Decision support tool for managing stands over 80 years old on the Olympic Peninsula, Washington

Draft

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For the Olympic Forest Collaborative

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Current condition worksheet

How is your stand currently functioning? Understanding the condition of your stand is critical to determining how well it is providing the functions you want now and in the future.

Instructions: Use any available data to complete this worksheet. Fill out basic stand data, and then summarize the conditions of the listed forest attributes. Field measurements, geospatial analyses, and expert consultation will likely be helpful. Appendix B describes likely differences between natural and planted stands.

Basic stand data			
Stand identification and context for working through decision framework			
Stand ID		Size of stand (acres)	
Personnel & date		Plant association (based on dominant plant species; use applicable Forest Service manual)	
Aspect (degrees)		Age since last stand-replacing disturbance	
Slope (%)		What disturbance caused stand replacement?	
Distance from salt water (miles)		Designated by USFWS as critical habitat for marbled murrelet or northern spotted owl?	
Elevation (ft)		Fire regime: mixed or high-severity only?	

Attribute	Description	Methods	Metrics
Canopy cover	Canopy cover, also called canopy closure, is the horizontal arrangement of leaves and branches. Typically, any plant material taller than 6 feet (2 meters) is counted as canopy. Both the amount of cover (mean %) and how it is distributed across the stand - such as the size and number of gaps in the canopy - is important.	Best determined using Lidar, but can use field measurements (e.g., densiometer) that represent conditions across stand. Also need to know canopy cover around potential murrelet trees (>33" DBH). Canopy is >6 ft tall.	•Mean % cover across stand •Variation in cover across stand •Gaps: size and number per acre •Canopy cover around murrelet trees
	My stand:		

Current condition worksheet

Canopy layers	Canopy layers refer to the height and vertical distribution of the tree canopy. There can be multiple distinct layers, continuous layers, or a single layer. The tallest, roughly continuous layer is called the overstory, the middle is mid-story or subcanopy, and the lowest is understory or regeneration. The number of layers and their height are important for wildlife use, tree species composition (e.g., shade-tolerant or shade-intolerant), and future forest structure.	Field determination or photo interpretation is best, as lidar is poor at detecting layers beneath the overstory. In the field, record tree heights and the abundance of seedlings and saplings. Distinct layers can be detected by creating a histogram of the heights of all trees and looking for modes. Photo interpretation uses field plots to verify interpretation of aerial photos.	•# and/or continuity of layers •% cover, height, and crown ratio of each layer •Presence of canopy over potential murrelet nest sites •Amount and distribution of conifer regeneration (<5" DBH)
	My stand:		
Standing dead and down wood	Standing dead wood is snags of various sizes and decay states. Down wood is logs or coarse woody debris (CWD) >4" in diameter. The amount, size, and distribution of both standing and down wood are important for a variety of ecological functions, and can vary greatly with the disturbance and harvest history of a stand. There may be substantial differences between planted and natural stands in this attribute.	Standing dead wood can be observed with the most detail in the field, but can also be detected using Lidar. Field measurements are best for down wood as Lidar is poor at detecting material on the ground. Tons/acre is a common unit for fuels, while number of logs >4" per acre or percent cover are often used with old-growth characteristics and wildlife needs.	•Standing dead: # snags/acre, DBH and height of snags, decay stage •Down wood: Mean # logs /acre, % cover of CWD (>4"), % of total biomass, tons/acre •Spatial distribution across stands •Amount of down wood in streams
	My stand:		
Tree size and growth rate	Tree size usually refers to the diameter at breast height (DBH) of trees >5" DBH. Larger trees are favored for many ecological values, such as wildlife habitat and old-growth characteristics. They also store more carbon. The abundance and range of tree sizes, and their ages, are also important.	In the field, measure the DBH of all or a representative sample of trees (>5" DBH) in plots. Also take representative tree cores to observe growth rates and ages. Lidar can detect the height and infer the diameter of overstory trees, but may miss understory trees. Lidar observations over time can measure growth rates.	•Histogram of DBH of all trees •Size and abundance of largest trees •QMD (weighted average of DBH) •Variation in tree size and age (using size classes or statistics) •Volume growth rates per tree and per acre •Diameter of large branches; presence of broken tops
	My stand:		

Current condition worksheet

Landscape continuity	Landscape continuity refers to the size of contiguous forest patches, which measures the fragmentation of forest structure and composition across the landscape. Large continuous areas of the same forest structure are beneficial for many ecological values. This attribute can help prioritize which stands to treat or how to treat an individual stand, by considering if treatment will ameliorate, not change, or worsen landscape fragmentation.	Lidar- or remote-sensing-based likely best, but field data could be used if available. Assess structural and compositional similarity of adjacent stands. This attribute may require expert interpretation. Can use coarse or qualitative metrics.	•Comparison of stand structure (canopy cover and layers, tree sizes, spatial pattern) and species composition to adjacent stands •Size of "patch", or contiguous forest structure
	My stand:		
Special attributes	Special attributes are unique to values considered in this decision framework, such as old-growth indices, herbs and shrubs, and landscape-level characteristics.	Either field or Lidar-based.	•Old-growth index (Franklin et al. 2005) •Tree density •Rates of tree mortality •Abundance and distribution of herbs and shrubs •Area and distribution of seral stages on the landscape
	My stand:		

Desired condition worksheet

How do you want your stand to function? The desired condition of your forest depends on the functions or values you care about. If you have multiple values, there can be alignment or trade-offs among the desired condition of various forest attributes. How will you balance them?

Instructions: Review the values, summaries, and references if needed. Circle or highlight the values important to you. In the bottom row, list your values and fill in the desired condition of each attribute based on the values you have chosen. You may need to balance trade-offs in desired conditions among values.

