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Living Dead Forests: Assessing Detrital Services in Puget Sound Pseudotsuga menziesii Ecosystems

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Assessing Detrital Services in Puget Sound *Pseudotsuga menziesii* Ecosystems

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Abbreviation	**Definition**
CSC	Climate-Smart Commodities
CWD	Coarse Woody Debris
HFF	H. F.
Forest	
ICF	Island Center Forest
LULUCF	Land-Use, Land-Use Change and Forestry
NCF	Nisqually Community Forest
NNRG	Northwest Natural Resource Group
NTFP	Non-Timber Forest Products

Abstract

Coarse woody debris (CWD), the detrital result of down wood recruitment, contributes to wildlife habitat, nutrient cycling, morphological processes like soil formation, and each forest's sense of place but if undermanaged can fuel wildfires or obstruct stakeholder use. Despite its ubiquity in Puget Sound Douglas fir (*Pseudotsuga menziesii*) forests in Washington, USA, few studies quantify the exact ecosystem services which down wood provides. This study seeks to understand how forest managers can estimate the ecosystem services of down wood and how human communities perceive down wood management between community, public, and private Douglas fir (*P. menziesii*) forests of the Puget Sound region. This study drew one hundred and fifty CWD samples in thirty down wood systems across those three management scenarios, then dehydrated the cores to determine the biomass, carbon, and moisture components. The researcher surveyed biodiversity, decomposition, and landscape properties of each system. Interviews conducted with managers and stakeholders gauged ecosystem service understanding and valuation. Species richness per log was significantly higher in the community forest management scenario than in public or private forests, though the private forest had higher species richness per m^3 of CWD. Biomass and carbon content correlated negatively with more advanced decomposition stages. Water content and slope were not significantly affected by management scenarios or decay class. Managers tended to promote wildlife, decomposition, and wildfire dynamics within down wood, while stakeholders perceived biodiversity and decomposition alongside aesthetic values and detriments. All participants expressed generally positive attitudes toward most CWD instances. The findings in this study contribute to the evolving landscape of literature surrounding detrital services, finding support for ecological forestry objectives in down wood management across the Puget Sound region's Douglas fir (*P. menziesii*) forests.

Introduction

Human degradation of forest ecosystems severely damages the natural processes and management potential of Earth's woodlands. This project seeks to understand ecosystem service contributions by coarse woody debris (CWD) under community, public, and private management strategies. The project's design measures the provisioning, supporting, and regulating mechanisms of down wood by vivisecting CWD logs across these management contexts to explore the internal composition of each system. By interviewing landowners and stakeholders, the study also explores down wood's cultural value. The robust dataset includes wood location, decay class, landscape, dimensions, species richness, dominant vegetation, biomass, carbon and water contents, canopy cover, and human perception of down wood. In its methods, analysis, and compilation into this research paper, this project follows the scientific process to produce rigorous, novel findings and analysis for the scientific community, also working to provide useful information for managers and stakeholders considering how to manage their woodlands and down wood stocks from an ecological forestry perspective.

This study is significant for its exploration of forest ecosystems through their detrital processes, rather than through the function of their predominant vegetation type, trees. Historically, dominant narratives of forest valuation considered only raw extractive potential, regardless of heterogeneity between the world's forests and ecological processes within forests (Chazdon et al., 2016). Live trees constitute just one element of a forest ecosystem. In an effort to decentralize trees from the scientific imagination, Frey et al. (2019) explores the ways in which humans can value extractive forest products beyond timber. In this study, the metric of down wood was chosen for its involvement in many systems throughout forests, especially in how down wood spans ecosystem service types. However, down wood resources are notoriously difficult to quantify, with large spatial variation across regions and specific landscape characteristics (Campbell et al., 2019). This study works to understand down wood on a regional scale so as to avoid small-scale generalizations while creating a data resource applicable to a substantial variety of community, public and private forests within the Puget Sound region. By assessing forest services through a down wood lens, this project creates a more holistic analysis of forest ecosystems. By operating on the regional scale, the findings will prove useful and the methods reproducible, while not oversimplifying realities within unconsidered regions.

