective, large-scale water-use, land-use, and resources management patterns developed in the Pacific Northwest over millennia. Whereas, immigrating cultures of European origin – engrained in monetary-based barter, land ownership, and environmental separatism, exploitation, and development – rapidly populated the region (Robbins and Wolf 1994, Mason et al 2012). Differences between the new cultures and indigenous cultures manifested in major changes in water- and land-use practices set the stage for rapid, dramatic, extensive, and permanent environmental change throughout the Pacific Northwest.

Chronologically, horses liberated by Pueblo Indians from Spanish colonies around the end of the 17^{th} century in present day New Mexico were the first major European influence to reach the Pacific Northwest (Robbins and Wolf 1994, Hessburg and Agee 2003). Through trading and raiding, Spanish horses made their way north along either side of the Rocky Mountains and by the 1730’s Utes, Shoshones, Salish and Kootenai, Nez Perce, and Cayuse had all acquired horses (Haines 1938, Robbins and Wolf 1994, Hessburg and Agee 2003). By the early 19th century the Yakama, Cayuse, and Nez Perce had amassed substantial horse herds (Haines 1938, Hunn 1990, Hessburg and Agee 2003). While Spanish horses inherently altered ecosystems through grazing pressure and increased competition with and displacement of native wildlife, major cultural changes the horse brought to Pacific Northwest indigenous populations had far-reaching environmental effects. Increased mobility, warfare, and livestock forage requirements were major cultural changes related to large Indian horse herds that substantially impacted Pacific Northwest landscapes because of increased ignition sites and reduced fire return intervals (Barrett and Arno 1982, Hunn 1990, Robbins and Wolf 1994, Williams 2003).

Imported diseases, such as smallpox, malaria, and influenza, preceded their human population origins and had destroyed up to 90 percent of the indigenous population by the 1840s (Hunn 1990, Williams 2004). The great reduction in native populations altered Indian-modified landscapes through reduced resources requirements and number, frequency, and sites of Indian ignition, prior to Euro-American encroachment (Williams 2004). These two impacts, diseases and horses, further confound the issue identified in Hessburg and Agee (2003) of determining spatial extent and pattern of Indian-modified landscapes preceding Euro-American settlement.

The British and American fur trade industry was responsible for the first considerable and permanent influx of European-originating cultures to the Pacific Northwest (Hunn 1990, Robbins and Wolf 1994, Hessburg and Agee 2003). While many tribes of the inland Pacific Northwest did not directly participate in fur trade, trading horses and venison for guns, ammunition, and other western products with non-Indian trappers was widely practiced (Hunn 1990, Williams 2003). Significant environmental impacts associated with the fur trade industry included: Indian and non-Indian settlement and agricultural practices centered about trading posts, degraded beaver (*Castor canadensis*) and river otter (*Lutra canadensis*) populations, degraded fisheries and fish habitat, introduced foreign plants and animals, and introduction of foreign diseases violently lethal to indigenous populations (Hunn 1990, Robbins and Wolf 1994, Hessburg and Agee 2003).

Following early trappers and explorers, Christian missionaries of the 1830's represented the first wave of Euro-American emigration to the recently acquired Oregon Country (Hunn 1990, Hessburg and Agee 2003). Missionaries also introduced foreign plants, animals, and disease, but their loftier goals of bestowing religion on and educating the "heathen savages" to promote the assimilation of indigenous people had different environmental impacts (Robbins and Wolf 1994). Religion was viewed as a viable approach to diplomatically assimilate Indians into Euro-American culture through the doctrines of faith and farming. Euro-Americans believed that to properly lay claim to land ownership Indians had to work and develop the land in their fashion, which played well into missionaries beliefs that conversion would prove more difficult if tribes continued long-standing semi-nomadic, communal resource practices (Hunn 199, Hessburg and Agee 2003). Converting Indians to Christian farmers aimed to permanently reduce or, where possible, eliminate the extent of traditional spiritual, land-use, water-use, and resource management practices, effectively reducing the overall number, frequency, and sites of ignitions and the myriad associated ecological effects related to frequent, low intensity fires throughout the region. Missionaries had converted few Indians between the 1830s and 1860s, but were much more successful in introducing exotic plants, animals, disease, and encouraging Euro-American settlers to occupy the Inland Northwest (Hunn 1990, Hessburg and Agee 2003).