			Desired condition of attributes based on value					
Value	Description	References	Canopy cover	Canopy layers	Standing dead and down wood	Tree size and growth rate	Landscape continuity	Special attributes
Forest health								
Old-growth characteristics	Old-growth forests are characterized not only by their age and the presence of large trees, but by their high levels of spatial heterogeneity that provide for a wide variety of habitats and functions. They also typically have high amounts of coarse woody debris and snags utilized by wildlife, insects, and microorganisms. But not all old-growth forests are the same: climate and topographic location play an important role in the development and appearance of these forests. Variable-density thinning in mature or younger stands increases structural variation to accelerate development toward old-growth, but precise outcomes depend heavily on the conditions prior to treatment.	Franklin et al. (2002), Freund et al. (2015), Kramer et al. (2020), Puettman et al. (2016), Williams and Powers (2019), Van Pelt and Nardkarni (2004)	Gaps of various diameters, some 20-40% of the dominant tree height ; **and** cover of dominant trees ≥35%	>2 tree cohorts; **or** trees of intermediate age present, creating a multi-layered or continuous vertical leaf distribution; **or** substantial canopy of intermediate shade-tolerants forming >0.5x shade-intolerant crown volume; **and** ~2 trees/acre emerging above overstory canopy	High levels: Logs and snags >4" diameter totaling 20% of biomass; **and** ≥5 snags/acre >8" DBH	Many sizes and ages, forming a reverse-J shape of cumulative diameter distribution; **and** standard deviation of DBH >25; **and** mean DBH of dominant Douglas-fir >24"; **and** ≥2 trees/acre of ≥39" DBH	Patch diameter ≥4-5x potential tree height	Old-growth index > 60 (Franklin et al. 2005 34-115 overstory trees per acre at age 80
Native understory plant diversity	Understory plant diversity depends on habitat conditions, disturbance history or stand age, and propagule availability. In westside, fire-infrequent or mixed-fire-severity forests, studies show that understory species generally persist through disturbance, though their relative abundances (and corresponding measures of diversity) shift depending on the life history traits of individual species. Canopy closure is a key factor, such that over the course of stand development, diversity peaks prior to canopy closure, minimizes under canopy closure, and increases again as the canopy re-opens in places. At a landscape scale, maintaining multiple seral stages of forest will help maintain species' availability, while at a stand scale, promoting old-growth microsite characteristics and variation such as gaps, deeply shaded microsites, and accumulations of coarse woody debris will maximize diveristy. Both structural factors and stand age itself are important: epiphytic lichens need old trees and forests, and fire-sensitive plants need areas that remain undisturbed to recover. Note that diversity depends on the metrics used and the spatial scale at which it is measured: the number and abundances of species detected and the factors affecting them may differ in small versus large areas.	Halpern (1989), Halpern and Spies (1995), Fonda and Binney (2011)	Gaps of various diameters, some 20-40% of the dominant tree height; **and** some areas of dense, deep shade	Multi-layered and/or continuous	Down wood similar to old-growth characteristics: Logs and snags >4" diameter totaling 20% of biomass	N/A	Continuous in structure and/or age with adjacent stands, for propagule dispersal; reduce fragmentation	Presence of hardwood trees in or beneath canopy Multiple seral stages across the larger landscape, including old forest with long rotation intervals
Water yield	Water yield is the amount of water runoff from a watershed, measured using streamflow. One factor influencing the amount and timing of yield is the vegetation in the watershed. For forests, the structure, spatial distribution, and disturbance history can all influence yield. It is generally believed that the removal of trees from a watershed increases short-term yield; recent research has investigated this, examining the effects of thinning and wildfire, and longer-term effects. Findings confirm that reducing leaf area, such as with thinning or wildfire, initially increases snowpack and melt-water yield, but in 5-10 years decreases yield to equal or below pre-disturbance levels if there is more sunlight radiating through the canopy and fast tree regrowth. Where rain is more important than snowpack, leaf area of rapidly-growing conifers is the most important factor. Forest regrowth continues to decrease yield until late mature or old-growth stages are reached. Yield can be enhanced by thinning from below or creating small forest gaps that accumulate and retain snow. To increase yield, >20% of stems or basal area must be removed.	Coble et al. (2020), Goeking and Tarboton (2020), Harpold et al. (2020), Harr (1983), Pollock and Beechie (2014), Sun et al. (2018)	Many small to medium-sized gaps (gap radius 0.1-0.5x canopy height) gaps, avoiding large (1.2-1.8x) gaps	Reduce leaf area of rapidly-growing trees: promote slow-growing overstory and shade-tolerant regeneration	12-25% stream area covered by logs to impound water flow	No rapidly-growing conifers	Continuity not important, but promote yield across watershed	At least 20% reduction in stems or basal area needed to increase low flow Focus thinning closer to streams to have the strongest effect on low flow