The first objective of the project is to produce a dataset quantifying services under rigorous scientific methodology. Within this objective, the study bridges the natural and the social sciences. In collecting natural science data, the project draws a substantial volume of information from a minimally disruptive methodology. That is to say that natural spaces and systems were interrupted only as far as new, useful information could be gained. This interruption was minimized by using available extraction and survey tools consistent with other, similar studies. In collecting social science data, information was derived from both expert forest managers and stakeholders in such a way that personal information and identifiers were removed and the possibility of risk is minimized if not entirely eliminated. The inclusion of social science data produces essential context that purely natural science data could understate or ignore. The process of interviewing experts and stakeholders also mitigated the researcher's positionality as an outsider whose presence in the region began at the start of the project. Next, the findings were analyzed to produce useful insights based on the data collected. Finally, these findings were explored in the context of existing literature to ground results in the landscape of other studies and provide direction for further studies. The result is a multidisciplinary look into a critical stage of forest development in an era of rapid environmental change.

Background

Forests, while characterized by their dominant vertical vegetation, depend upon diverse biotic and morphologic elements beyond live trees (Stein et al., 2014). Mismanagement practices like over-extraction and clearing threaten the formation and services of down wood, woody debris upon which species depend for habitat and sustenance (Bunnell & Houde, 2010). Tree debris retains nutrients within its microbiome, the internal and underlying space whose temperature is controlled by retained moisture, improving efficiency of forest processes (Herrmann & Bauhus, 2018). The continued recruitment of large wood to river systems controls water attenuation, nutrient uptake, and sedimentation (Wohl et al., 2019). The maintenance of natural decomposition processes also significantly impacts ecosystem services, including recreation (Janeczko et al., 2021). Organic litter contains a large volume of carbon within forest ecosystems (Ahirwal & Maiti, 2018) but climate change, fueling intense wildland fires, threatens that substantial carbon sink (Shapchenkova et al., 2023). Understanding the complex ecological and societal roles played by down wood would optimize management strategies for climate adaptation and ecosystem services in the Puget Sound region.

This study is an evolution of the existing scientific literature surrounding down wood in the context of climate change and sustainability. Studies like Harmon et al. (1986) solidify the purpose of down wood as a component of the ecosystem, understanding regulating, nutrient cycling, and morphological services within a down wood system. Harmon et al. follows Ehrlich & Ehrlich's (1981) coining the term 'ecosystem service,' based on Schumacher's (1973) concept of natural capital. Ecosystem valuation infamously eludes strong standardization (Costanza et al., 1997; Costanza et al., 2014), especially where ecosystem components lack extractable product. Understanding ecosystems as capable of providing 'services' is itself a frequently critiqued ontology, with opponents claiming the concept to be detrimentally anthropocentric (Schröter et al., 2014). This study will examine down wood through an ecosystem services or 'ecosystem processes' lens as per Krohs & Zimmer's (2023) argument in favor of this terminology as opposed to 'ecosystem functions.' Down wood systems contribute to each type of ecosystem service: provisioning, supporting, regulating, and cultural.

While down wood enriches the value of other timber products (Thorn et al., 2020) and provides habitat for species, contributing to non-timber forest products (NTFP) (Paillet et al., 2010; Chaudhary et al., 2016), the actual material within down wood is not sought for production at scale. Down wood has also been considered as a renewable resource for biofuel (Barrette et al., 2015), which would transform down wood from a supporting, regulating, and cultural ecosystem service into a purely provisioning resource. Riffell et al. (2011) considers the downsides of removing residual biomass from harvested forests, namely that additional ecosystem processes related to coarse woody debris (CWD) would be interrupted. Nonetheless, in instances where leaving residual biomass is incompatible with management objectives, use of CWD as biofuel is a potential avenue for provisioning valuation of down wood.

CWD benefits forests by providing biodiversity hubs across several taxa, contributing to the biodiversity within Washington's NTFP industries. Bunnell & Houde (2010) investigates the many ways animal populations benefit from down wood. Amphibians use the microclimates created within down wood to regulate body temperature, aquatic species benefit from diversified habitats and shelter, and these highways of the forest allow predators to quickly traverse larger distances, to name a few benefits. Log volume is the best habitat complexity predictor for biodiversity (Hekkala et al., 2023). Down wood microclimates host new seedlings, especially in drier conditions (Halofsky et al., 2020). 'Nurse logs,' down wood systems whose nutrients are being taken up by succeeding tree seedlings, are ubiquitous in the Pacific Northwest. An excellent example is the Olympic Penninsula's Hoh Rainforest, whose nurse logs contain such developed seedlings that the original CWD structure degrades to a point where the former nurse log's presence is only implied by the seedlings' stratified organization.