The discovery of precious metals in the West spurred another influx of Euro-Americans into the Pacific Northwest during the gold and silver rushes of the 1850s and 1860s (Robbins and Wolf 1994, Hessburg and Agee 2003). While the environmental impacts of industrial mining operations (e.g. reservoirs, ditches, canals, and steam-powered dredges) were severe, especially in aquatic and riparian environments (Hessburg and Agee 2003), operations also directly and indirectly impacted forests and rangelands. Miners directly impacted montane forest and riparian environments through burning to clear vegetation, but these fires often escaped and burned extensive areas of forests. Vegetation cover declines from these escaped fires advanced degradation through increased run-off and sedimentation and altered vegetation species and structure compositional and spatial patterns (Langston 1995, Hessburg and Agee 2003). Aquatic environments were also directly impacted by mining operations via heavy metals inputs such as arsenic and mercury, increased run-off and sedimentation, and decreased stream canopy cover from upland and riparian burning (Wilkinson 1992, Hessburg and Agee 2003). Indirect environmental impacts of mining operations included: the first large-scale cutting of inland forests to meet increased demand for timber products needed for mining construction, increased agriculture and settlements to meet miners' supply and service demands, increased river transportation and commerce to meet miners' service and industries' export demands, and increased timber harvest to meet growing non-mining regional demands (Robbins and Wolf 1994).

With most tribes marginalized to reservations and soaring beef prices in mining districts, enterprising cattlemen and sheepherders began stocking the forests and rangelands east of the Cascades with great livestock herds over the period from 1860s to 1890s (Robbins and Wolf 1994, Hessburg and Agee 2003). Overgrazing by cattle and sheep weakened rangeland conditions by increasing shrub and tree abundances and reducing native perennial forbs and bunchgrasses, while increasing exotic annual grasses, and altering fuel beds and fire behavior (Shinn 1980, Robbins and Wolf 1994). Cattle overgrazing in dry forest and grassland environments increased shrub and tree abundances and reduced native grasses, forbs, and shrubs, increased exotic forbs and annual grasses, and altered fuel beds and fire behavior (Shinn 1980, Robbins and Wolf 1994, Hessburg and Agee 2003). Cattle grazing in dry forest and grassland riparian zones disproportionately affected these areas due to livestock water requirements and elevated grazing concentration (Hessburg and Agee 2003). Cattle overgrazing also degraded adjacent aquatic environments through vegetation change, diminished fish habitat, increased stream bank erosion, and increased sedimentation and eutrophication (Hessburg and Agee 2003). Sheep overgrazing shared many of the same environmental impacts as cattle, but important differences of sheep are: lower water requirements and fewer associated riparian and aquatic impacts, more successfully grazed uplands and rangelands (due to wider forage selection, mouth capable of higher utilization, and lower water requirements), and greater impact on native bunchgrasses than cattle overgrazing (Hessburg and Agee 2003).

Starting in the mid-19th century, and with accelerated pace toward the turn of the century, industrial transformation of the Inland Northwest was marked by the rapid completion of transcontinental and ancillary railroads (Mills 1946, Robbins and Wolf 1994). Railways brought new industrial technologies that facilitated large-scale harvesting and milling of timber and agricultural products and for the first time an expedient, viable means of export to local, regional, and international markets (Bryan 1936, Robbins and Wolf 1994). Along with new technologies, the transcontinental railroad brought multitudes of Americans eager to establish themselves through development of the vast resources provided by the Pacific Northwest.

The combination of technology, Euro-American culture, and regional and international economic and political dynamics created the logging practice known as “high grade logging” (Hessburg and Agee 2003). High-grade logging is perhaps the single most ecologically significant forest practice Euro-American culture brought to the Pacific Northwest. The ecological significance of high-grade logging is attributed to the removal of many of the oldest/ largest/ healthiest trees and increased surface fuel loads after logging (Hessburg and Agee 2003). These practices lead to some of the region's most destructive and extensive human-caused fires during the 1920s and 1930s, placing added emphasis on extensive fire exclusion (Pyne 1982, Hessburg and Agee 2003).

