Manastash-Taneum Resilient Landscapes Project: Landscape Evaluations and Prescriptions

Ryan Haugo[1], William Gaines[2], James Begley[2], James Robertson[1], Derek Churchill[3], James Dickinson[4], Reese Lolley[1], Paul Hessburg[5],

May 2016

TAPASH Sustainable Forest Collaborative

The Nature Conservancy
Protecting nature. Preserving life.

[1]The Nature Conservancy, Seattle, WA, [2]Washington Conservation Science Institute, Wenatchee, WA, [3]University of Washington, Seattle, WA, [4]US Forest Service Okanogan-Wenatchee National Forest, Wenatchee WA, [5]US Forest Service Pacific Northwest Research Station, Wenatchee, WA

Table of Contents

Figures

Tables

Appendices

1. INTRODUCTION

1.1 Tapash Sustainable Forests Collaborative

The eastern Cascades of Washington State is an incredibly diverse and complex ecoregion that supports abundant fish and wildlife, a wide range of forest communities, and provides an array of critical ecosystem services including water, wood products, forage for grazing, and a wide variety of recreational opportunities. Ranging from the crest of the Cascades down to the shrub steppe of the Columbia Basin, the variability in the forests and rangelands of the east Cascades are driven by the interplay of topography, precipitation, soils, and disturbances such as fire, insects, flooding, and wind (Hessburg et al. 1999, Stine et al. 2014).

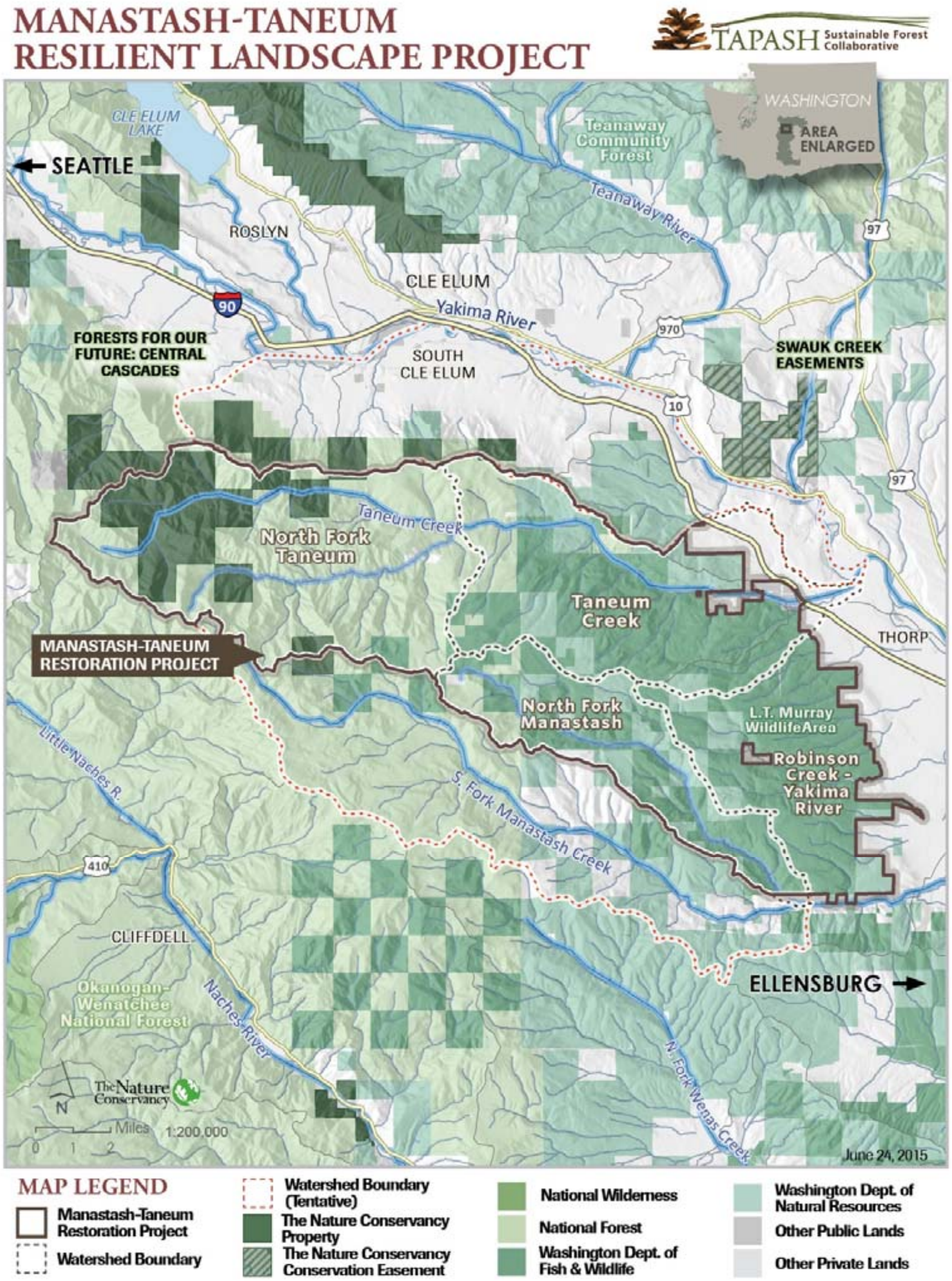
Similar to forests across western North America a history of wildfire suppression, intensive timber harvesting, and grazing throughout the 20th century has caused widespread degradation of forest, rangeland, and stream habitats and increased the risks of uncharacteristically severe wildfire (Hessburg et al. 2000, Bunting et al. 2002, Lehmkuhl et al. 2013, Hessburg et al. 2015). The resulting shifts in tree species composition and increases in forest density have resulted in decreased resilience of forests to drought and fire for many of the regions forests, and this occurs at a time when climate change is projected to increase drought stress and wildfire risks (Hessburg et al. 2000, Haugo et al. 2014, Littell et al. 2010). Twentieth century forest management also led to the building of extensive forest road networks which have dramatically altered watershed hydrology, increased sediment delivery into streams, reduced floodplain functioning, and fragmented aquatic habitats (Bisson et al. 2003, Rieman et al. 2010). These stressors of aquatic habitats have and will continue to be further exacerbated by the increases in stream temperatures and decreases in snowpack as a result of climate change (Mote 2003; Mantua et al. 2009; Isaak et al. 2010, 2012).

Across western North America and within the eastern Cascades, the challenges currently facing our forested ecosystems from past management and future climate change have prompted a wide scale shift in land management to focus on "ecological restoration" (Rieman et al. 2010, Gaines et al. 2012, USFS 2013, Hessburg et al. 2015). Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). However, efforts to conserve and restore the ecosystems of the eastern Cascades are further complicated by a diverse patchwork of private, state, tribal, and federal land ownerships, each with different forest management emphases and objectives.

In response to these challenges the Tapash Sustainable Forest Collaborative (http://www.tapash.org) was officially formed in 2007 through a Memorandum of Understanding between major landowners in the eastern Cascades of south-central Washington State, including the US Forest Service (USFS), Yakama Nation (YN), Washington Department of Natural Resources (WDNR), Washington Department of Fish and Wildlife (WDFW), and The Nature Conservancy (TNC). The Tapash collaborative provides a framework for cooperation and coordination between Tapash partners to restore ecosystems' resistance and resilience to climate change across 3 million acres in the eastern Cascades of south-central Washington State.

"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 Mission Statement.

Figure 1. Tapash Sustainable Forest Collaborative - Manatash-Taneum Resilient Landscape Restoration Project HUC12 subwatersheds and land ownership patterns



1.2 Manastash-Taneum Resilient Landscape Restoration Project Background

In the fall of 2014, the Tapash Collaborative launched the Manastash-Taneum Resilient Landscape Restoration Project as a flagship effort to demonstrate cross-ownership, integrated terrestrial and aquatic landscape scale ecosystem restoration. The USFS, WDFW, WDNR, and TNC all have significant ownerships within the Manastash-Taneum project area which includes four 6th field subwatersheds (12 Code HUC) comprising nearly 80,000 acres (Figure 1, Table 1). These subwatersheds were selected by the Tapash Collaborative because they contain a variety of significant aquatic and terrestrial resources and conservation values in addition to the diverse land ownership. These conservation values include, but are not limited to, habitat for federally listed steelhead (*Oncorhynchus mykiss*; NMFS 2008, YBFWRB 2009), bull trout (*Salvelinus confluentus*; USFWS 2015), and northern spotted owl (*Strix occidentalis caurina*; USFWS 2011). Additionally, in recent years these subwatersheds have received substantial conservation investments to protect former industrial timberlands, restore stream flows for fish passage, and replenish in-stream large wood to enhance aquatic habitat quality and floodplain functioning.

Table 1. Manatash-Taneum Ownership per HUC12 subwatershed

		Ownership				
Subwatershed	**Total ac.**	**USFS ac.**	**WDFW ac.**	**WDNR ac.**	**TNC ac.**	**Other* ac.**
North Fork Taneum Crk.	29,533	21,030	730		7,611	162
Taneum Crk.	25,848	3,693	13,465	4,743	16	
North Fork Manastash Crk.	13,451	1,287	8,467	3,264		433
Robinson Crk.	35,179		11,036	2,713		
Total	78,650	26,010	33,698	10,720	7,627	595

*Note: A significant amount of private, primarily non-forested lands in the Taneum Creek and Robinson Creek subwatersheds were excluded from the project area.

1.3 Manastash-Taneum Resilient Landscapes Restoration Project Objectives

Through a series of Tapash land manager meetings in 2015, the Tapash Collaborative developed the following Manastash-Taneum project objectives:

> *The Manastash-Taneum Resilient Landscape Restoration Project aims to restore the resiliency of forest and aquatic ecosystems in order to continue providing critical fish and wildlife habitat and ecosystem services (water, wood products, forage for grazing, and a wide-array of recreational opportunities), while reducing the risk of catastrophic fire to local communities in the face of a warming climate. Within the Manastash-Taneum project area the Tapash Collaborative will develop restoration projects using the best available science that effectively work across ownership and management boundaries and respect the differing objectives of each landowner. Restoration projects will seek to balance ecological objectives with economic viability, produce commercial timber products where possible, and maintain a diversity of sustainable recreational opportunities.*

Aquatic restoration projects will focus on improving watershed conditions, functions, and processes and restoring the complex aquatic habitats that contribute to the recovery of federally listed fish. Specifically, this includes restoring habitat connectivity between headwater tributaries, stream channels, floodplains, wetlands, and riparian vegetation and reducing road and stream interactions to improve aquatic habitat function, in-stream flow and sediment regimes, water quality, and biological functions (spawning, rearing, foraging, and migration). Aquatic restoration also includes improving natural stream channel floodplain access to restore the timing, variability, and duration of floodplain inundation.

Terrestrial restoration projects will focus on restoring patterns of vegetation and wildlife habitat successional patches and inherent fire and disturbance regimes from the scale of individual patches (1-100's of ac.) to local landscapes (e.g., subwatersheds, 1,000's to 10,000's of ac.). Restoration of vegetation and wildlife habitat pattern includes reestablishing the natural distribution of patch sizes, tree clump and gap patterns within patches, and a focus on retaining and promoting large/old trees and post-disturbance large snags and down logs across the landscape. Terrestrial restoration projects will be informed by both historic and future range of variability reference conditions as well fire, insect, and disease risk to ecological and social values. In addition, terrestrial objectives include the restoration of habitat effectiveness by reducing the impacts of roads on aquatic and terrestrial habitats.

To the extent possible aquatic and terrestrial restoration projects will be integrated, or at a minimum, coordinated, in order to increase operational efficiencies and promote "whole watershed" restoration outcomes.

Manatash-Taneum objectives adapted from the Tapash Sustainable Forests Collaborative mission statement (www.tapash.org), the Okanogan-Wenatchee Forest Restoration Strategy (2012), Hessburg et al. (2015) *Restoring fire-prone Inland Pacific landscapes: seven core principles*, and Yeager (2015) *Summary of Aquatic Resource Objectives and Recommended Design and Implementation Elements for the Mid and Upper Columbia Anadromous and Bull Trout Producing Watersheds of Eastern Washington.*

2. LANDSCAPE EVALUATION & PRESCRIPTION APPROACH

2.1 Why Integrated Terrestrial and Aquatic Landscape Evaluations?

Building upon decades of research, ecologists and land managers now understand the importance of working at landscape scales for the management of resilient ecosystems (Crow and Gustafson 1997, White and Harrod 1997, Reiman et al. 2010, Luce et al. 2012, Hessburg et al 2015). While terrestrial landscape evaluation tools are becoming well-developed (e.g., Hessburg et al. 2013, USDA Forest Service 2012), an integrated landscape evaluation approach that considers a broad suite of both terrestrial and aquatic ecosystem services and resource values is needed (Day et al. 2009). Rieman et al. (2010) suggest three steps to more successfully integrate the management of forests, fires, watersheds, and native fishes: 1) communication among disciplinary scientists, managers, and stakeholders, with a clear definition of management goals; 2) translation of goals to objectives within the contexts and constraints of the systems in question; and 3) spatially explicit integration of terrestrial and aquatic objectives to identify opportunities for convergent solutions.

Following these steps, the Tapash Collaborative is using the Manastash-Taneum project to test and develop a more closely integrated aquatic and terrestrial landscape evaluation. This evaluation will provide the Tapash Collaborative with the context of what is needed for "whole watershed" restoration within each subwatershed. The evaluation will also describe the contribution that each landowner can make to restore the resiliency of landscapes and watersheds through coordinated treatments across ownerships.

2.2 Forest and Stream Interactions

Forests and streams are tightly linked through a range of critical ecological processes and functions (Naiman and Turner 2000). These include the transfer of materials and energy that influence habitat structure (large wood and sediment), food webs and trophic dynamics (nutrients and organic carbon supply) and water quality and temperature (riparian shade) (Rieman et al. 2010). Forests can also strongly influence stream hydrology through impacts on snowpack dynamics, runoff, evapotranspiration, soil moisture, floodplain functioning and groundwater infiltration among other processes (Luce et al. 2012, Lundquist et al. 2013).

Aquatic habitats are structured by interactions among terrestrial and aquatic processes and climate (Bisson et al. 2003). For example, wildfires influence hillslope erosion, stream sedimentation, and large woody debris recruitment to streams (Benda et al. 2003, Miller et al. 2003). Certain types of disturbances, such as fire and landslides, are essential in the creation and maintenance of channel and riparian landforms (Benda et al. 2003, Miller et al. 2003). When human activities such as stream cleaning, log drives, diking, riparian logging, and damming have simplified channels, disturbances such as fires and landslides, may be a benefit in the long term because they may increase physical and biological diversity (Benda et al. 2003, Flitcroft et al. 2015). Land uses such as timber harvest, fire suppression, and road networks, can alter the frequency and magnitude of natural disturbances (Benda et al. 2003, Rieman et al. 2010).

Roads in particular have wide-ranging effects on hydrologic processes, watershed function, and fish habitats. The compacted surface of roads can lower infiltration capacity, alter and concentrate overland flow, and increase erosion and delivery of sediment to the stream system, which can degrade fish habitat quality (Dunham and Rieman 1999, Furniss et al.