Desired condition worksheet

Fire Management								
Restore fire regime and adapt to climate change	To restore the conditions naturally created by mixed- and high-severity fire regimes on the westside and to adapt the landscape to climate change, experts recommend managing for landscape-level heterogeneity of successional stages. For example, establish open, early-seral habitat in one place and closed-canopy, late-seral habitat in another. This requires understanding the current and desired distribution of seral stages on the landscape and how best to promote each stage. This landscape-level research is ongoing. One study (DeMeo et al. 2018) shows that on the Olympic Peninsula, the primary need is succession to later seral stages, so desired conditions are the same as old-growth characteristics. It is generally believed that thinning can be used to accelerate succession to these later seral stages. In mixed-severity forests, non-stand-replacing wildfire would have promoted structural variation and fewer saplings in old-growth stands.	DeMeo et al. (2018), Donato et al. (2020), Fonda and Binney (2011), Halofksy et al. (2020), Hessburg et al. (2021)	Same as old-growth characteristics	Same as old-growth characteristics	Same as old-growth characteristics	Same as old-growth characteristics	Continuous with adjacent stands to create larger patch sizes	Mix of seral stages across landscape: Early 1-30% Mid 8-36% Mature 15-30% Old 17-75% (primary need on Olympic Peninsula)
Protect an area from high-severity fire	All forests on the Olympic Peninsula historically experienced high-severity, stand-replacing wildfire as a part of their forest development. Reducing fuels to the point of preventing high-severity fire would remove a great amount of trees and woody debris, and heavily alter the ecological functioning of a stand. Thus, preventing high-severity fire is not consistent with ecological goals. However, fuel breaks may be useful to protect particular locations from severe fire, where protection is more important than ecological function. There is little guidance for fuelbreak design on the Olympic Peninsula; we use discussions about fuel breaks in fire-frequent systems as a guide.	Agee et al. (2000), Agee and Skinner (2005), Halofsky et al. (2020)	Basal area of ≤43 ft² per acre; **or** canopy cover <40%	No intermediate canopy layers	2 tons/acre litter and fine branches; down wood >3" does not affect fire spread	Larger (>16" DBH) only	Fragment forest between area to be protected and adjacent, intact forest with break 200-1200 feet wide	N/A
Carbon								
Carbon storage	Carbon storage is the amount of carbon currently in the forest. This excludes off-site factors such as forest products and substitution, which greatly increase complexity; introductions to these topics can be found in the literature synthesis. In mature forests of the Pacific Northwest, about 66% of carbon is in live trees, 12% in dead wood, 6% in understory plants, and 16% in the soil. Maximizing tree density and size will achieve the most storage; older, larger forests store more carbon than young forests. Thinning in westside forests initially reduces carbon by 25-40%, unless thinning intensity is low or the stand is very young and dense. There is mixed evidence as to whether it is regained over time. Thinning to reduce fire severity does not generally increase long-term, landscape-level carbon storage, especially in forests with infrequent fire. Effects of thinning on soil carbon are poorly understood, with studies showing no change in the top 6 inches but a 25% loss 8 to 60 inches deep. Increasing harvest rotations and reducing thinning intensity are management strategies to increase carbon storage, but can come at the cost of biodiveristy and structural complexity.	James et al. (2018), Simard et al. (2020), Zhou et al. (2013)	>80% above shrub layer and continuous across stand, except for gaps with abundant dead wood	On average across stand, continuous vertical distribution of foliage without large breaks (e.g., continuous layers, large crown volumes)	Down wood abundant in gaps (>8 logs/acre or >10% cover) **and** Abundant snags (~≥5 snags/acre >8" DBH), especially where live trees are less dense	Emergent trees with enough light penetrance to allow for shade-tolerant tree growth; **and** many large, codominant trees	Continuous	N/A
Carbon sequestration	Carbon sequestration is the amount of carbon from the atmosphere being converted to biomass each year. In a forest, this is often measured using tree growth per area over a specific timeframe (e.g., tons per acre per year). Maximizing growth per area will maximize sequestration. Young forests tend to have the the most rapid growth. In mature stands, thinning across size classes increases dominant tree growth rates up to 39%, though thinning from below has little effect. To enhance sequestration across a stand, increased tree growth must be balanced with the trees removed, though evidence is mixed as to how or if this can be achieved in mature stands; it depends on stand productivity and thinning intensity, as well as time since thinning. Most evidence points to stand-level sequestration in Douglas-fir forests becoming roughly equal to that before thinning in 5-10 years, but both higher and lower sequestration has been observed. Managing to purely increase growth will likely trade off with other values such as biodiversity and structural complexity.	Bose et al. (2018), McKinley et al. (2011), Puettman et al. (2016), Roberts and Harrington (2008)	Continuous or even pattern of canopy cover; no discontinuous gaps	Typically single layer, so that leaf area is concentrated in rapidly growing trees	No dead or dying trees	Many rapidly-growing trees, to maximize biomass growth across stand (tons/acre/year); **and** no suppressed or slow-growing trees	N/A	Very low tree mortality Maximum annual growth peaks around 50 years old

Desired condition worksheet

Owl and murrelet									
Marbled murrelet habitat	The marbled murrelet is a Threatened sea bird that forages in the ocean but nests in forests within ~39 miles of salt water. It is well-established that murrelets prefer to nest on platforms created from large branches or broken tops primarily in Douglas-fir in old-growth forest. These habitats are characterized by very large trees (minimum 33" DBH on Olympic Peninsula, 47" DBH preferred), multi-layered canopies with flyways around nest sites, and many platforms at least 4 inches diameter (but the larger the better). While large, contiguous patches of old-growth forest are preferred at a landscape scale, murrelets will evidently use very small patches of appropriate trees within a matrix of otherwise-unsuitable habitat. However, nests near areas that support crows and jays (murrelet predators), such as open areas with berry-producing shrubs, are less successful. In unmanaged old-growth, there are more platforms where surrounding tree density is lower, suggesting that thinning around target trees in younger forest would enhance branch size; however, these outcomes are uncertain.	Baker et al. (2006), Hamer (1995), Wilk et al. (2016), Zharikov et al. (2006)	Flyways (open canopy) around nest trees	Multi-layered or continuous; overstory canopy above nest sites	N/A	Very large (>33" DBH); with branches >4" diameter or broken tops for platforms	Large, continuous patches of old forest preferred but very small patches are used; no shrubby edges	Within 39 miles of salt water and <3500 feet elevation
Spotted owl habitat	The northern spotted owl is a Threatened terrestrial bird that nests and forages in forests in western North America, including the Olympic Peninsula. On the Olympic Peninsula, owls prefer old forest - multilayered canopies with most dominant trees >39" DBH - for both nesting and foraging of their primary prey, the northern flying squirrel. However, they will also use younger stands, in which they prefer 70% canopy cover, varied canopy structure, and ≥4 large snags (≥20" DBH) per acre. Nest sites differ between the east and west peninsula but are consistently in live trees or snags >39" DBH. Flying squirrels need mid-story visual occlusion - either dense trees or canopy at the 33-66 ft height. So where thinning is used to promote long-term complex habitat, Wilson (2010) recommends leaving intact skips that sufficiently limit visibility between gaps, keeping gaps very small (0.025 to 0.1 acres), retaining multiple tree size class, and promoting shade-tolerant species throughout the stand.	Buchanan et al. (1999), Forsman et al. (2005), Wilk et al. (2018), Wilson (2010)	70% target; keep gaps very small (<0.1 ac); retain intact skips that limit visibility between gaps	Overstory >66 feet tall; **and** canopy and/or dense tree boles in the mid-story layer (33-66 ft) to reduce predation on flying squirrels	≥4 large snags (≥20" DBH) per acre	Dominant trees with minimum 20" DBH (>39" DBH preferred)	Large contiguous patches of old forest best	Patchy or minimal shrubs and herbs
My values:		**My desired conditions:**							