Landscapes of the Pacific Northwest are the result of millennia of environmental change, millennia of intentional and systematic burning by indigenous nations, and great, rapid population expansion by European-originating cultures. Industrial technology, agricultural and logging practices, and fire exclusion – either through active suppression or through marginalization of indigenous cultures – have proved some of the most important pieces of the environmental and anthropogenic history of the region. Understanding the environmental and anthropogenic history of the last several hundred years in the region assists with recognition of current management issues and affords vital opportunities for managers and researchers to identify and implement resolutions. The following section outlines some important U.S. federal policies – shaped by a dynamic American culture – that have resulted in current policies, ownerships, land- and water-use practices, and management motivations, objectives, and activities (hereafter, "management regimes") and related ecosystem management issues.

2.4 Current Management

Some writers have associated passing of the Weeks Act in 1911 to the devastating forest fires that gained national attention as they burned portions of Idaho and Montana in 1910, though there is little evidence to support this view because the primary objectives of the law were to select, appraise, and purchase land (Davis 1983). The Weeks Act is, however, widely viewed as the official beginning of the already wide spread fire suppression policy, the dominant paradigm of public land management agencies for over half a century. While the focus of the Weeks Act was land acquisition for the national forest system, it stipulated federal authority to appropriate funds in the protection of private and state forestland and forested watersheds of navigable streams, effectively implementing extensive fire suppression over the next several decades.

While a social consensus on public land management has never existed in the U.S. (Hessburg and Agee 2003), the growing environmental conservation movement among citizens reached a national level manifested by several federal laws enacted in the 1960s and 1970s. The Multiple Use-Sustained Yield Act of 1960 was the first article of federal legislation enacted by congress that mandated the multiple-use philosophy on Nation Forests. The Wilderness Act of 1964 and repeal of the Forest Service's 10 AM policy in 1973 marked a change in the way citizens, managers, and legislators perceived fire in natural landscapes, fostering a shift from fire suppression to fire management (Hessburg and Agee 2003). The 1969 National Environmental Protection Act, the 1970 Clean Air Act, and the 1973 Endangered Species Act are three additional important laws resulting from the early environmental conservation movement. The laws created during this era of American history began to formalize planning, provide single-resource management, endorse multiple-use philosophy, shift toward a fire management paradigm, and still impact natural resource management presently (Hessburg and Agee 2003).

> In July 1993, as part of his plan for ecosystem management in the Pacific Northwest, President Clinton directed the Forest Service (FS) to "develop a scientifically sound and ecosystem-based strategy for management of Eastside forests." The President further stated that the strategy should be based on the

> Eastside Forest Ecosystem Health Assessment recently completed by agency scientists as well as other studies. The Chief of the Forest Service and the Director of the Bureau of Land Management (BLM) jointly directed through a [Eastside Forest Ecosystem Management Project] Charter that an ecosystem management framework and assessment be developed for lands administered by the FS and BLM east of the Cascade crest in Washington and Oregon and other lands in the United States within the interior Columbia Basin and portions of the Klamath and Great Basins … (Quigley et al. 1996)