1991, Luce and Black 1999, Jones et al. 2000, Luce et al. 2001, Trombulka and Frissell 2000, Meredith et al. 2014). Roads can also intercept subsurface flow and convert it to rapid surface runoff, extending channel networks and increasing watershed efficiency (Luce and Black 1999, Trombulka and Frissell 2000, Wondzell 2001). Roads reduce vegetative cover in streamside areas and accelerate delivery of water and increase erosion and sedimentation into streams (Trombulka and Frissell 2000, Wondzell 2001). Accelerated erosion, runoff, and sediment delivery from roads increases streambed fine sediment, which affects aquatic habitats and macroinvertebrate populations, and makes streambeds and banks more susceptible to erosion during high flow events (Luce and Black 1999, Wondzell 2001). At road-stream crossings, excessive flow velocities and undersized culverts can alter stream channel function and fragment fish habitat (Furniss et al. 1998). Other road-related impacts include reduced potential large wood available for in-channel wood and shade from riparian areas (Trombulka and Frissell 2000, Wondzell 2001, Meredith et al. 2014). Reducing non-climatic stressors, such as the impacts of roads on the aquatic and terrestrial environment, has been identified as an important adaptive strategy to reduce the effects of climate change (Strauch et al. 2014, Mantua and Raymond 2014).

The thermal environments that organisms experience strongly affect their vital rates, distribution, and abundance (Kingsolver 2009), especially stream fishes (Rieman et al. 2007, Ruff et al. 2011, Grenouillet and Comte 2014). To aid managers in the assessment and conservation of habitat for cold-water fishes, current available data on summer stream temperatures and projected summer stream temperatures for the 2040s and 2080s are available for all streams in the northwestern US (Ver Hoef et al. 2006, Isaak et al. 2010, http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). Generally, maximum summer stream temperatures <17^{0}C are considered to be “favorable” for salmon rearing, 17-21^{0}C “stressful” for salmon rearing, and >21^{0}C “fatal” (Mantua and Raymond 2014). The future availability of cold-water refugia for federally listed salmonids is of particular concern due to a warming climate (Mantua and Raymond 2014, Isaak et al. 2015).

Given the large number of interactions between forests and streams, this initial phase of the Manastash-Taneum project focuses on some of the most immediate links between forest management and aquatic habitats including road-stream interactions, aquatic habitat connectivity, the availability of cold-water, and the interactions between upslope processes (e.g., wildfires, landslides) and stream functions..

Table 2. List of limiting factors for steelhead relevant to the North Fork Taneum, Taneum, and North Fork Manastash watersheds (YBFWRB 2009).

Limiting Factors for Steelhead	
Degraded floodplains	Altered sediment routing
Degraded channel	Impaired fish passage
Degraded riparian area and large woody debris	

2.3 Aquatic Landscape Evaluation Methods
Through the Manatash-Taneum project we are developing an aquatic evaluation to compliment the Okanogan-Wenatchee Forest Restoration Strategy terrestrial landscape evaluation process (Hessburg et al. 2013). This initial phase of the aquatic evaluation focuses on the factors that have been identified as limiting for steelhead recovery (YBFWRB 2009; Table 2). The outcome of this process was to identify areas within each

subwatershed that provide opportunities to restore stream function, reduce the negative impacts of roads on the stream environment, improve the quality of rearing habitat for steelhead, and restore disturbance regimes. We hypothesized that by restoring environmental conditions conducive to spawning steelhead (they currently spawn in the assessment area), it will also result in more favorable conditions for other fish species (e.g., bull trout, historically but not currently present in the assessment area).

Our aquatic landscape evaluation process included the following steps:

Step 1: *Rectify the road and stream spatial data*. The spatial data available for our evaluation did not provide an accurate representation of road and stream locations across land ownerships. Thus, we used high-resolution imagery to rectify the road and stream layers. This task was very labor intensive but resulted in a highly accurate portrayal of the roads and streams making our evaluation more realistic and credible. This step was important because many of the aquatic indicators, such as road-stream crossings and proximity of roads to current and potential fish habitat, require accurate information about the location of streams and roads. As an example, there were approximately 20% more roads on the landscape than were mapped in any of the available roads datalayers.

Step 2. *Identify and map floodplains*. We used the floodplain mapping tool in TerrainWorks (Benda et al. 2007) to develop a floodplains spatial layer.

Step 3. *Identify and map current and intrinsic habitat potential for steelhead*. We obtained fish distribution data from the Washington Department of Fish and Wildlife to map current steelhead rearing habitat. We used the intrinsic potential habitat mapping tool in TerrainWorks (Benda et al. 2007), using the default values for steelhead, to identify potential habitat within each of the subwatersheds.

Step 4. *Assess road-stream interactions*. We evaluated the potential for road-stream interactions in a variety of ways. First, we assessed the potential for negative road-stream interactions in areas that may influence current or potential steelhead habitat. We did this by overlaying roads, trails, streams, and fish habitat layers in order to identify portions of roads (e.g., segments) that either occurred in floodplains or were within 300 feet of current or potential steelhead habitat. This resulted in a map showing portions of roads and trails that occurred in close proximity to current or potential steelhead habitat that we could review in the field.

Second, we intersected the road and stream layers to identify road-stream crossings. We overlayed stream-road crossings with current and potential steelhead habitat and identified road-stream crossings that we reviewed in the field for their potential to provide fish passage.

Third, we assessed the density of road-stream crossings in the remainder of the subwatershed (up-slope from the main channel) in order to evaluate the up-slope effects that roads may be having on the aquatic environment. In addition, this information can be used to identify priority areas for focused field evaluation of road-aquatic interactions using tools such as GRAIP (Geomorphic Road Assessment and Inventory Process; Black et al. 2012, Cissel et al. 2012). To date however GRAIP inventories have not been conducted.

Finally, as a general measure of watershed function, we calculated the overall density of roads in each subwatershed, and the density of roads within riparian zones (300 foot buffer) in each subwatershed. We then used the metrics from the Watershed Condition Framework to categorize each watershed based on its level of "function" (Potyondy and Geier 2010).

Step 5. *Cold-Water Refugia.* We assessed mean summer (August) stream temperatures along mainstem streams in each subwatershed using information from NorWeST (www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). The information available for each stream included a summary of current summer stream temperatures, and projected summer stream temperatures for the 2040s and 2080s. Detailed descriptions of how the stream temperature projections were developed are available in Ver Hoef et al. (2006) and Isaak et al. (2010). We then categorized portions of streams into "favorable" for salmonid rearing if the mean August stream temperatures were currently or projected to be <17^{0}C, "stressful" for salmonid rearing if mean August stream temperatures were currently or projected to be 17-21^{0}C, and "fatal" if mean August stream temperatures were currently or projected to be >21^{0}C (Mantua and Raymond 2014).

Step 6. *Natural Disturbance Regimes*. Because of the important interactions between natural disturbances such as fire and landslides to the stream ecosystems (Benda et al. 2003, Miller et al. 2003), we used information from the terrestrial landscape evaluation to assess how current disturbance regimes have departed from historical regimes. We assumed that by restoring natural disturbance regimes, the role of fire and associated landslides would also be restored (Rieman et al. 2010). We used both the Stand Level Fire and Vegetation Cover-Structure components of the terrestrial landscape evaluation (see below) to assess departure and help to identify restoration opportunities.

Step 7. *Field review*. We conducted a field review in order to: 1) evaluate the road and stream layer, 2) review areas where roads or trails were in close proximity to streams or in floodplains that provided current or potential steelhead habitat, 3) review road-stream crossings for fish passage that occurred in close proximity to current or potential steelhead habitat, and 4) identify opportunity areas for restoration.

Step 8. *Identify restoration opportunities*. We used information gathered from the spatial data and field review to identify areas within each subwatershed that provided opportunities to implement restorative actions, and to identify areas where additional field survey information is needed. We used this information to develop a "landscape prescription", which is a detailed list of actions and locations that could be implemented to restore aquatic and terrestrial ecosystem resiliency, and address limiting factors for steelhead recovery.

2.4 Terrestrial Evaluation Methods
The Manastash-Taneum terrestrial landscape evaluations and prescriptions follow the Okanogan-Wenatchee Forest Restoration Strategy (OkaWen FRS; USDA Forest Service 2012, Hessburg et al. 2013) evaluation process. This process is based upon the concept that a stand by stand approach to forest restoration without establishing a landscape context for the location, amount, and type of restoration treatments will not lead to resilient forested landscapes. The OkaWen FRS process provides a framework to directly apply the seven principles of landscape restoration outlined by Hessburg et al. (2015):

Principle 1: Important ecological processes[1] operate across spatial scales – from tree neighborhoods to regional landscapes. *Implication: Planning and management must incorporate and link the tree neighborhood, patch, drainage/hillslope, local landscapes, and regional landscapes.*

Principle 2: Topography provides a natural template for vegetation and disturbance patterns across the landscape hierarchy scales. *Implication: Use topography to guide restoration treatments*

Principle 3: Disturbance and succession drive ecosystem dynamics. *Implication: Focus on restoring the ecosystems' inherent fire/disturbance regimes and vegetation successional patterns; other ecological processes will follow.*

Principle 4: Predictable distributions of forest-patch sizes naturally emerge from interactions climate-disturbance-topography-vegetation. *Implication: focus on restoring the natural distribution of forest patch sizes across landscapes.*

Principle 5: Patches are "landscapes within landscapes: *Implication: focus on restoring characteristic tree clump and gap patterns within stands/patches*.

Principle 6: Widely distributed large, old trees, provide a critical ecological backbone for forested landscapes. *Implication: focus on retaining and promoting large/old trees and post-disturbance large snags and down logs*.

Principle 7: Traditional patterns of land ownership and management disrupt inherent landscape and ecosystem patterns. *Implication: develop restoration projects that effectively work across forest ownership and management allocations*.

Current conditions within each of the Manastash-Taneum subwatersheds were mapped across ownerships through interpretation of recent high-resolution aerial photography. Successional patches (sensu Hessburg et al. 2015) were delineated from the aerial photography and for each successional patch, 23 derived attributes representing a range of vegetation, wildlife habitat, and fire, insect, and disease susceptibility ratings were calculated from the photo-interpreted attributes (Hessburg et al. 2013; Table 3). Photo-interpretations were initially conducted by Pete Olsen (Okanogan-Wenatchee National Forest). James Begley (Washington Conservation Science Institute) subsequently conducted field review and refinement of the photo-interpreted data layers.

The next step in the evaluation process assessed the departure of present day conditions within each watershed from both "Historic Range of Variability" (HRV) and "Future Range of Variability" (FRV) reference conditions for each derived attribute (Table 3). HRV describes the range of conditions may have existed within a particular subwatershed based upon its biophysical settings prior to 20th century management (Landres et al 1999, Keane et al. 2009). FRV is a "climate change analogue" reference condition that estimates the range of conditions that may develop within a subwatershed if historic ecosystems were allowed to adapt naturally to a predicted warmer-drier climate in absence of 20th century management (Gartner et al 2008; Keene et al 2009). By comparing current conditions to

[1] Fish and wildlife dispersal, hydrology, and the frequency, severity, and extent of disturbances such as fire, insects, disease, wind, and floods.

both the historic and future reference conditions, managers are better able to assess options that mimic patterns and processes under which species have evolved, but also consider what resilient landscapes may look like in the future (Hessburg et al. 2013, 2015).

Table 3. Okanogan-Wenatchee Forest Restoration Strategy terrestrial landscape evaluation photo-interpretation derived attributes.

Vegetation*	**Wildlife Habitat cont.**
Struct. Class x Cover Type x PVG	N. Spotted Owl Potential
Struct. Class x Cover Type	White Headed WP
Structure Class x PVG	**Wildfire Hazard**
Cover Type x PVG	Crown Fire Potential
Physiognomic type	Rate of Spread
Cover Type	Flame length
Structure Class	Fire Line Intensity
Med-Large Tree Presence	Fuel Loading
Late Successional - Old Forest	Fuel Consumption
Remnant Large Tree	Smoke PM10
	Smoke PM5
Wildlife Habitat	**Insect Hazard**
Marten	Douglas-fir Beetle Hazard
N. Spotted Owl Current	W. Spruce Budworm

*Note: See Appendix A for summary and description of vegetation and forest structural attributes.

The HRV and FRV reference conditions were from early to mid-20th century aerial photography that was conducted as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP; Hessburg et al. 1999). The ICBEMP project photo-interpreted 337 subwatersheds across the interior Columbia Basin. These subwatersheds were nested within a classification of "Ecological Sub Regions" (ESR's; Hessburg et al. 2000). The ESR's represented a broad classification of bio-geo-physical settings. Each ESR in eastern Washington has a set of 8-20 reference subwatersheds with historic air photo interpretation following the same interpretation protocols and developing the same derived attributes (Table 3) as the present day Manastash-Taneum current condition mapping. HRV reference conditions were then developed for each Manastash-Taneum subwatershed through comparison with the historic data from subwatersheds in the same ESR. Historic data from subwatersheds in the next warmer and drier ESR were used to develop the FRV reference conditions (Gartner et al. 2008).

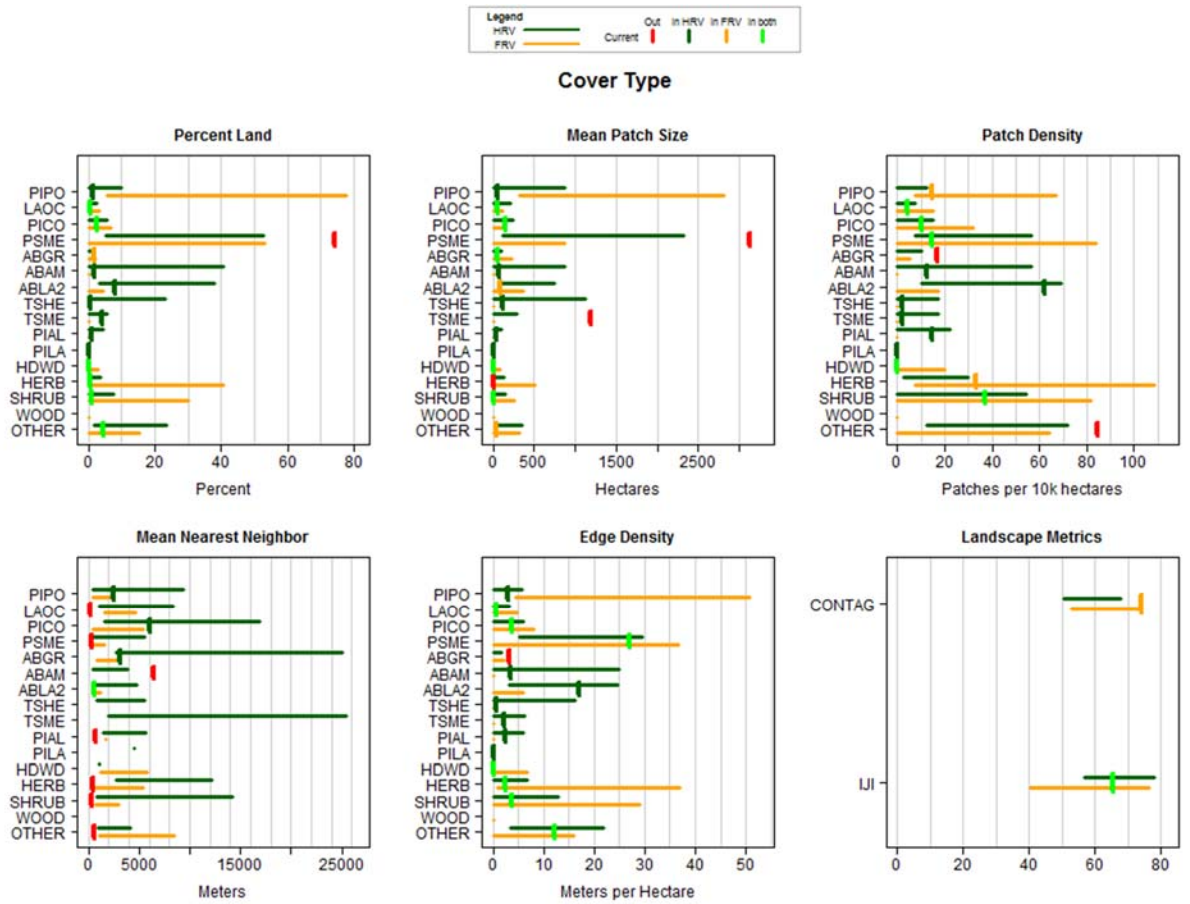
Central to the landscape evaluation process is comparing not just how the abundance of the vegetation, wildlife habitat, wildfire and insect measures may have departed from HRV/FRV, but how the spatial patterns may have departed. "Spatial pattern" refers to the size, shape, and configuration of patches as defined by vegetation, wildlife habitat, wildfire and insect measures. These spatial patterns are a critical driver of ecosystem processes and functioning (Hessburg et al. 2015). For example, simply evaluating the amount of northern spotted owl habitat within a subwatershed does not capture whether that habitat is fragmented across many small patches or aggregated together in few large patches. Similarly, the distribution of vegetation patch sizes has a significant influence on the spread of fire across a landscape (Hessburg et al. 2015). Within each of the Manastash-Taneum subwatersheds, we used 6 different spatial metrics in addition to overall abundance to compare each vegetation, wildlife habitat, wildfire, and insect measure to HRV and FRV reference conditions (Table 4, Figure 2). The departures of current conditions from HRV and FRV reference conditions for each subwatershed are described in the following *Landscape Evaluation Summaries and Landscape Prescriptions* section.