No action

No action, also known as "passive management," is the management choice of not actively changing the forest using thinning, patch cuts, burning, mastication, or other activities. Like active management, it results in certain outcomes for forest attributes. These outcomes follow from what we know about natural forest development. We can use typical patterns of development combined with the current conditions of the forest to predict the outcomes and their timing.

Age 80 marks the beginning of the "maturation" phase for many stands. This phase will continue for 100-150 years. Processes are shifting from uniform tree growth and canopy closure to clumped mortality and increasing structural variation. A given stand could be in a range of conditions, primarily depending on the remnant trees and dead wood remaining after the stand-initiating disturbance, and the productivity of the site. Here, we describe the possible conditions of each forest attribute at age 80, the processes at work, and the timeframe of future conditions under natural forest development.

Much of the knowledge communicated here is based on "Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example" by Franklin et al. (2002).

Instructions: Use the information provided in the table to complete the last row about the future of your stand, which will be transferred to the Cross-walk.

	Canopy cover	Canopy layers	Standing dead and down wood	Tree size and growth rate	Landscape continuity	Special attributes
Possible conditions at 80	Canopy cover is likely high and fairly uniform, after it initially closed around age 25-50. In some stands trees may be less dense and canopy cover slightly less. The rate at which closure occurs varies with site productivity, the density of tree regeneration, and the amount and distribution of remnant trees.	Unless there are many remnant trees, there is likely only a single, high canopy layer, following of the natural pruning of lower canopy branches earlier in development. Shade-tolerant seedlings may be starting to establish on the forest floor.	There is typically the lowest biomass of dead wood in the stand during the maturation phase, because dead wood from the initial disturbance has largely decayed and inputs have only been from small trees. Large but short snags, remnant from the initial disturbance, may be present.	Aside from remant trees, the initial, shade-intolerant cohort of trees is likely of fairly uniform size. Small, shade-tolerant trees may be starting to regenerate under the canopy. While age 80 is generally past the most rapidly-growing phase of development, individual Douglas-fir trees still have 40% of their total height and crown spread to reach.	If a single disturbance originated the adjacent stands, structure is likely quite similar among them.	Tree mortality rates are shifting from uniform to more variable. Old-growth index well below between 25 and 50. Tree density quite variable but declining. Herbs and shrubs beginning to re-establish.
Developmental processes	The canopy will remain closed until density-independent mortality, or tree death through agents such as disease, wind, and insects (as opposed to competition among trees), creates openings of various sizes. This process typically begins around age 80 but does not become a dominant process until after 300. During this time there is a shift from uniform to spatially-aggregated patterns of mortality.	During the maturation phase, the dominant trees achieve their maxmum hieght and crown spread. The establishment and growth of the mid- and understory tree layers can be highly variable, due to factors such as seed source, germination substrates, competition with shrubs and herbs, stand density, and environmental conditions.	Competition-based mortality has driven tree mortality thus far, and density-independent processes that can kill larger trees (and create sizable dead wood) are just beginning.	As with canopy layers, tree sizes will not diversify much from the uniform overstory trees until density-independent mortality (death due to wind, disease, or insects) increases. Very small shade-tolerant trees may be present and increasing. Damage to trees from various causes becomes more common, so individual tree architecture becomes slightly more complex.	As mortality becomes more clumpy and less uniform, stands have the potential to become more different.	Mortality is becoming less competition-related and more disease- and disturbance-related; herbs and shrubs develop as the canopy opens. Few large trees, large snags and low log volume and tree size diversity results in a low old-growth index.

No action

Future condition	Occasional gap creation due to disease, etc. and decreasing levels of "thinning" due to competition. Substantial gap creation occurs after 300 years old. Heavily shaded microsites under groups of dense, shade-tolerant trees begin to form at 100-120 years old.	Slowly increasing lower canopy layers. As mortality increases during this phase, more light becomes available to stimulate lower canopy development. At 150 years old, the mid-story canopy begins to substantially develop, and at 250-300, the canopy will be becoming roughly continuous from the ground to the tallest trees	The production of larger logs and snags will not accelerate until after age 150, once gap creation becomes a more important process.	Mid-size trees will develop at the same time as the mid-story canopy does, around age 150. Starting around this age, individual trees will become more complex and variable, depending on damage and surrounding density.	Large patches of old forest have the most potential to contain the most structural diversity, such as enormous trees, heavily shaded microsites, and large gaps. Fewer unique structure will develop in smaller patches.	Clumped mortality increases, and herbs and shrubs increase in abundance. The old-growth index increases as trees grow and larger trees die.
The likely future of my stand:						

Variable-density thinning (VDT)

Commercial "thinning" on the Olympic National Forest is typically a type of active management that cuts trees in an uneven pattern and incorporates patch cuts, called variable-density thinning (VDT). The basic goal is to maintain the existing cohorts of trees while increasing variation in structure. For example, managers could cut some trees in one patch, leave all trees in another, and cut all trees from yet another patch. This results in a forest with a clumpy pattern that can serve a variety of ecological functions.