This legislative activity lead to the Eastside Forest Ecosystem Health Assessment that studied the effects of Forest Service management practices on the sustainability of eastern Oregon and Washington ecosystems (Quigley 1996). The Eastside Forest Ecosystem Health Assessment (EFEHA), and other pertinent literature, identified primary causes of declining ecosystem health, resiliency, and sustainability throughout the region: past logging and fire exclusion (Weaver 1943, Weaver 1955, Oliver et al. 1994, Robbins and Wolf 1994, Hessburg and Agee2003, Williams 2004), increased severe wildfire and smoke production (Agee 1994, Huff et al. 1995, Hummel and Agee 2003, Hessburg et al. 2005, Hessburg et al. 2007), increased insect and pathogen epidemics (Hessburg et al. 1994, Lehmkuhl et al. 1994), altered forest structure and species compositions (Weaver 1947, Camp 1999, Harrod et al. 1999, Hummel and Agee 2003, Larson and Churchill 2012), degraded fish and wildlife habitat (McIntosh 1994, Marcot 1994, Hessburg and Agee 2003), and altered spatiotemporal patterns (Hessburg et al. 1999, Hessburg et al. 2000, Agee 2003, Hessburg and Agee 2003, Hessburg et al. 2005). The EFEHA resulted in several publications, cited in the preceding text, recommending methods and practices that could be used to restore stressed ecosystems. In a concerted effort to restore landscape sustainability and resiliency, the Okanogan-Wenatchee National Forest developed a restoration strategy founded on the Eastside Forest Ecosystem Health Assessment and other relevant literature and recommendations. The legislative, research, and management activities of the 1990s and early 21st century was a manifestation of the recognition of degraded and declining ecosystem health, resiliency, and sustainability on public lands throughout the region.

Apart from federal environmental policies and management, federal Indian policies play an extensive, important role, both historically and presently, in natural resource management of the region. The Yakama Nation and their ancestral civilizations have existed throughout the inland Pacific Northwest and surrounding regions since time immemorial. After the Yakama Nation Treaty of 1855, and subsequent congressional and executive ratification of the treaty in 1859, the Yakama Nation has operated as a sovereign nation within the United States. While U.S. federal Indian policy mandates tribes operate under the same federal environmental laws as federal land management agencies, the management of Yakama Reservation natural resources has been, and continues to be, different from adjacent and surrounding lands under federal, state, and private ownerships.

A fundamental difference between tribal and non-tribal management regimes is the motivation of management decisions. Indian tribes are motivated by a responsibility of trans-generational reciprocity and stewardship of resources, engrained in an enduring perception of place, perpetuity, and human-ecosystem integration (Raish et al. 2005, Colegrove 2006, Morishima 2006, Rigdon 2006, Mason et al. 2012). In contrast, traditional western/scientific management decisions are based on a conceptual separation of humans from the environment and primarily concerned with theories of general interest and applicability, thus focusing on the control of nature (Pierotti and Wildcat 2000, Kimmerer 2000, Mason et al. 2012).

Tribal and neighboring non-tribal communities have similar social, environmental, and economic factors. Nonetheless, tribal government must make decisions and take actions, without the options of indecision or endless appeals through legal processes on matters that are fundamentally issues of policy (Morishima 2006). While citizen participation is an integral component of natural resource management, Sturtevant (2004) noted that decisions must be made at a scale that "evokes shared values, collective action, and a sense of place." Tribal communities are a prime example where the characteristics of shared cultural identity, continuity of place, interactional capacity, and a moral ethic founded in resource stewardship abound (Morishima 2006). Numerous tribal communities and accompanying forest management programs function as potential models that could be incorporated into non-tribal management regimes to enhance aggregate ecological conditions of landscapes. Pierotti and Wildcat (2000), Kimmerer and Lake (2001), Caldararo (2002), Raish et al. (2005), Stevenson (2005), Colegrove (2006), Morishima (2006), Peterson (2006), Rigdon (2006), Berry (2009), Mason et al.(2012), and Whyte (2013), to name a few, represent a growing movement and body of literature supporting the increased role of tribal resource management regimes and traditional knowledge to enhance landscape ecosystem management.

As North America was settled by cultures of European descent, the continent divided into various ownerships defined by many ecologically arbitrary legal boundaries. Presently, aggregate ecological conditions of landscapes are controlled by the spatial pattern and dynamics of individual owners and ecological interactions among those ownerships (Spies 2004). However, landscape dynamics of individual ownerships are controlled by a complex of economic, social, political, and biophysical forces, confounding ecosystem management and research (Spies 2004). The next section outlines a framework developed to identify issues, prioritize treatment areas, and assess treatment alternatives across management regimes in dry and mesic mixed-conifer forests on the eastern slope of the Southern Washington Cascades.