We identified potential "Landscape Treatment Areas" (LTA's) within each subwatershed based upon the Landscape Prescriptions and used an evaluation of soil moisture deficit (*sensu* Stephenson 1998) to help align the LTA's with natural topographic and soil patterns (Principle 2, Hessburg et al. 2015). Based upon topographic position and soil water holding capacity, soil moisture deficit estimates vegetation stress due to seasonal lack of water and has been found to correlate well with a range of ecological important attributes including forest structure and composition, fuel moisture, and fire behavior, (Lutz et al. 2010, Kane et al. 2015). Deficit was calculated following Churchill el al (2013) using a 10m digital elevation model, SSURGO soils data (http://websoilsurvey.nrcs.usda.gov/) and ClimateWNAclimate data (http://www.climatewna.com/)).

Table 4. Spatial metrics used in Okanogan-Wenatchee Forest Restoration Strategy terrestrial landscape evaluations.

Class Metrics	**Basic Interpretation**
Percent Land	Percentage of the landscape occupied by a given class type. Ecologically important in describing landscape composition
Mean Patch Size	Average patch size for a class type across a subwatershed. Represents the typical patch size. An important component of habitat quality.
Patch Density	Number of patches on the subwatershed by patch type (class). Indicates how fragmented is a given class type.
Mean Nearest Neighbor	Average distance between any given patch and the closest patch of the same class. Represents the isolation of individual patches.
Edge Density	The total length of edge of a given class type relative to the subwatershed size. A proxy for edge effect and fragmentation.
Landscape Metrics	
Contagion	How easy it is to move within a patch type, aggregated across all patch types present on the landscape. A measure of the connectivity within each class type.
Interspersion - Juxtaposition	How intermixed patches are across the subwatershed. Reflects the ability to move from one patch type to all other patch types.

Figure 2. Example of the terrestrial landscape evaluation metrics output for forest cover types within the North Fork Taneum subwatershed. Vertical lines represent current conditions and horizontal bars represent HRV (green) and FRV (yellow) reference conditions. See Appendix B for complete terrestrial evaluation output for all subwatersheds.



3. LANDSCAPE EVALUATION SUMMARIES AND LANDSCAPE PRESCRIPTIONS

3.1 Aquatic Evaluation Summaries

Across Manastash-Taneum, the measured indicators suggest that roads (and other travel routes) are having a considerable influence on the aquatic environment in all subwatersheds, but especially those that have existing or potential rearing habitat for steelhead (Figures 3-5, Table 5). There are many opportunities to reduce the road-stream interactions, restore hydrologic functions and processes, address limiting factors for steelhead, and restore native disturbance regimes. Sections 4 – 7 below provide detailed summaries of the Aquatic Evaluations for each subwatershed.

Generally, habitat connectivity within the current and potential steelhead habitat was good in the Taneum drainage. However, we limited our field review of road-stream crossings to the Taneum and North Fork Taneum, because steelhead currently occupy portions of these subwatersheds. There is one undersized culvert in the North Fork Taneum (see further details below) that could present a passage barrier during certain times of the year, such as low flow. In addition, this culvert is not sized to handle anticipated high flows. Efforts are currently underway to address stream flows in the lower reaches of the North Fork Manastash, which would provide steelhead access to about 8 miles of additional habitat. This restored access may warrant further evaluation of road-stream crossings as was conducted in the Taneum drainage.

Headwater streams in the North Fork Taneum and North Fork Manastash subwatersheds are likely to become increasingly important cold-water refugia as stream temperatures in lower reaches are projected to increase (Isaak et al. 2012). These changes are projected to be most dramatic in the Taneum subwatershed, where nearly the entire portion of the stream that is currently used as rearing habitat by steelhead is likely to reach summer temperatures considered to be "stressful" for rearing salmonids (Table 6). It will become increasingly important to reduce non-climate related stressors on steelhead habitat. Forest and road restoration projects in the upper portions of the North Fork Taneum and North Fork Manastash to restore large tree structure, stream shade, and reduce negative road-stream interactions (e.g., potential for fine-sediment delivery) would help to conserve cold-water habitats.

.

Table 5. A comparison of indicator variables showing the road-stream interactions for each subwatershed in the Manastash-Taneum Large Landscape Restoration Project.

Sub-watershed	Route Density (mi./sq.mi.)	Road Density Condition Rating[1]	Miles Steelhead Potential Habitat[2]	Miles Steelhead Rearing Habitat[3]	Route Miles in 100 m Buffer of Steelhead Habitat	Number of Crossings within 100 m of Steelhead Habitat
North Fork Taneum	4.4	Poor	14.2	0	19.5	89
Taneum	6.5	Poor	----	14.1	14.9	25
North Fork Manastash	5.1	Poor	7.7	0	11.3	
Robinson Canyon	1.5	Fair	0.3	0	NA	NA

1/Based on Forest Service Watershed Condition Framework (Potyondy and Geier 2010).
2/Potential habitat is not currently used for rearing by steelhead but has the potential to be in the future.
3/Rearing habitat is currently being used by Steelhead based on most current survey information

Table 6. Miles of current or potential steelhead rearing habitat by stream temperature category within each subwatershed based on current and projected (2040, 2080) mean August stream temperatures[1] (data not available for Robinson Canyon).

Subwatershed	Miles of Current or Potential Steelhead Rearing Habitat within Stream Temperature Categories[2]								
	Current			**2040s**			**2080s**		
	Favorable	Stressful	Fatal	Favorable	Stressful	Fatal	Favorable	Stressful	Fatal
North Fork Taneum	14.2	0	0	14.2	0	0	14.2	0	0
Taneum	13.1	1.0	0	8.1	6.0	0	0	13.6	0.5
North Fork Manastash	7.7	0	0	7.2	0.5	0	5.7	2.0	0

1/Stream temperature from www.fs.fed.us/NorWeST
2/Categories based on Mantua and Raymond (2014)

Figure 3. Distribution of roads and current and potential habitat for steelhead within the Manastash-Tanuem project area.

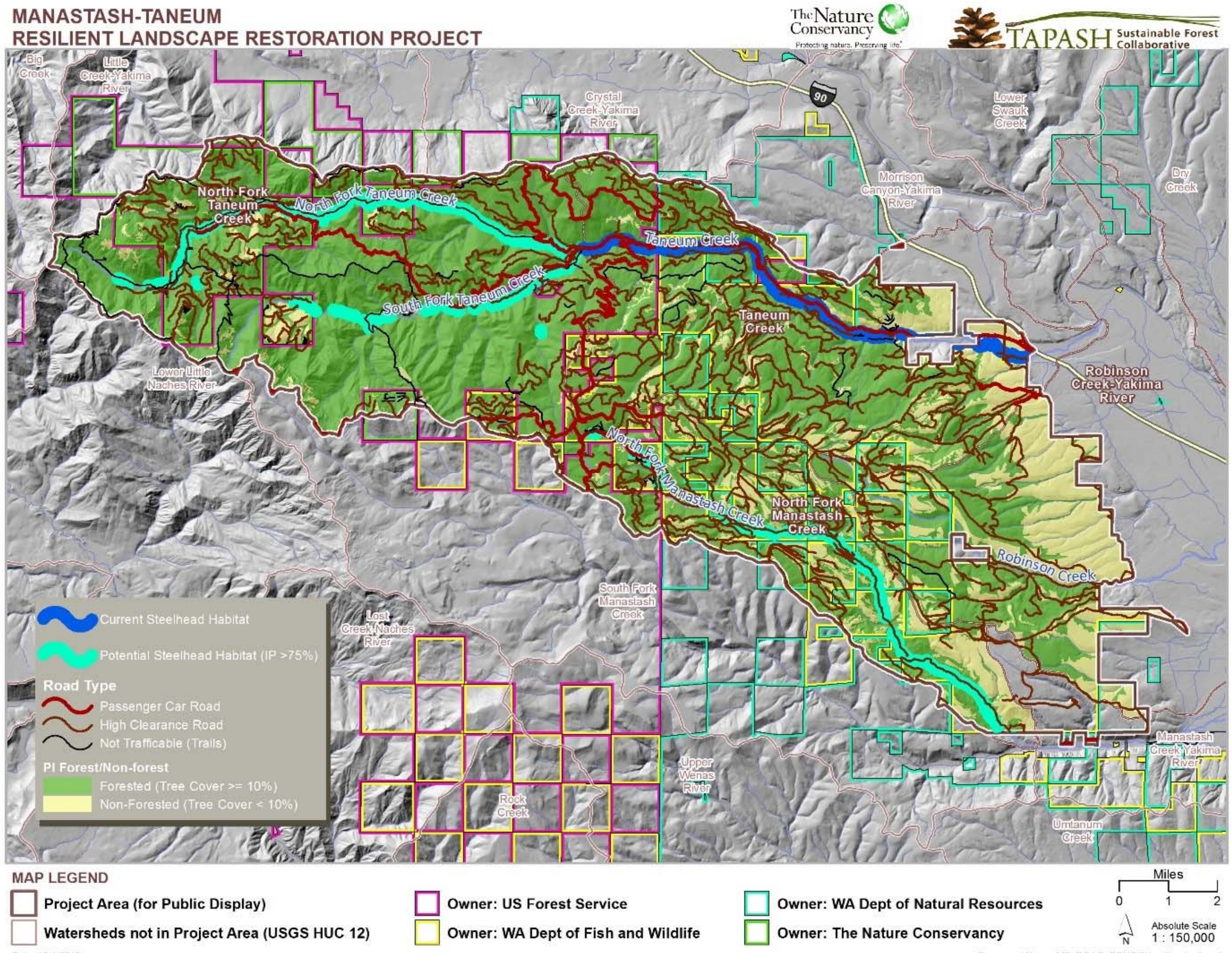


Figure 4. Road densities in relation to current and potential steelhead habitat within the Manastash-Taneum project area.

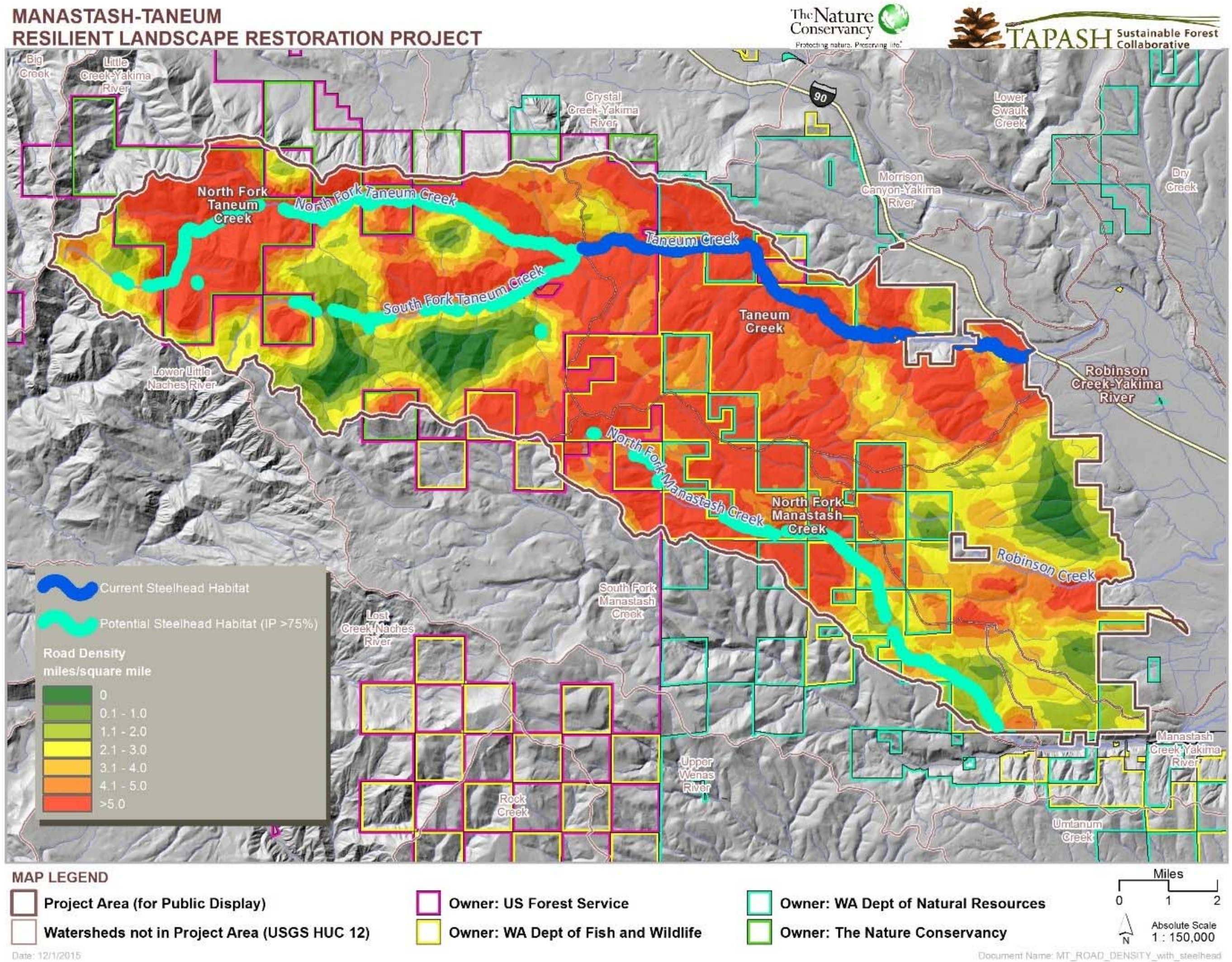
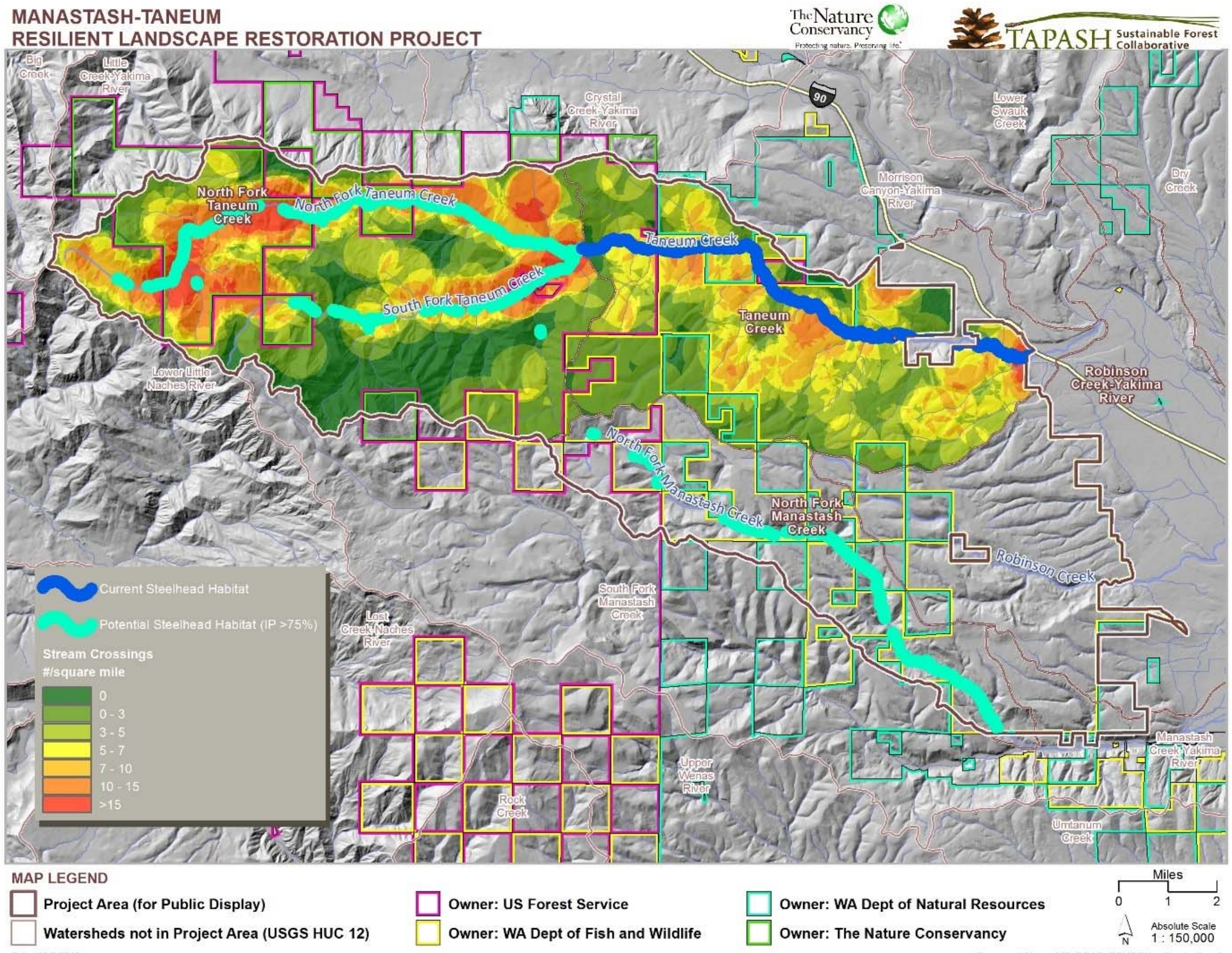