Within the broad goal of increasing structural variation in the existing forest, VDT can take specific actions to work toward particular goals. These specific actions describe, or "prescribe," what to do to change a given structural attribute. Examples include creating gaps of certain sizes, removing trees around potential wildlife trees, and retaining or creating snags. These prescriptions serve to specify how VDT will change forest structure, and to protect or leave unchanged certain attributes or locations.

In the table below, we outline how VDT can be used to change the forest attributes relevant to the values in this decision framework. We describe typical goals for each attribute, actions used to achieve the goals, the timeframe of outcomes, and concerns and scientific uncertainties about it. This information allows the reader to understand what active management intends to do, the different types of actions it can take, and what we know from science about the likely outcomes from these actions.

Instructions: Use the information provided in the table to complete the last row regarding the likely outcome of VDT in your stand, which will be transferred to the Cross-walk.

	Canopy cover	Canopy layers	Standing dead and down wood	Tree size and growth rate	Landscape continuity	Special attributes
Goals	1) Create gaps 2) Reduce canopy cover overall and/or in selected areas	1) Increase the number of canopy layers by creating opportunity for mid- and understories to develop 2) Remove lower canopy layers or ladder fuels	1) Retain and/or increase standing dead and down wood 2) Reduce surface fuels	1) Promote large trees and branches by reducing competition 2) Increase or maintain diversity of tree sizes 3) Increase individual tree growth rates	1) Reduce fragmentation and increase patch size 2) Increase fragmentation for fuel break purposes	1) Reduce mortality rates 2) Alter seral stage to achieve landscape-level targets 3) Alter species composition 4) Reduce tree density
Actions	1) Cut all trees in select areas to create gaps of a chosen size 2) Thin to a target density or basal area and spacial pattern	1) Remove overstory trees to increase light reaching the lower canopy 2) Remove mid- and understory trees	1) Cut and leave trees on the ground; direct operators to not remove logs; girdle or top trees to create snags 2) Remove logs and snags; accompany with prescribed fire	1) Thin around wildlife trees 2) Thin select size classes to increase size diversity, or across classes to maintain diversity 2) Thin across stand to reduce competition	Many: use as appropriate to 1) make stand more similar to adjacent stands or 2) make more different from adjacent stands	1) Thin to reduce competition and remove dying trees 2) Many actions possible, use as appropriate 3) Thin less desirable species and plant seedlings 4) Thin trees

Variable-density thinning (VDT)

Timeframe of outcomes	Immediate	5-10 years for mid- and understory to increase growth	Immediate for some dead wood, ~1-10 years for trees to become snags, 5+ years to decay, later mortality increasing dead wood over decades	Immediate change in size distribution; 5-10 years for trees to increase growth rates	Immediate structural changes, but landscape-level goals may take decades to achieve	Immediate density and mortality changes with thinning; decades for seedlings to become overstory
Concerns and uncertainties	•Small gaps may close quickly •Differences between natural and cut gaps include pit-and-mound topography, presence of down tree boles, damage to adjacent trees that create habitat features	•Must thin sufficiently (to thresholds of basal area or retention %) to enhance lower canopy growth or allow for shade-intolerant seedlings to grow	•Thinned stands often have reduced mortality and dead wood recruitment •Hazardous snags must be removed for safety during operations •Must specify in prescription to retain or create standing dead and down wood •In the past, thinning reduced dead wood. New prescriptions can direct operators to retain or increase it, but there is little science about outcomes	•Large branch development likely depends on age and canopy structure of tree before thinning (so choose target trees wisely) •Few studies as of yet on the outcomes or timeframe of branch development after thinning •While individual trees grow faster with thinning, stand-level growth rate (sequestration) outcomes are mixed	•Multiple landowners makes landscape-level management challenging	•Planted seedlings may not survive •Landscape-level targets for fire regime restoration are a new science and have not been tested
VDT outcome for my stand:						

Cross-walk

What is the path forward for your forest? Once you know the current and desired conditions of the attributes of your stand, you can determine their discrepancy and what direction the attributes need to move in, if any. Then, you can consider the likely outcomes from different management options and decide which option to pursue.

Instructions, Part 1: Copy your current and desired attribute conditions from the Current Condition and Desired Condition Worksheets. Then, calculate the discrepancy between the current and desired conditions and record the direction or change necessary to move from your current to your desired condition.

Part 2: Next, copy the bottom rows from the two support tables that describe the outcomes from VDT or no action management for your stand. Compare these outcomes with the change needed to move toward the desired condition, and circle which management option(s) align for each attribute. Consider differences in course of action among attributes, and record your conclusions in the last row.

Part 1: Attribute cross-walk

	Canopy cover	Canopy layers	Standing dead and down wood	Tree size and growth rate	Landscape continuity	Special attributes
Current condition (copy from Current Condition Worksheet)	My stand:	My stand:	My stand:	My stand:	My stand:	My stand:
Desired condition (copy from Desired Condition Worksheet)						
Change to move toward desired condition						

Part 2:Management options

Cross-walk

No action: The future of my stand (copy from Support table - No action)						
VDT: Outcome for my stand (copy from Support table - VDT)						
My direction to move aligns with: (circle one, both, or neither)	No action Thinning	No action Thinning	No action Thinning	No action Thinning	No action Thinning	No action Thinning
My conclusions:						

Appendix A. Threshold tables

Range of variability table: Below are ranges or estimates encountered in the literature for forest attributes applicable to the Olympic Peninsula and relevant to topics of interest to the Olympic Forest Collaborative. Developed in association with the literature review. Applicability to the four literature review topics is indicated in the first four columns. TPA/TPH = trees per acre/hectare.