Figure 5. Density of road-stream crossings in the Manastash-Taneum landscape restoration project area (note road-stream crossing densities were not calculated for North Fork Manastash or Robinson Canyon due to poor quality road data)



3.2 Terrestrial Evaluation Summaries

Although the Manastash-Taneum project area contains very large environmental gradients, the terrestrial landscape evaluations revealed several common trends. As is expected given the management history of these subwatersheds, the trends are consistent with the impacts of past wildfire suppression and industrial forest management Sections 4 – 7 below provide detailed summaries of the Terrestrial Evaluations for each subwatershed..

Across all subwatersheds except Robinson Canyon, Douglas-fir cover was overabundant compared to HRV and FRV (Figure 6). Similarly, closed canopy conditions generally and the Young Forest Multi-Story structural stage specifically (see Appendix A for structural stage definitions) were typically overabundant compared to both HRV and FRV reference conditions (Figure 7). Slightly complicating the interpretation of these results is that the forest structural stage and cover type departures where often specific to a particular potential vegetation group (e.g., cold forest, moist forest, dry forest; see Appendix A for definitions) within the subwatershed. Assessing the spatial patterns of forested vegetation revealed general trends towards fragmentation. Within the North Fork Taneum, Taneum, and North Fork Manastash subwatersheds patch densities (too high), mean nearest neighbor distances (too low), and edge density (too high) spatial metrics departed from HRV and FRV for many vegetation measures.

Trends in wildlife habitat abundance varied considerably amongst the subwatershed reflecting the underlying environmental gradients. Both current and potential future northern spotted owl habitats are concentrated in the North Fork Taneum subwatershed where the majority of moist forests (potential vegetation group) are found (Figure 21). While the abundance of current northern spotted owl habitat is within the HRV (but exceeding FRV in North Fork Taneum), it is overly fragmented with too many small, disconnected habitat patches compared to HRV and FRV across all subwatersheds. Similarly, most common departures for white-headed woodpecker, goshawk, and American marten habitat was fragmentation with too many small, disconnected habitat patches compared to HRV and FRV.

The HRV and FRV reference conditions for the wildfire and insect disturbance measures tended to be extremely wide with the only true departures found in the North Fork Taneum subwatershed (elevated crown fire and western spruce budworm hazard). Nevertheless, mapping of current condition wildfire and insect hazards can and should be integrated into the planning of restoration management actions.

Figure 6. Manatash-Taneum vegetation cover types. See Appendix C for complete set of maps for each terrestrial measures.

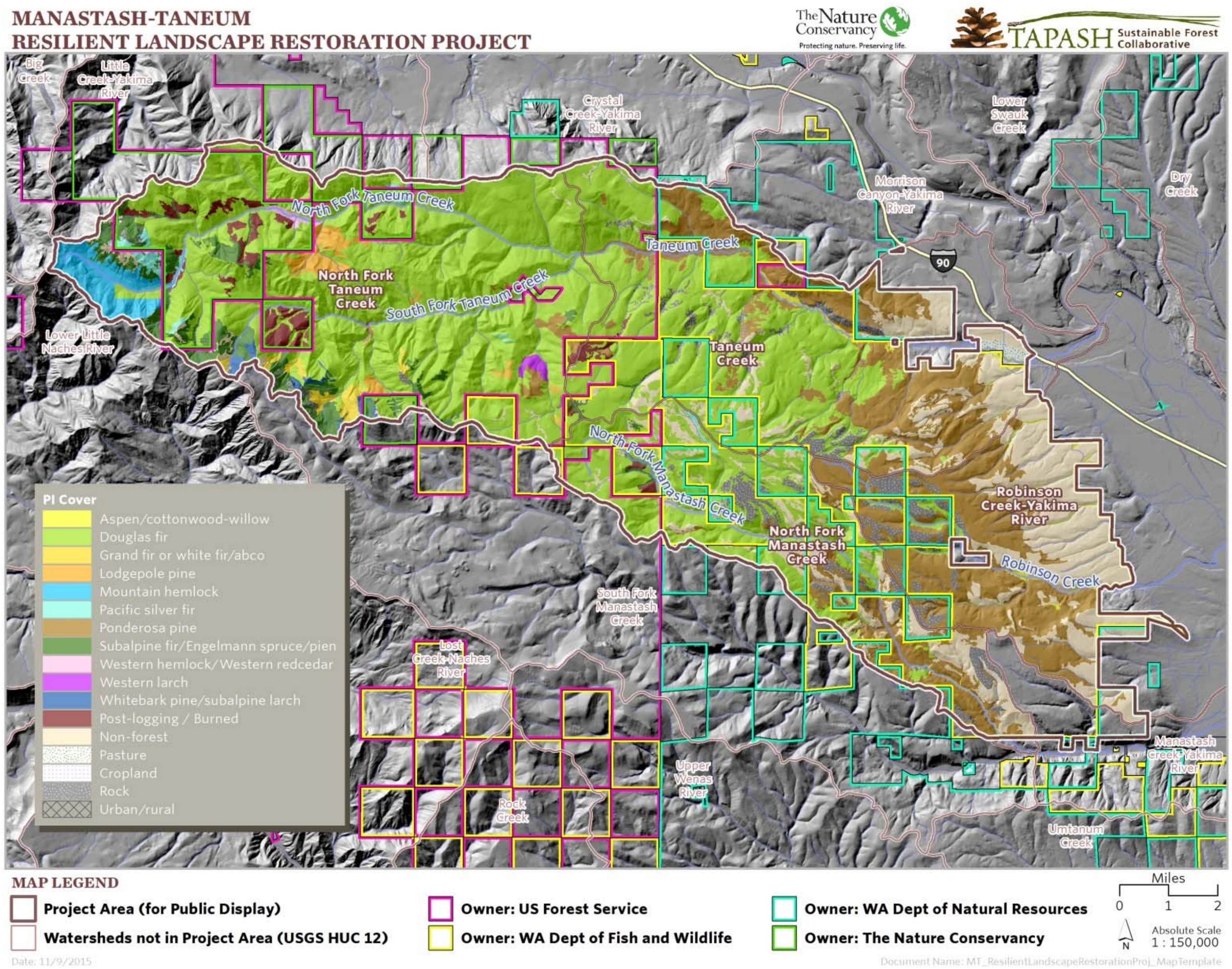


Figure 7 . Manatash-Taneum terrestrial vegetation structural stages. See Appendix C for complete set of maps for each terrestrial measure.

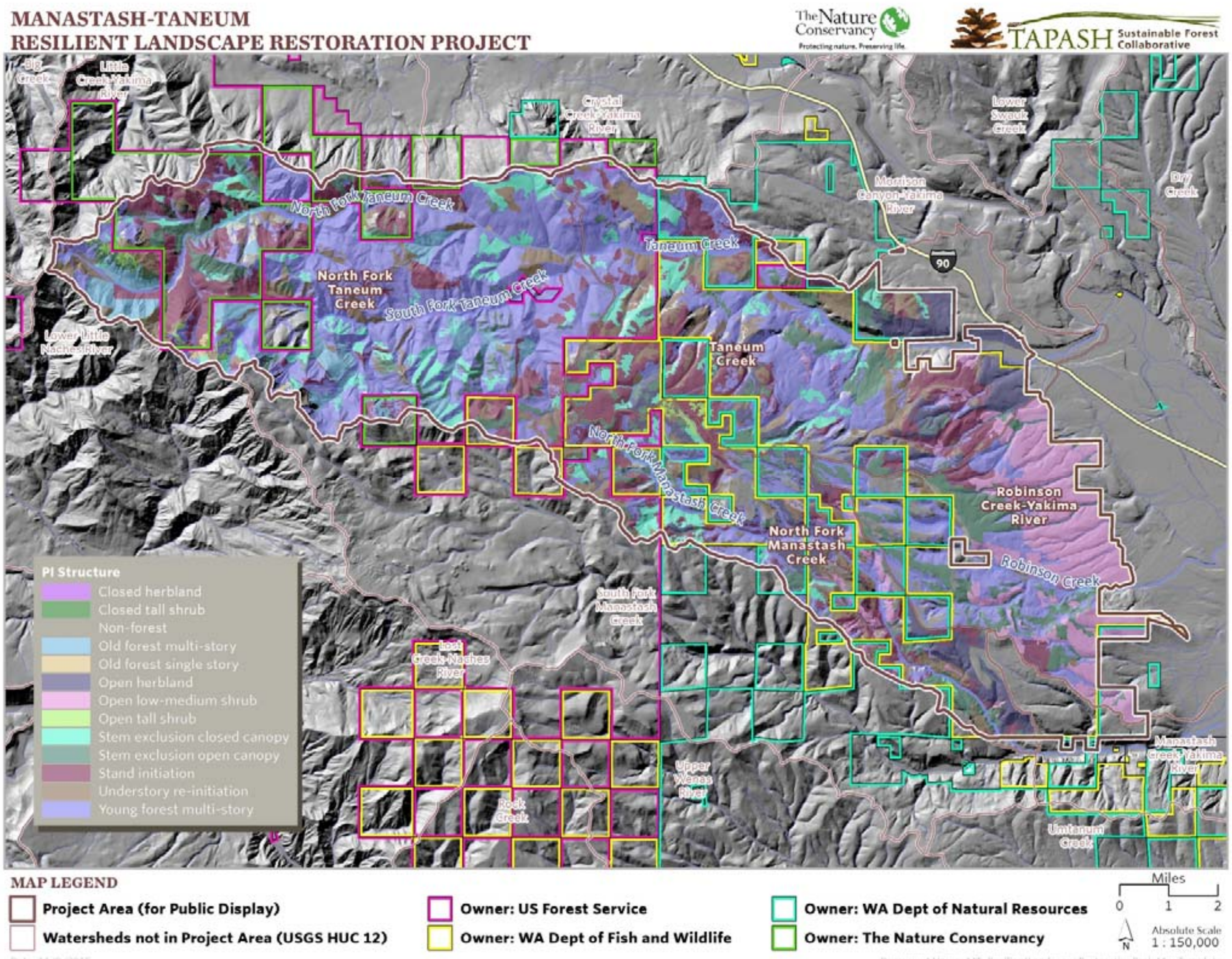


Figure 8. Manatash-Taneum current northern spotted owl habitat. See Appendix C for complete set of maps for each terrestrial measure.

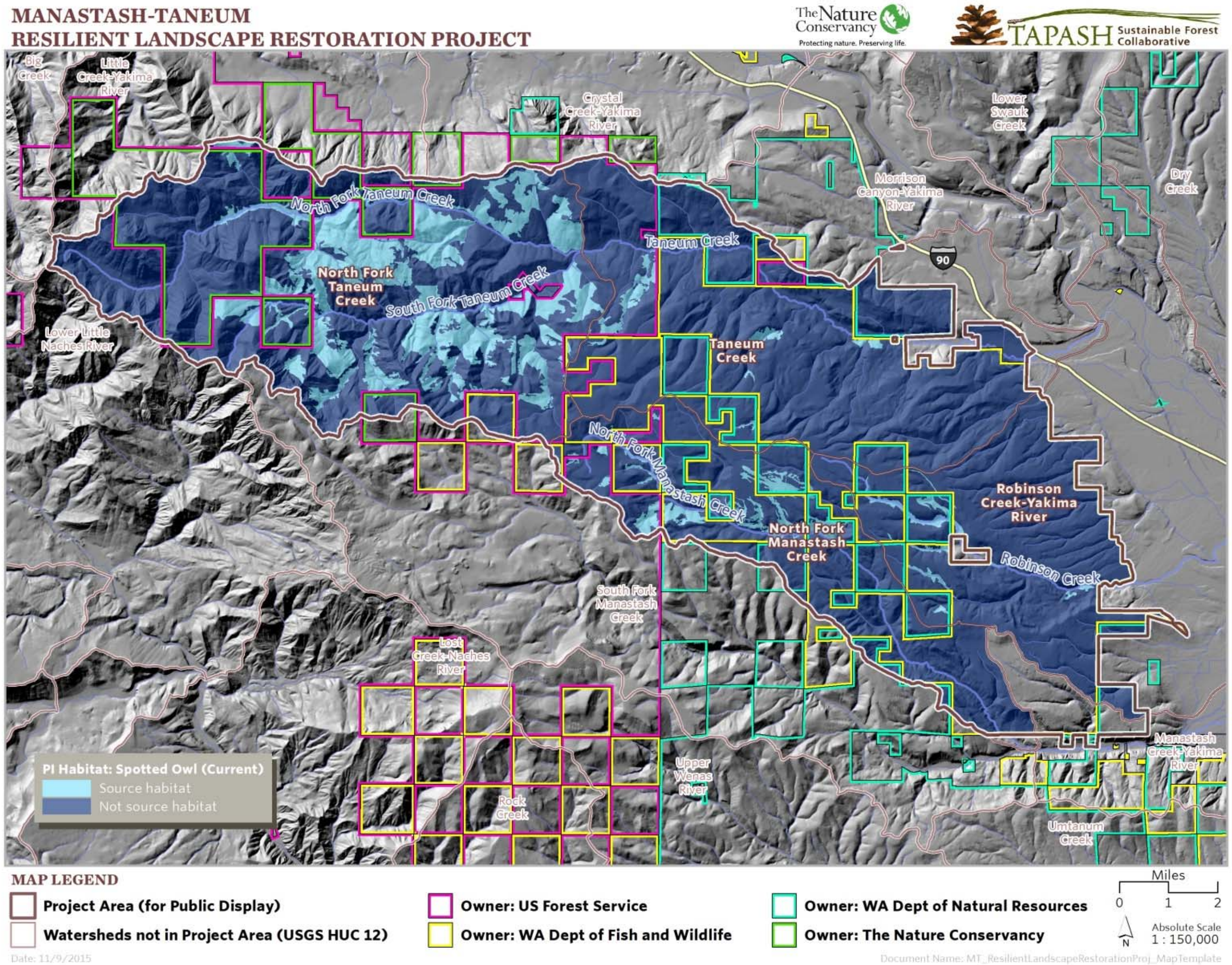
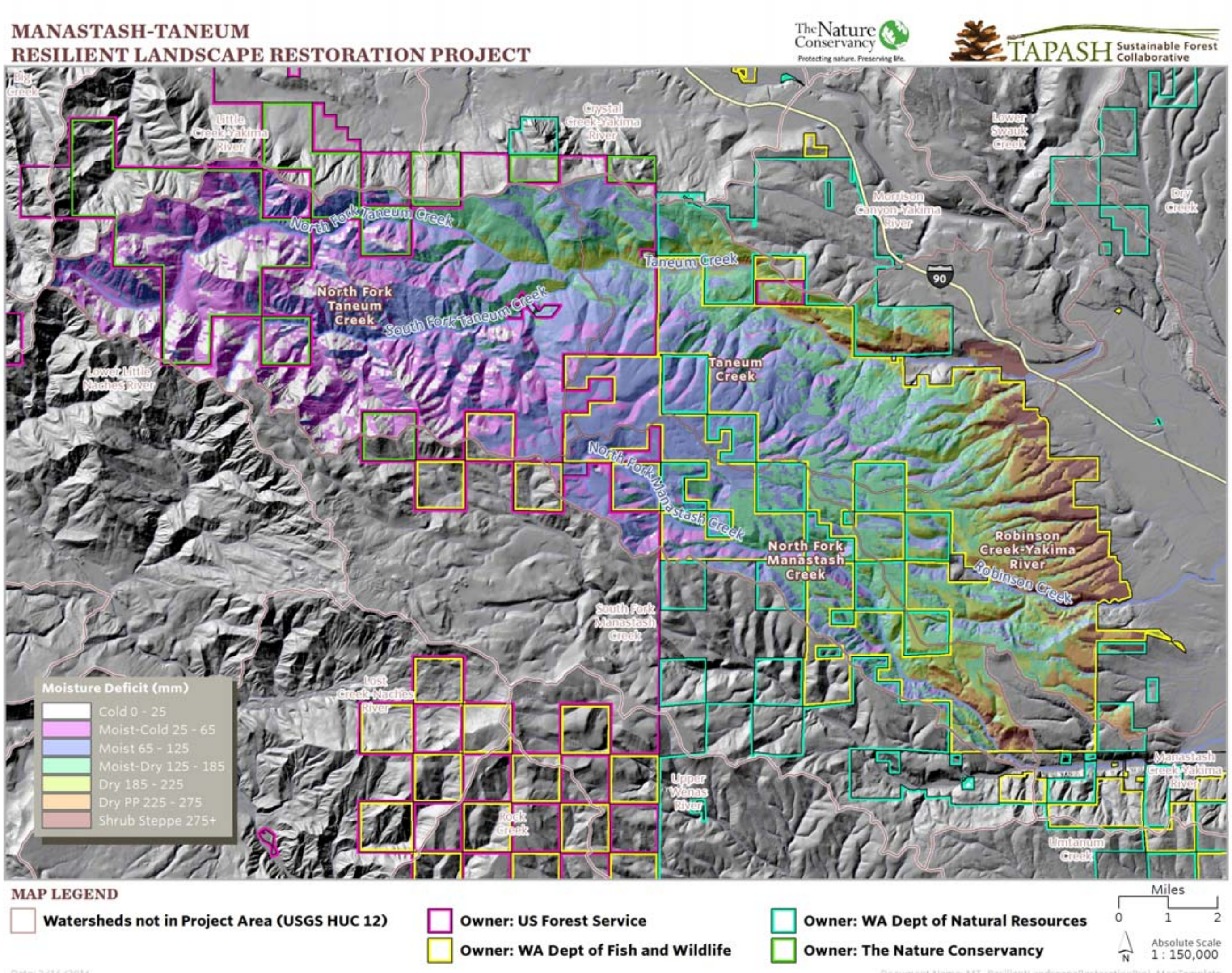


Figure 9. Manatash-Taneum moisture deficit. See Appendix C for complete set of maps for each terrestrial measure.



3.3 Restoration Opportunities Summary

Across the Manastash-Taneum project area we have identified a series of aquatic and terrestrial "restoration opportunity areas" based upon the landscape evaluations and prescriptions (Tables 6 and 7, Figures 10 and 11). The opportunity areas present potential locations for active management projects to address the key landscape evaluation departures and prescriptions. However, they are not exclusive and active restoration activities within other locations in the Manastash-Taneum project area may also address the key landscape departures and prescriptions. Each restoration opportunity area will require additional in-field scoping, evaluation, and environmental review prior to project implementation. Also importantly, additional field review may lead to significant modifications / adjustments.

Within the North Fork Taneum Creek and Taneum Creek subwatersheds we have identified 5 distinct "opportunity areas" for aquatic restoration projects (Figure 10, Table 7). Each of these aquatic restoration opportunity areas focuses on issues related to road-stream interactions and potential negative impacts on steelhead habitat.

Table 7. Aquatic restoration opportunities areas within the Manastash-Taneum landscape restoration project area.

Aquatic Restoration Opportunity Area	Applicable Ownerships
NF Taneum Area #1: Section 21, Confluence of Lookout Creek and North Fork Taneum -Water / sediment drainage from road into stream - Potential need for culvert improvements -High density of road/stream crossings	TNC
NF Taneum Area #2: Section 23, Confluence of Butte Creek and North Fork Taneum -Undersized main culvert, potential barrier to fish passage -Burned area delivering sediment -Small culverts receiving from burned area, crushed and occluded -High density of road/stream crossings	TNC
NF Taneum Area #3: Sections 33,34,27 along South Fork Taneum Creek -Stream adjacent road (3300-135) confining stream channel, contributes sediment, and reduces large woody debris in stream section within potential steelhead habitat	USFS
NF Taneum Area #4: Sections 26,27 Confluence of First Creek and North Fork Taneum -3300-116 road with significant channeling, gullying leading to potential steelhead habitat. -Dispersed camp sites delivering sediment to main channel	USFS
Taneum Area #1: Sections 29, 30 Confluence of Cedar Creek and Taneum Creek -Incised channel delivering sediment to existing steelhead habitat -Culverts small and partially occluded	WDFW & USFS

Table 7: Continued.

Aquatic Restoration Opportunity Area	Applicable Ownerships
Taneum Area #2: Sections 29 Taneum Creek	
-Dispersed camping delivering sediment to existing steelhead habitat	WDFW & USFS
Taneum Area #3: Sections 28, 29 Taneum Creek	
-Sediment from road and dispersed camping into existing steelhead habitat	WDFW & USFS
Taneum Area #4: Confluence of First Creek and North Fork Taneum	
-Stream adjacent road (mainline 3300) confining stream channel, contributes sediment, and reduces large woody debris in stream section within existing steelhead habitat -Dispersed camping sites delivering sediment within existing steelhead habitat	WDFW & USFS
Taneum Area #5: Sections 36, 1, Taneum Creek	
-Stream adjacent road (mainline 3300) confining stream channel, contributes sediment, and reduces large woody debris in stream section within existing steelhead habitat	WDFW & USFS

Across the entire Manastash-Taneum project area we have identified over 17,000 acres of terrestrial restoration opportunity areas where active management may be used to address key ecological departures and further the objectives of the landscape prescriptions (Table 8,). Within Figure 11 we identify three general categories of terrestrial restoration opportunities.

Terrestrial Opportunities Category A – Variable density thinning (mechanical or prescribed fire) of mostly young forest multi-story and stem exclusion closed canopy structural stages, converting to stem exclusion open canopy for long-term development into old forest single story. Generally promoting ponderosa pine and western larch (where already present) and reducing Douglas-fir cover. These areas occur predominately on southerly aspects. Restoration activities need to include protections for riparian areas, floodplains, and wet patches of cedar. Long term these lands are NOT targeted to provide northern spotted owl source habitat. But, present day activities need to avoid any areas with current owl activity.

Terrestrial Opportunities Category B - Generally pre-commercial thinning of stand initiation structural stage to encourage development of desirable dominants and co-dominants. Long-term targets may be either open canopy single story or close canopy multi-story.

Terrestrial Opportunities Category C- Variable density thinning (mechanical or prescribed fire) in predominately young forest multi-story to accelerate development of complex multi-canopy layer structure.

At this stage of the analysis, we have not identified which acres are suitable for thinning via tractor yarding, cable yarding, prescribed fire, etc. Silvicultural prescriptions will vary dramatically amongst terrestrial restoration opportunity areas based upon the landscape prescriptions and objectives for within-stand spatial patterns. Techniques such as the

"Individuals-Clumps-Openings" approach can be used to quantify, prescribe, and implement appropriate within stand spatial patterns (Churchill et al. 2013).

Table 8. Terrestrial restoration opportunities areas within the Manastash-Taneum landscape restoration project area.

Treatment Category	Acres	Applicable Ownerships
North Fork Taneum Creek		
-A & C; Variable density thinning in moist-forest YFMS to either promote open-canopy conditions (A) or multi-layer (C)	~4,000	USFS
-B; Pre-commercial thinning in moist-forest SI to accelerate structural development	2,000+	TNC primarily, also USFS
Taneum Creek		
-A; Variable density thinning in moist & dry forest YFMS & SECC to promote open-canopy conditions	4,600+	WDFW, USFS, also WDNR
-B; Pre-commercial thinning in dry-forest SI to accelerate open canopy structural development	1,500+	Mostly WDFW, also WDNR and USFS
North Fork Manastash Creek		
-A; Variable density thinning in dry forest YFMS & SECC to promote open-canopy conditions	2,000+	WDFW, WDNR
-B; Pre-commercial thinning in dry-forest SI to accelerate open canopy structural development	1,200+	Mostly WDFW, also WDNR and USFS
Robinson Crk.		
-A; Variable density thinning in dry forest YFMS and SI to promote open-canopy conditions	2,300+	Mostly WDFW, also WDNR
Total	17,600+	

Figure 10. Aquatic restoration opportunities areas within the Manastash-Taneum landscape restoration project area.

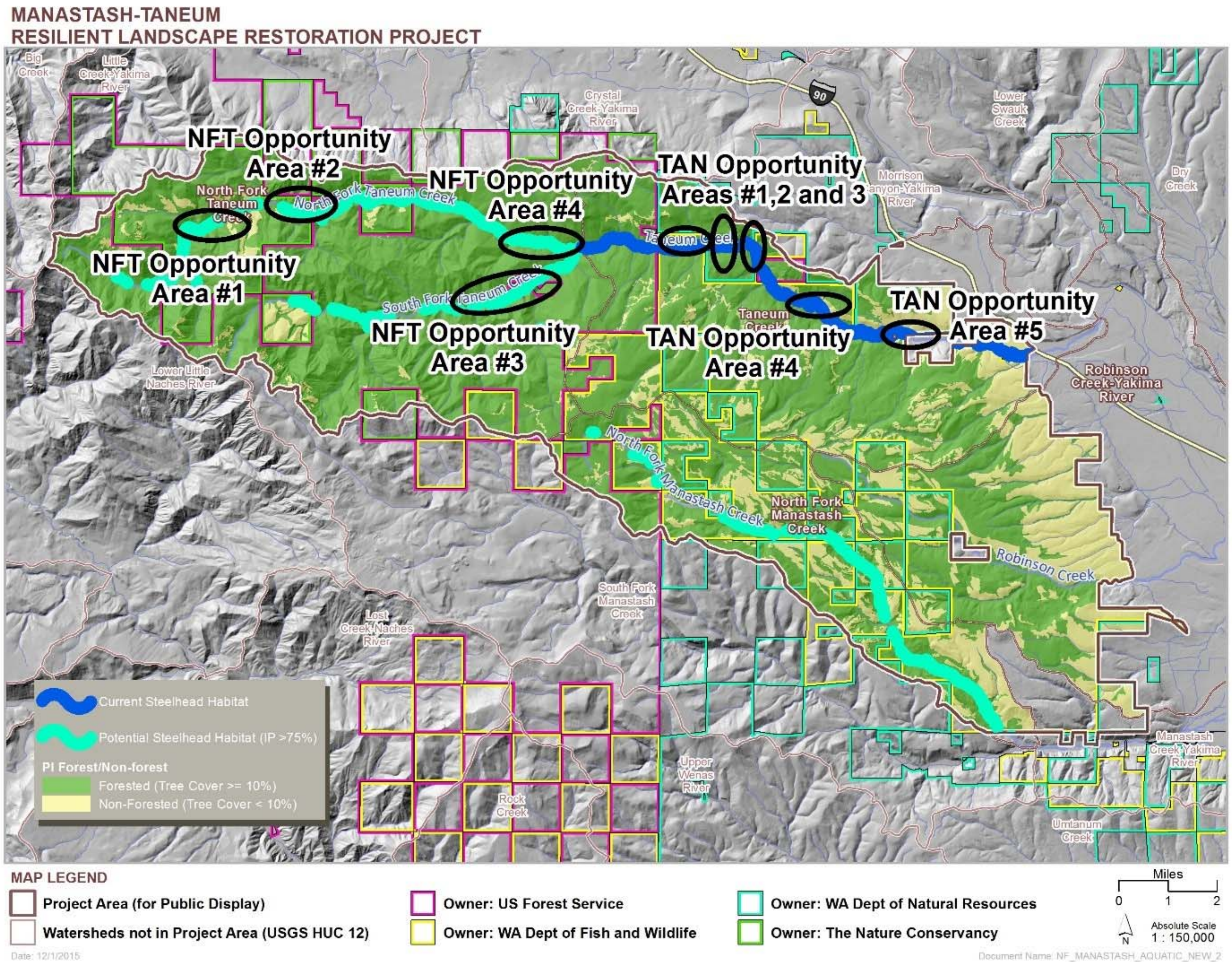
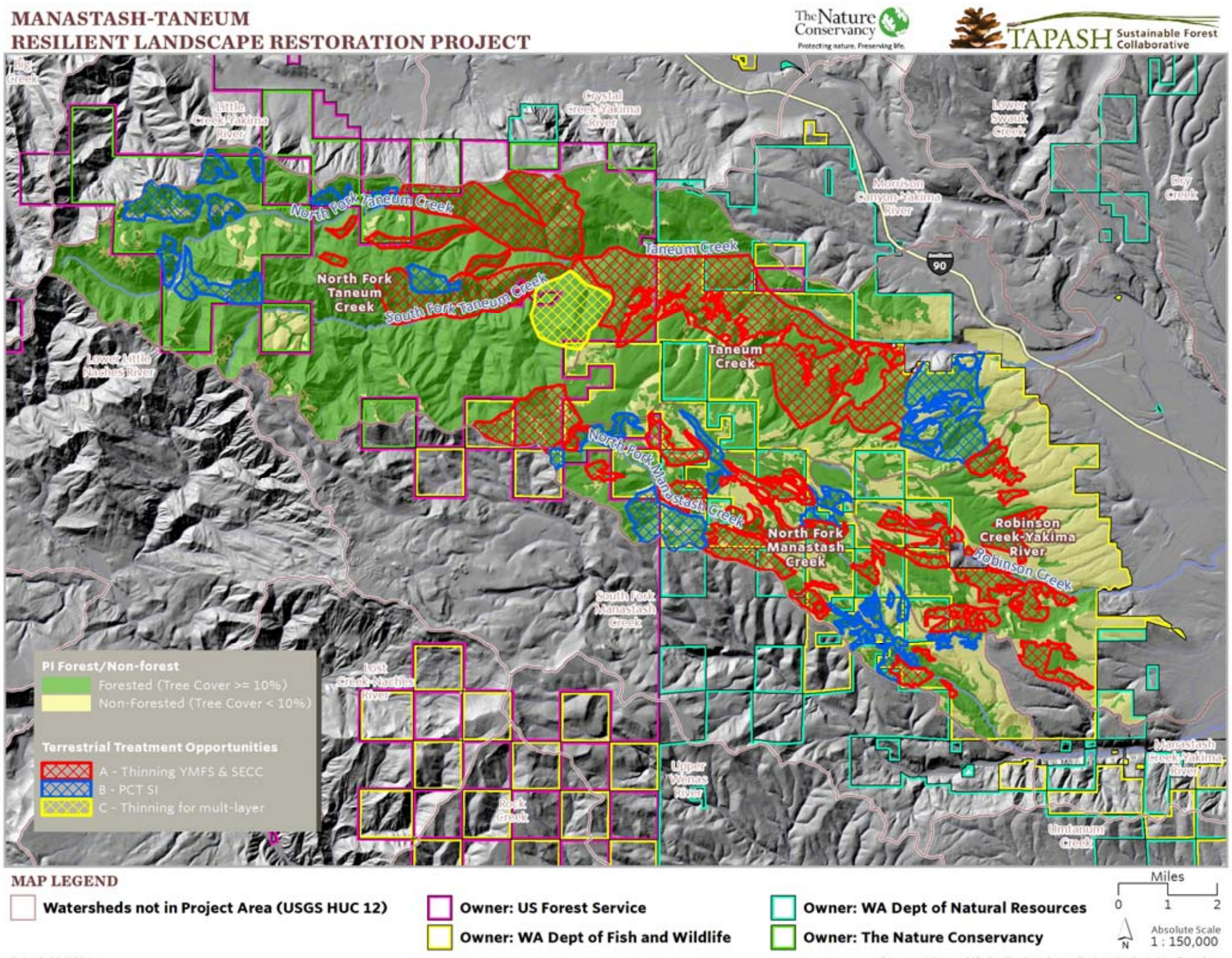