Forest structure	Wildlife	Fire management	Carbon	Attribute	Range/Estimate	Description	Reference	Notes
x				Tree diameter at 4.5' (DBH)	65-80 cm; 26-31 in	Overstory tree definition in Oly. Hab. Dev. Study of forests 55-85 yo	Willis et al. 2018	
x				DBH	40-60 cm; 16-24 in	Midstory tree diameter definition in Oly. Hab. Dev. Study	Willis et al. 2018	
x				DBH	20-40 cm; 8-16 in	Potential future mid-story tree definition in Oly. Hab. Dev. Study	Willis et al. 2018	
x				DBH	33-40 cm; 13-16 in	Mean tree diameter in forests 80 to ~160 yo	Freund et al. 2014	
x				Basal area (BA)	58-67 m^2ha^{-1}; 253-292 ft^2ac^{-1}	Mean basal area of two natural stands 80 to ~160 yo	Freund et al. 2014	
x				Years of Douglas-fir establishment	32-99 years (mean 60)	Length of establishment period of Douglas-fir regeneration following stand-replacing fire in western WA and OR forests	Freund et al. 2014	
x				Overstory/total BA	50-67/69-79 m^2ha^{-1}; 218-292/301-344 ft^2ac^{-1}	Range of mean BA of four stands ~190 years old (next stage past mature)	Freund et al. 2015	Could use to inform targets in mature forest
x				Overstory/total tree density	62-85/162-310 TPH; 25-34/66-125 TPA	Range of mean TPH of four stands ~190 years old	Freund et al. 2015	Could use to inform targets in mature forest
x				DBH	6.5-78 in (mean 35.1); 16.4-198 cm (mean 89.1)	Range of Douglas-fir DBH among 9 western WA and OR old-growth stands	Freund et al. 2015	
x				DBH	2-48 in (mean 13.7); 5-121.9 cm (mean 35.8)	Range of western hemlock DBH among 9 western WA and OR old-growth stands	Freund et al. 2015	
x				Snag density[1] >10-cm (4-in) DBH	34-90 snags ha^{-1}; 14-36 snags ac^{-1}	Range of values for four stands ~190 years old, roughly 45-cm mean diameter	Freund et al. 2015	Could use to inform targets in mature forest
x				Canopy closure rate	1.5-2%	Rate at which crowns close over small gaps	Puetmann et al. 2016	
x				Log density > 10-cm (4-in) diameter	20-117 logs ha^{-1}; 8-47 logs ac^{-1}	Range of values for four stands ~190 years old	Freund et al. 2015	Could use to inform targets in mature forest
x				Mean epicormic branch ht	18-26 m; 59-85 ft	Range of values for four stands ~190 years old	Freund et al. 2015	Could use to inform targets in mature forest
x				Mortality rate	0.28%-0.90%	Annual Douglas-fir mortality rates	Spies et al. 1990, Bible 2001	
		x		Percent area in early seral habitat (0 to ~40-70 yr)	1-30%	For high-severity regimes: Landscape-scale reconstructed % area based on reconstructed fire return intervals	Donato et al. 2020	Not for mixed-severity fire regimes
		x		Percent area in mid-seral forest (~40-70 to ~80 yr)	8-36%	For high-severity regimes: Landscape-scale reconstructed % area based on reconstructed fire return intervals	Donato et al. 2020	Not for mixed-severity fire regimes
		x		Percent area in mature forest (~80-200 yr)	15-30%	For high-severity regimes: Landscape-scale reconstructed % area based on reconstructed fire return intervals	Donato et al. 2020	Not for mixed-severity fire regimes
		x		Percent area in old forest (>200 yr)	17-75%	For high-severity regimes: Landscape-scale reconstructed % area based on reconstructed fire return intervals	Donato et al. 2020	Not for mixed-severity fire regimes
x	x			Time until vertical diversification	~150 yr	With no disturbance, vertical diversification may not be significant until 150 yrs	Franklin et al. 2002, Tepley et al. 2013	
x	x			Time until horizontal diversification	>300 yr	Until agents like wind and fungi start killing trees, canopies can be closed with few gaps	Franklin et al. 2002	
			x	Carbon removed, control burn	10%	Average carbon removed	Campbell et al. 2012	
			x	Carbon removed, thinning	30%	Average carbon removed	Campbell et al. 2012	
			x	Carbon removed, control burn plus thinning	50%	Average carbon removed	Campbell et al. 2012	

			x	% of ecosystem carbon	12-22%	Carbon combusted in wildfire	Campbell et al. 2007; Meigs et al. 2009	Less than thinning
			x	% ecosystem carbon in live and dead trees	60%	The amount of carbon in living trees as a percent of total carbon	McKinley et al. 2011	
	x			DBH	137 cm; 54 in	Mean DBH of murrelet nest trees on Olympic Peninsula	Wilk et al. 2016	
	x			Dominant or remnant tree DBH	51-99 cm; 20-39 in	DBH of dominant or remnant trees in stands occasionally used by northern spotted owl on the Olympic Peninsula	Wilk et al. 2018	
	x			Dominant tree DBH	99 cm; 39 in	DBH of dominant trees in preferred northern spotted old habitat on the Olympic Peninsula	Wilk et al. 2018	
	x			BA of trees 40-55-cm (16-22-in) DBH	25-35 m^2 ha^{-1}; 109-152 ft^2 ac^{-1}	Preferred non-old forest foraging habitat for northern spotted owl in Oregon	Irwin et al. 2012, 2015	
	x			Mean canopy closure	86%	Mean canopy closure of stands occupied by murrelets	Hamer 1995	
	x			Platform size	>35 cm; >14 in	Most common murrelet nesting platform size in western WA	Hamer 1995	

Thresholds table: Below are estimates of thresholds for values above or below which an ecological shift occurs as encountered in the literature for topics of interest to the Olympic Forest Collaborative that are applicable to the Olympic Peninsula. Developed in association with the literature review. Applicability to the four literature review topics is indicated in the first four columns. TPA/TPH = trees per acre/hectare.