Figure 11. Terrestrial restoration opportunity areas within the Manastash-Taneum landscape restoration project area.



4 North Fork Taneum Subwatershed

4.1 North Fork Taneum Aquatic Evaluation and Prescription

The North Fork Taneum subwatershed is 29,537 acres in size and includes a considerable amount of potential habitat for steelhead, in both the North and South Forks of Taneum Creek (Fig. 6), that is currently not being used for rearing. The downstream barriers that previously prevented access for fish to the Taneum and North Fork Taneum have been addressed. The overall road density is high, giving the watershed a poor condition rating. However, road densities are not evenly distributed across the watershed (Fig. 7). Road densities are especially high (>5 miles/square mile) in the western portion of the subwatershed, and on the north sides of both the North and South Forks of Taneum Creek. The main road (Rd 33) along the North Fork Taneum Creek occurs within floodplains, is confining the channel, reducing the potential for large wood recruitment, and creating a situation that can cause chronic delivery of sediment to the stream.

The terrestrial landscape evaluation showed that forested habitats are generally overly fragmented compared to both the HRV and FRV, and that the abundance of young forest-multi-story (YFMS) and stand initiation (SI) are overabundant compared to HRV and FRV. The crown fire potential "high" category is considerably above the FRV, indicating a considerable risk of large-scale fire, making this subwatershed susceptible to large-scale disturbances and increases the risk of effects to hydrologic and watershed functions. The terrestrial landscape prescription identified opportunities across landownerships to restore forest vegetation structure and composition to more resilient conditions, which in turn would reduce the risk of uncharacteristically severe fires and contribute to the recovery of listed fish species (Bisson et al. 2003, Reiss et al. 2008).

We identified four restoration opportunity areas along the main-stem of the North and South Forks of Taneum Creek (Fig. 8). In addition, we identified areas with high densities of roads and road-stream crossings where additional fieldwork could identify opportunities to reduce road densities and restore watershed processes and functions (Fig. 9). Finally, there is an opportunity to review the current location of the main road (Rd 33) and determine if it could be relocated to reduce the negative impacts this road is having on the aquatic environment.

Collectively these projects would address the following limited factors identified for steelhead recovery: degraded floodplains, degraded channel, degraded riparian area and large wood, altered sediment routing, and impaired fish passage.

Opportunity Area 1 – Section 21, confluence of Lookout Creek and North Fork Taneum

-Water and sediment drains onto bridge then gets routed into the stream (NFT photos 1.1 and 1.2). Water and sediment also drains into ditch alongside the road and then delivered into the stream (NFT photos 1.3, 1.4, and 1.5). There are also other areas with culverts that need consideration for improvement (NFT photos 1.7, 1.8, and 1.9). General area has a high amount of road/stream crossings (10-15 crossings per square mile).

Opportunity Area 2 – Section 23, confluence of Butte Creek and North Fork Taneum

-Culvert may be undersized and could potentially be a barrier to anadromous fish populations (NFT photo 2.1) during periods of low flows. Areas directly north were burned in the recent Taneum Ridge fire and contribute sediment immediately downstream from the aforementioned culvert (NFT photo 2.2 and 2.3). Small culverts receiving water and sediment from the previously burned area are crushed and occluded (NFT photos 2.4, 2.5, and 2.6).). General area has a very high amount of road/stream crossings (>15 crossings per square mile).

Opportunity Area 3 – Sections 33,34,27 along South Fork Taneum Creek

-The 3300-135 road is immediately adjacent to the stream within potential steelhead habitat. This road parallels directly alongside the stream and confines the channel, contributes sediment, and has reduced the source for large wood. Field survey of this road would reveal the best options for restoration actions.

Opportunity Area 4 – Sections 26,27, confluence of First Creek and North Fork Taneum

The 3300-116 road has significant channeling on the road surface and gullying on the side leading to the main channel and potential steelhead habitat (NFT photos 4.1 and 4.2). There are dispersed camping sites directly adjacent to the stream that have roads delivering sediment to the main channel (NFT photos 4.3 and 4.4).

Reduce Road Density and Road-Stream Crossings

Conduct field surveys to identify specific roads/motorized trails and road-stream crossings for restoration, including integration with areas identified for terrestrial restoration treatments. These areas include the areas adjacent to and upslope from Opportunity Areas 1-4 (Fig. 8)

4.2 North Fork Taneum Terrestrial Landscape Evaluation

The North Fork Taneum subwatershed (UYK_0503) is 29,537 acres comprised primarily of moist forests (20,923 ac.) with smaller amounts of cold forests (5,540 ac.), dry forests (2,530 ac.), and other non-forested vegetation types (540 ac.). Ownership is dominated by the US Forest Service (21,030) with a lesser amount managed by The Nature Conservancy following recent acquisition from Plum Creek Timber (7,611 ac.). Historical Range of Variability (HRV) reference conditions were based upon Ecological Sub Region (ESR) 4, and Future Range of Variability (FRV) reference conditions were based upon ESR 11.

Vegetation

- Overall, vegetation patches are overly fragmented with patch density, mean nearest neighbor, and edge density spatial metrics departed from HRV and FRV for many vegetation measures.
- Cover of Douglas-fir is far over abundant compared to both HRV and FRV while the cover of Ponderosa pine (365 ac. current) is on the low end of HRV and is extremely low compared to FRV.
- Within moist forests, the abundance of the young forest multi-story (yfms) and stand initiation structural stages (si) are over abundant compared to HRV and FRV.

Vegetation Variable	Current	HRV	FRV
Cover - (acres)			
Douglas-fir	21,933	1,500 - 15,600	0 - 15,700
ponderosa pine	352	0 - 2,900	1,500 - 22,900
Structural Stage - (acres)			
Moist Forest – YFMS	9,604	0 - 6,000	0 - 5,300
Moist Forests – SI	4,004	0 - 1,500	0 - 3,000

Wildlife Habitat

- The amount of white -headed woodpecker and goshawk habitat is within HRV and FRV but is overly fragmented.
- The amount of American marten habitat is over FRV and is overly fragmented.
- The amount of current northern spotted owl habitat is within HRV but is over-abundant compared to FRV and is overly fragmented.
- The amount of potential future northern spotted habitat is within HRV and FRV, but is also overly fragmented.

Wildlife measure	Current	HRV	FRV
Habitat - Percent Land (acres)			
spotted owl - current	7,598	970 - 12,000	0 - 5,400
spotted owl – future	8,076	1,700 - 18,100	760 - 18,100
Habitat - Patch Density (patches per 10k hectares)			
spotted owl - current	35	9 - 47	0 - 35
spotted owl – future	91	9 - 47	2 - 45
Habitat - Edge Density (meters per hectare)			
spotted owl - current	34	4 - 27	0 - 25
spotted owl – future	36	8 - 30	1 - 35

Disturbance

- Crown fire potential "high" category is way above FRV.
- Western spruce budworm "moderate hazard" is above HRV and FRV while the "low hazard" category is at the lower end of the FRV range.

Disturbance measure	Current	HRV	FRV
Crown Fire Potential (acres)			
Low	6,671	4,200 - 16,100	12,000 - 27,000
Moderate	7,270	23,400 - 8,300	1,500 - 10,700
High	15,592	5,700 - 19,200	0 - 7,100
Western Spruce Budworm Hazard (acres)			
Low	6,657	1,800 - 10,600	27,100 - 28,200
Moderate	9,103	1,200 - 8,200	3,300 - 8,000
High	13,773	13,700 - 24,700	9,600 - 23,300

4.3. North Fork Taneum Terrestrial Landscape Prescription

- **Reconnect vegetation and habitat patches based on patterns of topography/soil**
    - Across the watershed, focus on connecting similar patches for most cover-structure and wildlife habitats to reduce to total number of patches and edge densities based upon inherent patterns of topography and soil within the watershed.
- **Treat moist-forest stand initiation**:
    - Use pre-commercial thinning to accelerate successional development of moist forest si, which is found predominately on The Nature Conservancy (2,684 ac., 67% of all mf-si) and US Forest Service (1,002 ac., 25% of all mf-si) ownerships.
- **Treat moist-forest young forest multi-story:**
    - Within moist forests, convert ~ 4,000 acres of yfms to stem exclusion open canopy (seoc) in order to accelerate development of old forest structures while reducing crown fire potential and western spruce budworm hazard.
    - Depending upon treatment and succession rates within the current si, another ~1,000 acres of yfms may be converted to stand initiation
    - Treatments of moist forest - young forest multi-story will necessarily be focused on US Forest Service lands which contain 91% (8,773 ac.) of the moist forest - yfms.
- **Decrease disturbance hazards.**
    - Use treatments in moist forest – young forest multi story to reduce fire and insect hazards, particularly in locations where treatment can be used to protect northern spotted owl current and future habitat.
- **Promote ponderosa pine and western larch cover**
    - Where possible, use treatments within si and yfms to reduce Douglas-fir cover and promote ponderosa pine and western larch. This is particularly valuable within relatively drier locations based upon topography and soils, and can be used to create larger patches of habitat for white-headed woodpeckers.
- **Long-term habitat shifts across subwatershed**
    - Plan for a long term shift of northern spotted owl and other late successional habitats from mesic and dry forests “lower” in the subwatershed (eastern half of subwatershed) to the moist and cold forests “higher” in the watershed (western half of the subwatershed) where they will be most sustainable.
    - Identify landscape locations in the dry and mesic forests, such as north slopes and valley bottoms, where closed-canopy multi-layered habitats are most likely to be sustained and can be managed for future replacement habitat.
- **Increase wildlife habitat effectiveness**
    - Develop an integrated approach to access management that reduces overall effects of travel routes on aquatic and terrestrial habitats, while providing access needed for recreation and forest management.

5. Taneum Subwatershed

5.1 Taneum Aquatic Evaluation and Prescription

The Taneum subwatershed is 25,726 acres in size and includes a considerable amount of current rearing habitat for steelhead (Fig. 6). The overall road density is high, giving the watershed a poor condition rating. Road densities are fairly evenly distributed across the watershed (Fig. 7). The main road (Rd 33) along Taneum Creek, occurs within floodplains, is confining the channel, reducing the potential recruitment of large wood, and has the potential to chronically deliver sediment to the stream.

The terrestrial landscape evaluation showed that forested habitats are generally overly fragmented compared to both the HRV and FRV, and that within the dry forests, the abundance of stem exclusion closed canopy (SECC), young forest-multi-story (YFMS) and stand initiation (SI) are overabundant compared to HRV and FRV. The terrestrial landscape prescription identified opportunities across landownerships to restore forest vegetation structure and composition to more resilient conditions, which in turn would reduce the risk of uncharacteristically severe fires and contribute to the recovery of listed fish species (Bisson et al. 2003, Reiss et al. 2008).

We identified five restoration opportunity areas along the main-stem Taneum Creek (Fig. 8). In addition, we identified areas with high densities of roads and road-stream crossings where additional fieldwork could identify opportunities to reduce road densities and restore watershed processes and functions (Fig. 9). Finally, there is an opportunity to review the current location of the main road (Rd 33) and determine if it could be relocated to reduce the negative impacts this road is having on the aquatic environment.

Collectively these projects would address the following limiting factors identified for steelhead recovery: degraded floodplains, degraded channel, degraded riparian area and LWD, and altered sediment routing.

Opportunity Area 1 – Section 29,30, confluence of Cedar Creek and Taneum Creek

Incised channels deliver sediment to main channel within existing steelhead habitat and culverts are small and partially occluded (T photos 1.1, 1.2, and 1.3).

Opportunity Area 2 – Section 29, Taneum Creek

There are dispersed camping sites in the floodplain directly adjacent to the stream delivering sediment to the main channel into existing steelhead habitat (T photos 2.1. 2.2, and 2.3).

Opportunity Area 3 – Sections 28, 29, Taneum Creek

There is an unnamed/numbered road with a bridge. Sediment is delivered from the road surface and dispersed campsites into existing steelhead habitat (T photos 3.1, 3.2, 3.3, and 3.4).

Opportunity Area 4 – Sections 33,34, Taneum Creek

-The mainline 3300 road is immediately adjacent to the stream within existing steelhead habitat. This road parallels directly alongside the stream, confines the channel, reduces floodplain potential, contributes sediment, and has reduced the source for LWD (T photos 4.1 and 4.2). There are dispersed camping sites in the floodplain directly adjacent to the stream delivering sediment to the main channel (T photos 4.3 and 4.4).

Opportunity Area 5 – Sections 36,1, Taneum Creek

The mainline 3300 road is immediately adjacent to the stream within existing steelhead habitat. This road parallels directly alongside the stream, confines the channel, reduces floodplain potential, contributes sediment, and has reduced the source for LWD (T photos 5.1 and 5.2).

Reduce Road Density and Road-Stream Crossings

Conduct field surveys to identify specific roads and road-stream crossings for restoration, including integration with areas identified for terrestrial restoration treatments. These include: the areas adjacent to and upslope from Opportunity Area 1; the area to the south of Taneum Creek and Opportunity Area 3 along Shadow Creek; the area to the south of Taneum Creek and Opportunity Area 4 between Shadow Creek and Yahne Canyon (Fig. 8).

5.2 Taneum Terrestrial Landscape Evaluation

The Taneum Creek subwatershed (UYK_0504) is 25,726 acres comprised primarily of dry forests (12,109 ac.) with smaller amounts of moist forests (6,194 ac.) and other vegetation types (7,545 ac.). Washington Department of Fish and Wildlife is largest landowner (WDFW; 13,465 ac.) followed by Washington Department of Natural Resources (WDNR; 4,743 ac.), US Forest Service (USFS; 3,693 ac.) and others (3,931 ac.). Historical Range of Variability (HRV) reference conditions were based upon Ecological Sub-Region (ESR) 11, and Future Range of Variability (FRV) reference conditions were based upon ESR 90.

Vegetation

- Overall, vegetation patches are overly fragmented with patch density, mean nearest neighbor, and edge density spatial metrics departed from HRV and FRV for many vegetation measures.
- Cover of Douglas-fir is at the high end both HRV and FRV, especially within dry forests, while the cover of ponderosa pine is on the lower end of HRV and FRV.
- Within dry forests, the stem exclusion closed canopy (secc), stand initiation (si), and young forest multi-story (yfms) structural stages are over abundant compared to HRV and FRV

Vegetation Variable	Current	HRV	FRV
Cover - (acres)			
Douglas-fir	11,399	0 - 13,700	0 - 11,400
ponderosa pine	6,515	1,400 - 20,000	0 - 16,300
Dry forest - Douglas-fir	5,750	0 - 3,000	0 - 2,300
Structural Stage - (acres)			
Dry forest – SI	3,062	0 - 2,600	0 - 2,200
Dry forest – SECC	1,419	0 – 200	0 - 130
Dry forest – YFMS	4,221	0 - 2,300	0 - 2,300

Wildlife Habitat

- The amount of white-headed woodpecker, goshawk, and northern spotted owl current habitat is at the lower end of HRV and FRV.
- The amount of potential future northern spotted owl habitat is within HRV and FRV, but is overly fragmented.

Wildlife measure	Current	HRV	FRV

Habitat - Percent Land (acres)			
spotted owl - current	492	0 - 4,700	0 - 4,100
spotted owl - future	8,896	700 - 15,800	0 - 14,600
Habitat - Patch Density (patches per 10k hectares)			
spotted owl - future	88	3 - 45	0 - 27
Habitat - Edge Density (meters per hectare)			
spotted owl - future	53	1 - 35	0 - 33

Disturbance

- Fire and insect hazard variables are all within very wide HRV and NRV ranges.

5.3 Taneum Terrestrial Landscape Prescription

- **Reconnect vegetation and habitat patches based on patterns of topography/soil**
    - Across the watershed, focus on connecting similar patches for most cover-structure and wildlife habitats to reduce to total number of patches and edge densities based upon inherent patterns of topography and soil within the watershed.
    - In particular, focus on connecting patches of northern spotted owl potential future habitat and white-headed woodpecker habitat.
- **Thinning dry forest closed canopy patches to create open canopy conditions**
    - Within dry forest, convert 900+ acres of stem exclusion closed canopy and 3,700+ acres of yfms to open canopy conditions (likely to stem exclusion open canopy, seoc) in order to accelerate the development of old forest single story (ofss) and to reduced fire potentials. Prioritize thinning where large (25"+ dbh) ponderosa pine and/or western large are already present.
        - Thinning of dry forest yfms can include WDFW (2,471 ac. total), USFS (1,042 ac.) and WDNR (684 ac. total) ownerships.
        - Essentially all dry forest secc could be thinned on WDFW (388 ac. total), USFS (193 ac. total) and WDNR (277 ac. total) ownerships.
    - Within dry forests, thin stand initiation wherever possible to accelerate successional development and promote open canopy stand conditions with ponderosa pine / western larch cover.
        - Includes dry forest si on WDFW (1,888 ac.), USFS (177 ac.) and WDNR (957 ac.) ownerships.
- **Promote ponderosa pine and western larch cover**
    - Where possible, use thinning treatments to reduce Douglas-fir cover and promote ponderosa pine and western larch. This is particularly valuable within relatively drier locations based upon topography and soils, and can be used to restore habitat abundance and patch sizes for white-headed woodpeckers.
- **Balance thinning and wildlife habitat**
    - Thinning of closed canopy patches needs to be balanced with the maintenance of northern spotted owl and goshawk habitat. Use thinning to protect closed canopy wildlife habitats from transmission of fire and insect disturbances.
    - Due to the transient nature of closed-canopy, multi-layered habitats within the dry and mesic forests, considered identifying landscape locations, such as north slopes and valley bottoms, where these habitats are most likely to be sustained and can be used for future replacement habitat.
- **Increase wildlife habitat effectiveness**

- Develop an integrated approach to access management that reduces overall effects of travel routes on aquatic and terrestrial habitats, while providing access needed for recreation and forest management.

6. North Fork Manastash

6.1 North Fork Manastash Aquatic Evaluation and Prescription

The North Fork Manastash subwatershed is 13,447 acres in size and includes about 8 miles of potential habitat for steelhead (Fig. 6). The overall road density is high, giving the watershed a poor condition rating. The road densities are not evenly distributed across the watershed, with the highest densities occurring in the western portion (Fig. 7).

The terrestrial landscape evaluation showed that forested habitats are generally overly fragmented compared to both the HRV and FRV, and that within the dry forests, the abundance of stem exclusion closed canopy (SECC), young forest-multi-story (YFMS) and stand initiation (SI) are overabundant compared to HRV and FRV. The terrestrial landscape prescription identified opportunities across landownerships to restore forest vegetation structure and composition to more resilient conditions, which in turn would reduce the risk of uncharacteristically severe fires and contribute to the recovery of listed fish species (Reiss et al. 2008).

Reduce Road Density and Road-Stream Crossings

Conduct field surveys to identify specific roads and road-stream crossings for restoration, including integration with areas identified for terrestrial restoration treatments.

6.2 North Fork Manastash Terrestrial Landscape Evaluation

The North Fork Manastash subwatershed (UYK_0509) is 13,447 acres comprised primarily of dry forest (8,127 ac.) with smaller amounts of moist forest (1,291 ac.) and other vegetation types (4,033 ac.). Ownership is dominated by Washington Department of Fish and Wildlife (WDFW, 8,467 ac.) along with Washington Department of Natural Resources (WDNR, 3,264 ac.), US Forest Service (USFS, 1,287 ac.) and other ownerships (433 ac.). Historical Range of Variability (HRV) reference conditions were based upon Ecological Sub Region (ESR) 11, and Future Range of Variability (FRV) reference conditions were based upon ESR 90.

Vegetation

- Overall, vegetation patches are fragmented with patch density (too high), mean nearest neighbor distances (too low), and edge density (too high) spatial metrics departed from HRV and FRV for many vegetation measures.
- Cover of Douglas-fir is in excess of both HRV and FRV, particularly within dry forests. Ponderosa pine and western larch are both at the low end of HRV and FRV.
- Particularly within dry forests, the abundance of stand initiation (si), stem exclusion closed canopy (secc), and young forest multi story (yfms) structural stages are at the upper end or exceeding HRV and FRV. The stem exclusion open canopy (seoc), old forest single story (ofss) and old forest multi story (ofms) structural stages are all at the low end of HRV and FRV.

Vegetation measure	Current	HRV	FRV
Cover (acres)			
Douglas-fir	6,608	0 - 7,100	0 - 6,000
ponderosa pine	2,526	700 - 10,420	0 - 8,500
Dry forest - Douglas-fir	5,458	0 - 1,600	0 - 1,200

Structural Stage (acres)			
Dry forest - SI	2,043	0 - 1,300	0 - 1,100
Dry forest - SECC	511	0 - 0	0 - 0
Dry forest - YFMS	2,213	0 - 1,200	0 - 1,200

Wildlife Habitat

- The amount of white headed woodpecker habitat is at the low end of HRV and FRV is overly fragmented. Abundance of goshawk habitat is also at the low end of HRV and FRV.
- The amount of current and potential future northern spotted owl habitat are both within HRV and FRV, but are also both overly fragmented.

Wildlife measure	Current	HRV	FRV
Habitat (acres)			
white headed woodpecker	532	0 - 2,300	0 - 1,700
spotted owl - current	1,116	0 - 2,500	0 - 2,200
spotted owl - future	3,337	350 - 8,300	0 - 7,700

Disturbance

- Crown fire potential “high” category is above HRV and FRV while the “low” category is at low end of HRV and FRV.
- Western spruce budworm “moderate hazard” is above HRV and FRV while the “low hazard” category is at the lower end of the FRV range.

Disturbance measure	Current	HRV	FRV
Crown Fire Potential (acres)			
low	7,615	5,400 - 12,261	5,900 - 13,400
moderate	2,420	700 - 4,900	0 - 4,300
high	3,416	0 - 3,200	0 - 2,800
Western Spruce Budworm Hazard (acres)			
low	5,743	1,200 - 12,900	1,400 - 13,400
moderate	5,032	150 - 1,600	0 - 3,500
high	2,676	400 - 10,600	0 - 9,200

6.3 North Fork Manastash Terrestrial Landscape Prescription

- **Reconnect vegetation and habitat patches based on patterns of topography/soil**
  - Across the watershed, focus on connecting similar patches for most cover-structure and wildlife habitats to reduce to total number of patches and edge densities based upon inherent patterns of topography and soil within the watershed.
  - In particular, focus on connecting patches of white headed woodpecker, northern spotted owl current, and northern spotted owl potential future habitat.
- **Thinning dry forest closed canopy patches to create open canopy conditions**
  - Within dry forest, convert 500+ acres of stem exclusion closed canopy and 1,500+ acres of yfms to open canopy conditions (likely to stem exclusion open canopy, seoc) in order to accelerate the development of old forest single story (ofss) and to reduced fire potentials. Prioritize thinning where large (25"+ dbh) ponderosa pine and/or western large are already present.
    - Thinning of dry forest yfms can include WDFW (1,072 ac. total), WDNR (925 ac. total), and to a lesser extent, USFS (73 ac.) ownerships.
    - Essentially all dry forest secc could be thinned on WDFW (307 ac. total), USFS (148 ac. total) and WDNR (55 ac. total) ownerships.
  - Within dry forests, thin stand initiation wherever possible to accelerate successional development and promote open canopy stand conditions with ponderosa pine / western larch cover.
    - Includes dry forest si on WDFW (1,672 ac.), USFS (124 ac.) and WDNR (218 ac.) ownerships.
- **Promote ponderosa pine and western larch cover**
  - Where possible, use thinning treatments to reduce Douglas-fir cover and promote ponderosa pine and western larch. This is particularly valuable within relatively drier locations based upon topography and soils, and can be used to restore the abundance and spatial pattern of white-headed woodpecker habitat.
- **Decrease disturbance hazards.**
  - Use thinning treatments in dry forests to reduce fire and insect hazards,.
- **Balance thinning and wildlife habitat**
  - Thinning of closed canopy patches needs to be balanced with the maintenance of northern spotted owl and goshawk habitat. Use thinning to protect closed canopy wildlife habitats from transmission of fire and insect disturbances.
  - Due to the transient nature of closed-canopy, multi-layered habitats within the dry and moist forests, considered identifying landscape locations, such as north slopes and valley bottoms, where these habitats are most likely to be sustained and can be used for future replacement habitat.
- **Increase wildlife habitat effectiveness**
  - Develop an integrated approach to access management that reduces overall effects of travel routes on aquatic and terrestrial habitats, while providing access needed for recreation and forest management.

7. *Robinson Creek*

7.1 Robinson Creek Terrestrial Landscape Evaluation

The Robinson Creek subwatershed (UYK_0507) is 35,131 acres and has some dry forest (6,628 ac.), no moist or cold forest, and is predominately covered with other vegetation types (28,551 ac.). Ownership is split between Washington Department of Fish and Wildlife (WDFW, 11,036 ac.), Washington Department of Natural Resources (WDNR, 2,713 ac.), and other ownerships (21,430 ac.). Historical Range of Variability (HRV) reference conditions were based upon Ecological Sub Region (ESR) 11, and Future Range of Variability (FRV) reference conditions were based upon ESR 90.

Vegetation

- Within dry forests, the abundance of the young forest multi story (yfms) structural stage is above both HRV and NRV.
- Tree species cover is dominated by ponderosa pine, in-line with HRV and NRV.
- Relatively low level of forest vegetation cover across the subwatershed complicates comparisons of present day and HRV / NRV vegetation reference conditions.

Vegetation measure	Current	HRV	FRV
Cover (acres)			
ponderosa pine	6,244	1,900 - 27,200	0 - 22,400
Structural Stage (acres)			
Dry forest - YFMS	3,596	0 - 3,200	0 - 3,100

Wildlife Habitat

- The amount of white headed woodpecker is within HRV and FRV but is overly fragmented.
- The amounts of current northern spotted owl and potential future northern spotted owl habitat are at the low end of HRV and NRV ranges and are overly fragmented.

Wildlife measure	Current	HRV	FRV
Habitat (acres)			
white headed woodpecker	2,681	0 - 5,800	0 - 4,600
spotted owl - current	486	0 - 6,400	0 - 5,700
spotted owl - future	3,487	900 - 21,600	0 - 20,000

Disturbance

- Disturbance measures including crown fire potential and western spruce bud hazard categories are within HRV and FRV ranges. However, the majority of currently forested lands have “high” western spruce budworm habitat.

Disturbance measure	Current	HRV	FRV
Crown Fire Potential (acres)			
low	33,942	14,400 - 32,000	15,400 - 35,100
moderate	891	1,800 - 12,800	0 - 11,100
high	346	0 - 8,500	0 - 7,400

Western Spruce Budworm Hazard (acres)			
low	31,070	3,200 - 33,600	3,700 - 35,100
moderate	70	390 - 9,500	0 - 9,100
high	4,039	1,100 - 27,800	0 - 24,000

7.2 Robinson Creek Terrestrial Landscape Prescription

- **Reconnect vegetation and habitat patches based on patterns of topography/soil**
    - Across the watershed, focus on connecting similar patches for most cover-structure and habitat types to reduce to total number of patches and edge densities based upon inherent patterns of topography and soil within the watershed.
    - In particular, focus on connecting patches of white headed woodpecker, northern spotted owl current, and northern spotted owl potential future habitat.
- **Thinning dry forest closed canopy patches to create open canopy conditions**
    - Within dry forest, convert 2,000 + acres of yfms to open canopy conditions (likely to stem exclusion open canopy, seoc) in order to accelerate the development of old forest single story (ofss) and to reduced fire potentials. Thinning may also include closed canopy stand initiation (si). Prioritize thinning where large (25"+ dbh) ponderosa pine and/or western large are already present.
        - Thinning of dry forest yfms can include WDFW (2,660 ac. total), WDNR (699 ac. total) ownerships.
- **Decrease disturbance hazards.**
    - Use thinning treatments in dry forests to reduce fire and insect hazards, particularly focusing on spruce budworm hazard.
- **Balance thinning and wildlife habitat**
    - Thinning of closed canopy patches needs to be balanced with the maintenance of northern spotted owl habitat. Use thinning to protect closed canopy wildlife habitats from transmission of fire and insect disturbances.
    - Due to the transient nature of closed-canopy, multi-layered habitats within the dry and mesic forests, considered identifying landscape locations, such as north slopes and valley bottoms, where these habitats are most likely to be sustained and can be used for future replacement habitat.
- **Increase wildlife habitat effectiveness**
    - Develop an integrated approach to access management that reduces overall effects of travel routes on aquatic and terrestrial habitats, while providing access needed for recreation and forest management.