Forest structure	Wildlife	Fire management	Carbon	Attribute	Threshold value(s)	Description	Reference	Notes
x				Overstory basal area (BA)	>18 m^2 ha^{-1}; >80 ft^2 ac^{-1}	Above this BA, establishment of Douglas-fir seedlings is limited	Lam and Maguire 2011	Cited in Powers and Wessell report
x				Overstory BA	<10 m^2 ha^{-1};<43 ft^2 ac^{-1}	Above this BA, growth or understory-midstory trees increases rapidly	Acker et al 1998b (cited in	Cited in Powers and Wessell report, similar to 20 TPA of 20" trees
x				Overstory BA	10 m^2 ha^{-1}; 43 ft^2 ac^{-1}	Below this, understory tree growth responds to thinning	Acker et al. 1998b	as cited in Wessell and Powers
x				Overstory BA	10-15 m^2 ha^{-1}; 45-65 ft^2 ac^{-1}	Below this, multiple cohorts of shade-intolerant trees can establish	Tepley et al. 2013	Data and modeling for western OR
x				Overstory BA	14-15 m^2 ha^{-1}; 60-65 ft^2 ac^{-1}	Above this, only shade-tolerant trees establish	Tepley et al. 2013	Data and modeling for western OR
x				Tree density	~100 TPH; 40 TPA	Commonly used as most intense treatment tree density for leave trees	Cole et al. 2017, Spies et a	Ares et al. as cited in CCMAP, Spies and Pollock articles as cited in Churchill review
x				Tree density	100-120 TPH; 40-49 TPA	Below this tree density younger stands can grow at similar rates to early growth of older trees in natural stands	Tappeiner et al. 1997	
x				Overstory tree density	44 TPH; 18 TPA	Multiple cohorts of shade intolerants can establish	Tepley et al. 2013	
x				Overstory tree density	59-64 TPH; 24-26 TPA	Above this, shade-intolerant trees are excluded	Tepley et al. 2013	
x				Gap diameter	0.4x canopy tree height	Diameter of gap below which Douglas-fir seedlings do not establish	Gray and Spies 1996	In OG forests of western Cascades
x				Gap diameter	0.2x canopy tree height	Diameter of gap above which western hemlock will establish	Gray and Spies 1997	In OG forests of western Cascades
x				Neighborhood distance	30 m; 98 ft	Beyond this radius, neighbor trees have little influence on structural development of a tree crown	Kramer et al. 2019	

x				# of Snags	12 snags ha^{-1} > 20-cm DBH; 5 snags ac^{-1} >8-in DBH	If less than this amount, more snags should be created to emulate natural stands	Puetmann et al. 2016	
	x		x	Gap area	0.04 ha; 0.1 ac	Above this gap size, northern flying squirrel abundances are reduced	Wilson 2010	
	x			% Retention	45-70%	Below this retention range, flying squirrel populations decline in the short term	Halloway et al. 2012	
	x			Height	10 - 20 m; 33-66 ft	Height in which the canopy or tree stems must obstruct visibility to protect flying squirrels from over-predation	Wilson 2010	Need this visual obstruction (also called occlusion) to maintain flying squirrel populations. Canopy can also occur above or below this level, but this mid-story level is important. Can be in the form of tree canopy or dense tree stems.
	x			Distance from sea	>39 mi; >63 km	Further than this, murrelets dramatically decline WWA	Hamer 1995	
	x			Elevation	>1067 m; 3500 ft	Above this, murrelets dramatically decline WWA	Hamer 1995	
	x			Platform size	10-20 cm; 4-8 in	Minimum size of platform on which murrelets will nest in western WA	Hamer 1995	
	x			DBH	83 cm; 33 in	Minimum DBH of murrelet nest trees in Olympic Peninsula	Wilk et al. 2016	
	x			Canopy closure	70%	Ideal threshold for spotted owl use in younger, understory re-initiation forests on Olympic Peninsula	Buchanan 1999	
	x			Canopy closure	90%	Maximum threshold for spotted owl use in younger, understory re-initiation forests on Olympic Peninsula	Buchanan 1999	
	x			Density of snags >20-in (51-cm) DBH and >15-ft (5-m) height	≥10 snags ha^{-1}; ≥4 snags acre	Ideal threshold for spotted owl use in younger, understory re-initiation forests on Olympic Peninsula	Buchanan 1999	
	x			Density of trees ≥10-cm (4-in) DBH	939 TPH; 380 TPA	Maximum tree density in stands foraged in by northern spotted owls on the Olympic Peninsula	Buchanan 1999	
	x			Cover of downed wood	5%	Minimum recommended for stands that will be used by the northern spotted owl on the Olympic Peninsula	Buchanan 1999	
	x			Shrub cover	10%	Minimum recommended for stands that will be used by the northern spotted owl on the Olympic Peninsula	Buchanan 1999	
			x	Rotation length	80-100 yrs	Above this rotation length the increase in carbon stores with increasing rotation length slows	Harmon et al. 2009, Fain et al. 2018	
			x	Tree density	300 TPH; 212 TPA	Below this tree density after thinning, there is no detectible difference in aboveground carbon from controls	Burton et al. 2013	
		x		Basal area	10 m² ha^{-1}; 43 ft² ac^{-1}	Target basal area of fuel break	Agee and Skinner 2005	
		x		Crown bulk density	0.1 kg m^{-3}	Target crown bulk density of fuel break	Agee et al. 2000	