8. Monitoring and Adaptive Management

Monitoring and adaptive management are important components of collaborative landscape restoration (Salafsky et al. 2005, Stankey et al. 2005, Gaines and Lehmkuhl 2015, Hessburg et al. 2015). Monitoring and adaptive management provide a framework for the evaluation of how restorative aquatic and terrestrial actions add up to more resilient landscapes and watersheds (Salafsky et al. 2005). By using the terrestrial and aquatic indicators that were developed to evaluate landscape and watershed conditions, managers can periodically assess progress towards restoration across landownerships. For the Tapash Manastash-Taneum Landscape Evaluation Project, it is suggested that once land managers have developed relatively concrete ideas of projects to implement the landscape prescriptions (e.g., Proposed Actions) that the landscape terrestrial and aquatic indicator metrics be re-run to assess the cumulative impacts of these projects on moving the landscapes and watersheds towards more resilient conditions. In this manner, project proposals may be modified or future projects identified so the collaborative can continue to meet or make progress towards their *Mission* and *Objectives*.

Literature Cited

Aplet, G.H., and W.S. Keeton. 1999. Application of historic range of variability concepts to biodiversity conservation. Pages 71-86 in: R. Baydack, H. Campa, and J. Haufler. (eds.). Practical approaches to the conservation of biodiversity. Island Press, Washington, DC.

Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management 178: 105-119.

Benda, L.E., D.J. Miller, K. Miller [and others]. 2007. NetMap: a new tool in support of watershed science and resource management. Forest Science 53: 206-219.

Bisson, P.A., B.E. Rieman, C. Luce, P.F. Hessburg, D.C. Lee, J.L. Kershner, G.H. Reeves, and R.E. Gresswell. 2003. Fire and aquatic ecosystems of the western USA: current knowledge and key questions. Forest Ecology and Management 178: 213-229.

Black, T. A., R. M. Cissel, and C. H. Luce. 2012. The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 1: Data Collection Method. General Technical Report RMRS-GTR-280WWW. US Department of Agriculture Forest Service Rocky Mountain Research Station, Fort Collins, CO.

Bunting, S.C.; Kingery, J.L.; Hemstrom, M.A.; Schroeder, M.A.; Gravenmier, R.A.; Hann, W.J. 2002. Altered rangeland ecosystems on the interior Columbia Basin. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-553.

Churchill, D. J., A. J. Larson, M. C. Dahlgreen, J. F. Franklin, P. F. Hessburg, and J. A. Lutz. 2013. Restoring forest resilience: From reference spatial patterns to silvicultural prescriptions and monitoring. Forest Ecology and Management 291:442-457.

Cissel, R. M., T. A. Black, K. A. T. Schreuders, A. Prasad, C. H. Luce, D. G. Tarboton, and N. A. Nelson. 2012. The Geomorphic Roads Aanlysis and Inventory Package (GRAIP) Volume 2: Office Procedure. General Technical Report RMRS-GTR-281WWW. US Department of Agriculture Forest Service Rocky Mountain Research Station, Fort Collins, CO.

Crow, T.R., and E.J. Gustafson. 1997. Concepts and methods of ecosystem management: lessons from landscape ecology. In: Boyce, M.S.; Haney, A. eds. Ecosystem Management: Applications for sustainable forest and wildlife resources. Yale University Press, New Haven, CN: 54-67.

Day, J.W., jr., C.A. Hall, A. Yanez-Arancibia, D. Pimentel, C. Ibanez Marti, W.J. Mitsch. 2009. Ecology in times of scarcity. BioScience 59: 321-331.

Dunham, J.B., and B.E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications 9: 642-655.

Flitcroft, R. L., J. A. Falke, G. H. Reeves, P. F. Hessburg, K. M. McNyset, and L. E. Benda. 2016. Wildfire may increase habitat quality for spring Chinook salmon in the Wenatchee River subbasin, WA, USA. Forest Ecology and Management 359:126-140.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. In: Meehan, W.R. ed. Influence of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society, Bethesda, Ml. Special Publication 19: 297-323.

Furniss, M.J., T.S. Ledwith, M.A. Love, B.C. McFadin, and S.A. Flanagan. 1998. Response of road-stream crossings to large flood events in Washington, Oregon, and northern California. USDA Forest Service, San Dimas Technology and Development Center, San Dimas, CA. 14 pp.

Gaines, W.L., D.W. Peterson, C.A. Thomas, and R.J. Harrod. 2012. Adaptations to climate change: Colville and Okanogan-Wenatchee National Forests. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-862.

Gaines, W.L. and J.F. Lehmkuhl. 2015. Monitoring, Adaptive Management, and Information Gaps. Pages 103-125 in Lehmkuhl, J., W. Gaines, D.W. Peterson, J. Bailey, and A. Youngblood. Eds. Silviculture and Monitoring Guidelines for Integrating Restoration of Dry Mixed-Conifer Forest and Spotted Owl Habitat Management in the eastern Cascade Range. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-915.

Gartner, S., K.M. Reynolds, P.F. Hessburg, S. Hummel, and S. Twery. 2008. Decision support for evaluating landscape departure and prioritizing forest management activities in a changing environment. Forest Ecology and Management 256: 1666-1676.

Girvetz, E., and F. Shilling. 2003. Decision support for road system analysis and modification on the Tahoe National Forest. Environmental Management 32(2): 218-233.

Grenouillet, G.A., L. Comte. 2014. Illuminating geographical patterns in species' range shifts. Global Change Biology 20: 3080-3091.

Haugo, R., C. Zanger, T. DeMeo, C. Ringo, A. Shlisky, K. Blankenship, M. Simpson, K. Mellen-McLean, J. Kertis, and S. Stern. 2014. A new approach to evaluate forest structure restoration needs across Oregon and Washington. Forest Ecology and Management 335: 37-50.

Hessburg, P.F., B.G. Smith, S.D. Kreiter, C.A. Miller, R.B. Salter, C.H. McNicoll, and W.J. Hann. 1999. Historical and current forest and range landscapes in the interior Columbia River Basin and portions of the Klamath and Great Basins. Part 1: Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-458.

Hessburg, P.F., B.G. Smith, R.B. Salter, R.D. Ottmar, and E. Alvarado. 2000. Recent changes (1930s-1990s) in spatial patterns of interior northwest forests, USA. Forest Ecology and Management 136: 53-83.

Hessburg, P. F., and J. K. Agee. 2003. An environmental narrative of Inland Northwest United States forests, 1800-2000. Forest Ecology and Management **178**:23-59.

Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. Forest Ecology and Management 211: 117-139.

Hessburg, P. F., K. M. Reynolds, R. B. Salter, J. D. Dickinson, W. L. Gaines, and R. J. Harrod. 2013. Landscape evaluation for restoration planning on the Okanogan-Wenatchee National Forest, USA. Sustainability **5**:805-840.

Hessburg, P. F., D. J. Churchill, A. J. Larson, R. D. Haugo, C. Miller, T. A. Spies, M. North, N. A. Povak, R. T. Belote, P. H. Singleton, W. L. Gaines, R. E. Keane, G. H. Aplet, S. L. Stephens, P. Morgan, P. A. Bisson, B. E. Reiman, R. B. Salter, and G. H. Reeves. In Press. Restoring fire-prone Inland Pacific landscapes: seven core principles. Landscape Ecology.

Isaak, D.J., C. Luce, B.E. Rieman. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. Ecological Applications 20: 1350-1371.

Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwestern US from 1980-2009 and implications for salmonid fishes. Climatic Change 113: 499-524.

Isaak, D.J., M.K. Young, D.E. Nagel, D.L. Horan, and M.C. Groce. 2015. The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century. Global Change Biology doi: 10.1111/gcb.12879.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14: 76-85.

Kane, V. R., J. A. Lutz, C. A. Cansler, N. A. Povak, D. Churchill, D. F. Smith, J. T. Kane, and M. P. North. 2015. Water balance and topography predict fire and forest structure patterns. Forest Ecology and Management 338:1-13.

Kingsolver, J.G. 2009. The well-temperatured biologist. The American Naturalist 174: 755-768.

Lehmkuhl, J.F.; Lyons, A.L.; Bracken, E.; Leingang, J.; Gaines, W.L.; Dodson, E.K.; Singleton, P.H. 2013. Forage composition, productivity, and utilization in the eastern Washington Cascade Range. Northwest Science 87(3): 207-231.

Littell, J. S., E. E. Oneil, D. McKenzie, J. A. Hicke, J. A. Lutz, R. A. Norheim, and M. M. Elsner. 2010. Forest ecosystems, distributions, and climatic change in Washington State, USA. Climate Change 102:129-158.

Luce, C.H., and T.A. Black. 1999. Sediment production from forest roads in western Oregon. Water Resources Research 35: 2561-2570.

Luce, C.H., B.E. Rieman, J.B. Dunham, J.L. Clayton, J.G. King, and T.A. Black. 2001. Incorporating aquatic ecology into decisions on prioritization of road decommissioning. Water Resources Impact (May): 8-14.

Lundquist, J. D., S. E. Dickerson-Lange, J. A. Lutz, and N. C. Cristea. 2013. Lower forest density enhances snow retention in regions with warmer winters: a global framework developed from plot-scale observations and modeling. Water Resources Research **49**:6356-6370.

Lutz, J. A., J. W. Van Wagtendonk, and J. F. Franklin. 2010. Climate water deficit, tree species ranges, and climate change in Yosemite National Park. Journal of Biogeography 37:936-950.

Mantua, N., I. Tohver, and A. Hamlet. 2009. Impacts of climate change on key aspects of freshwater salmon habitat in Washington State. In: Elsner, M.M.; Littel, J.; Binder, L.W., eds. The Washington Climate Change Impacts Assessment. Seattle, WA: Center for Science in the Earth System, Joint Institute for the Study of Atmosphere and Oceans, University of Washington: 217-254.

Mantua, N.J., and C.L. Raymond. 2014. Climate change, fish, and fish habitat in the North Cascade Range. Pages 235-270 in Raymond, C.L., D.L. Peterson, and R.M. Rochefort, Eds. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-892.

Medhurst, R.B., M.S. Wipfli, C. Binckley, K. Polivka, P.F. Hessburg, and R.B. Salter. 2010. Headwater streams and forest management: does ecoregional context influence logging effects on benthic communities? Hydrobiologia 641: 71-83.

Meredith, C., B. Roper, and E. Archer. 2014. Reductions in instream wood in streams near roads in the interior Columbia River Basin. North American Journal of Fisheries Management 34(3): 493-506.

Miller, D., C. Luce, and L. Benda. 2003. Time, space, and episodicity of physical disturbance in streams. Forest Ecology and Management 178: 121-140.

Mote, P. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters 30: 1601-1604.

Naiman, R.J., and M.G. Turner. 2000. A future perspective on North America's freshwater ecosystems. Ecological Applications 10: 958-970.

National Marine Fisheries Service (NMFS). 2008. Middle Columbia River steelhead recovery plan. Portland, OR.

Polivka, K.M., E.A. Steel, and J.L. Novak. 2015. Juvenile salmon and steelhead occupancy of stream pools treated and not treated with restoration structures, Entiat River, Washington. Canadian Journal of Fisheries and Aquatic Sciences 72: 166-174.

Ptyondy, J.P., and T.W. Geier. 2010. Forest Service watershed condition framework technical guide. USDA Forest Service, Washington, DC.

Reiss, K.Y., K. Gallo, P. Dawson, D. Konnoff, and L. Croft. 2008. Process for evaluating the contribution of national forest system lands to aquatic ecological sustainability. A Regional Pilot Project conducted on the Okanogan-Wenatchee and Colville National Forests. USDA Forest Service, Pacific Northwest Region, Region 6. Portland, OR.

Rieman, B.E., D.J. Isaaks, S. Adams. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. Transactions of the American Fisheries Society 136: 1552-1565.

Rieman, B.E., P.F. Hessburg, C. Luce, and M.R. Dare. 2010. Wildfire and management of forest and native fishes: conflict or opportunity for convergent solutions? BioScience 60: 460-468.

Ruff, C.P., D.E. Schindler, J.B. Armstrong. 2011. Temperature-associated population diversity in salmon confers benefits to mobile consumers. Ecology 92: 2073-2084.

Salafsky, N., R. Margoluis, and K. Redford. 2005. Adaptive management: a tool for conservation practitioners. Washington, DC: World Wildlife Fund. http://www.fosoline.org/wordpress/wp-content/uploads/2010/06/AdaptiveManagementTool.pdf.

Stankey, G.H., R.N. Clark, and B.T. Bormann. 2005. Adaptive management of natural resources: theory, concepts, and management institutions. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-654.

Stephenson, N. L. 1998. Actual evopotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales. Journal of Biogeography 25:855-870.

SER. 2004. The SER international primer on ecological restoration, version 2. Society for Ecological Restoration Science and Policy Working Group.

Stine, P., P. Hessburg, T. Spies, M. Kramer, C.J. Fettig, A. Hansen, J. Lehmkuhl, K. O'Hara, K. Polivka, P. Singleton, S. Charnley, A. Merschel, and R. White. 2014. The ecology and management of moist mixed-conifer forests in eastern Oregon and Washington: a synthesis of the relevant biophysical science and implications for future land management. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-897.

Strauch, R.L., C.L. Raymond, and A.F. Hamlet. 2015. Climate change, hydrology and access in the North Cascade Range. Pages 48-112 in Raymond, C.L., D.L. Peterson, and R.M. Rochefort, Eds. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-892.

Trombulka, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18-30.

USDA Forest Service (USFS). 2012. The Okanogan-Wenatchee National Forest Restoration Strategy: adaptive ecosystem management to restore landscape resiliency. USDA Forest Service, Pacific Northwest Region. Portland, OR.

U.S. Fish and Wildlife Service (USFWS). 2011. Revised Recovery Plan for the northern spotted owl (*Strix occidentalis caurina*). U.S Fish and Wildlife Service, Portland, OR.

U.S. Fish and Wildlife Service (USFWS). 2015. Draft mid-Columbia recovery unit implementation plan for bull trout recovery plan. U.S Fish and Wildlife Service, Portland, OR.

Ver Hoef, J.M., E.E. Peterson, and D.M. Theobald. 2006. Spatial statistical models that use flow and stream distance. Environmental and Ecological Statistics 13: 449-464.

White, P.S., and J. Harrod. 1997. Disturbance and diversity in a landscape context. In: Bissonette, J.A. ed. Wildlife and Landscape Ecology. Springer-Verlag, New York, NY: 128-159.

Wondzell, S.M. 2001. The influence of forest health and protection treatments on erosion and stream sedimentation in forested watersheds of eastern Oregon and Washington. Northwest Science 75(Special Issue): 128-140.

Yakima Basin Fish and Wildlife Recovery Board (YBFWRB). 2009. Yakima steelhead recovery plan. Yakima Basin Fish and Wildlife Recovery Board. http://www.ybfwrb.org.