Appendix B. Planted vs Natural stands

A planted stand has been planted by humans, most likely with a fairly high density of Douglas-fir seedlings. These stands are likely to have been intensely harvested (clearcut or harvested with <25% retention) rather than eliminated by a catastrophic natural disturbance such as a high-severity fire or windstorm. Both of these characteristics (planted seedlings and the disturbance that removed the existing stand) lead to the two primary differences between planted and natural stands:

1) Presence of remnant trees and dead wood: Intense harvesting removes most of the wood in a stand, while wind or fire typically leave much dead wood and some live trees that serve as seed sources, future dead wood, and structural components. The first table below shows differences among disturbances in the abundance and/or spatial distribution of these remnant features.

2) Timing and composition of tree regeneration: Natural Douglas-fir-western hemlock stands undergo seedling establishment over the course of 32 to 99 years (with a mean of 60 years; Freund et al. 2014), while planted stands are typically planted in 1-3 seasons. The period of tree regeneration affects not only the conditions of the early-seral environment, but whether and when subsequent phases of forest development, such as canopy closure and competitive exclusion, occur. The age distribution of the stand can also affect structure for many years.

They key differences between planted and natural stands will likely lead to differences in a stand's condition at age 80 among the six attributes utilized in this decision framework. The second table summarizes the possible observed differences among the attributes.

Table AppB1. Remnant features following different stand-regenerating disturbances (from Franklin et al. 2002)

	Wildfire	Windstorm	Clearcut
Large living trees	Few	Few	None
Snags	Abundant	Commong	None
Down logs	Common	Abundant	Few
Intact tree regeneration	Patchy	Yes	Variable
Undisturbed forest floor	Patchy	Patchy	Variable

Table AppB2. Differences in attributes for stands at age 80 that originated via different disturbances and regeneration scenarios.

	Canopy cover	Canopy layers	Standing dead and down wood	Tree size and growth rate	Landscape continuity	Special attributes
Planted after clearcut	•High cover and uniform across stand •Possible density-independent mortality (due to wind, insects, or disease) has created gaps	•Single overstory layer •Possibly some very small shade-tolerant regeneration in understory	•Almost no remnant large-diameter snags or down wood •Small-diameter snags and down wood from competitive (density-dependent) mortality •Possible new moderate-diameter dead wood from density-independent mortality (due to wind, insects, or disease)	•No legacy live trees in the stand •Uniform size distribution of overstory •Possibly some very small shade-tolerant regeneration in understory	•Likely fragmented with small patches of different harvest dates, but patch size and continuity with adjacent stands dependent on harvest planning	•Genetics: Low genetic variability, depending on source of planting stock. Possibly adapted to future climate if assisted migration utilized. •Tree mortality primarily due to competition; some possible due to wind or disease •Herbs and shrubs low abundance under dense canopy, unless gaps present

Appendix B. Planted vs Natural stands

Planted after partial-retention harvest (aggregated or dispersed)	•Aggregated: Variable within aggregates, high cover and uniform in harvest areas •Dispersed: High cover and uniform across stand •Possible density-independent mortality (due to wind, insects, or disease) has created gaps	•Aggregated: Multi-layered or continuous canopy in aggregates, with single overstory layer in harvest area •Dispersed: Few remnant trees emergent above overstory canopy •Possibly some very small shade-tolerant regeneration in understory	•Large-diameter snags possibly retained or created through harvest and still present •Large-diameter down wood primarily in retained aggregates •Some small-diameter snags and down wood from competitive (density-dependent) mortality •Possible new moderate-diameter dead wood from density-independent mortality (due to wind, insects, or disease)	•May be a few very large, legacy live trees in the stand •Aggregated: Range of tree sizes present in aggregates •Dispersed: Likely two classes of remnant, larger trees and planted cohort	•Likely fragmented with small patches of different harvest dates, but patch size and continuity with adjacent stands dependent on harvest planning •Aggregates provide very small remnant patches (possible use by spotted owl)	•Genetics: Low genetic variability of planted cohort, depending on source of planting stock Possibly adapted to future climate if assisted migration utilized. Planted trees distinct in genetics from retained trees. Presence of remnant genetic variability proportional to % retention. •Tree mortality in dispersed or harvest area due to competition; some wind or disease-caused mortality possible, especially in aggregates •Herbs and shrubs low abundance under dense canopy; more abundant in gaps or aggregates
Natural after wind or wildfire	•Uniform or discontinuous possible, depending on density and speed of regeneration •Likely less than 85% average cover •Possible density-independent mortality (due to wind, insects, or disease) has created gaps	•Likely deeper canopy due to longer regeneration period (though may be single-layer) •Presence of emergent, remnant trees above overstory •Possibly some very small shade-tolerant regeneration in understory	•Fairly abundant but highly decayed large-diameter snags and down wood that persisted through disturbance •Moderate abundance of moderate or large-diameter dead wood that died since disturbance •Abundance of small-diameter dead wood dependent on intensity of competitive (density-dependent) mortality, which could have been high or non-existent	•May be a few very large, legacy live trees in the stand •Wide age distribution of overstory cohort with possible size variation as well	•Olympic Peninsula high-severity wildfire likely occured in large patch sizes •Wind events can be small or large patch sizes	•Genetics: Regeneration from local parent trees. Likely more genetic variation than planted stock. No opportunity for assisted migration. •Tree mortality rates variable, depending on competition intensity •Abudance of herbs and shrubs variable; more abundant if canopy cover is discontinuous •Contributes to natural distribution of seral stages on landscape

Appendix C. References

Desired Condition worksheet

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