Douglas fir (*Pseudotsuga menziesii*) trees dominate the Puget Sound ecozone, identifiable for their distinctive appearance and sought for their valuable wood. In stands where Douglas fir (*P. menziesii*) was non-native, α-diversity was only significant for soil fungi, while all other plant and animal populations were relatively lower (Glatthorn et al., 2023). Alpha diversity is as of yet uncalculated for down wood from Douglas fir (*P. menziesii*) in the region. A study by Sandström et al. (2019) found that species impacted by down wood presence included saproxylic insects, ground insects, lichens, fungi, reptiles, and cavity-nesting birds. Ground-nesting insect and bird diversity was not impacted by down wood restoration while saproxylic insects and fungi were, positively so. The authors concluded that forest management practices can be manipulated to improve alpha-diversity by artificially recruiting down wood to the forest floor. Understanding the variety of species, as well as which species are dominant within each down wood system can show how CWD contributes to ecosystem provisioning.

Before Harmon et al., Ausmus (1977) identifies the biochemical mechanisms by which wood material becomes soil. Decomposition rates and respiration rates within decaying logs are important fluxes by which sequestered carbon releases at the end of a tree's life cycle (Yu et al., 2019). The limiting factor for carbon loss in organic soils is availability of soil organic matter (Dungait et al., 2012), so biomass and corresponding carbon masses are the metrics measured in this study. Measuring carbon content also demonstrates the carbon stocks on an often-overlooked regional scale, as per Campbell et al. (2019). Woodall et al. (2019) finds existing inventory assessments of down wood particularly lacking, especially across the United States' diverse biomes. This study seeks to fill this information void by creating a dataset which represents down wood composition within the Puget Sounds' Douglas Fir (*P. menziesii*) forest biome. Carbon content of down wood depends heavily upon tree species, though through the process of decomposition, decisive species identifiers can be lost (Guo et al., 2014). Because of decay variability, this study assesses CWD according to ecosystem type, rather than between species.

The Washington Department of Natural Resources (2020) estimates that down wood hosts around 135 million metric tons, or 5% of the total carbon stored in Washington's forest ecosystems. The same report asserts that declines in down wood are inadequately tracked, as losses due to removal and combustion could be influencing perceived loss of down woody material. The Washington State Greenhouse Gas Emissions Inventory found that Land-Use, Land-Use Change, and Forestry (LULUCF) contributed to between 20.6 and 22 million metric tons of carbon dioxide equivalent each year from 2015 to 2019 (Waterman-Hoey, 2022). Specific measurements for carbon and water content in down wood are monitored in Andrews Experimental Forest, near McKenzie Bridge, Oregon (Means et al., 1992). In that test, carbon content was measured as 100 megagrams/hectare and moisture content as 559-10,700 liters/log. These measurements are among the closest to the data this project will produce, though this study assesses nutrients in the more northern Puget Sound region in a contemporary context. Means et al.'s measurements fill the gaps in the data collected for this project, namely the outflow of carbon from a down wood system through respiration

Moisture content is also an important factor in CWD morphology and climate impacts. Piaszczyk et al. (2022) and Progar et al. (2000) found a strong negative correlation between moisture content and respiration rates in CWD, and can therefore be used as a proxy to understand relative respiration of a down wood system. The controlling factor on moisture retention in down wood is soil cover types (Dhar et al., 2022). Many of the trees in this study's forests, however, are deposited upon root mats and older CWD structures, creating a unique and understudied water sequestration mechanism. While CWD assists with moisture retention in arid climates (Goldin & Hutchinson, 2014), the Puget Sound region will experience heightened precipitation under leading climate projections, with drying only intensifying in the summer (Rutledge & Brandt, 2023). Halofsky et al. (2020) finds that down wood serves as fuel for wildfires in the more arid portions of Eastern Washington, though in the Puget Sound region, infrequent but more intense wildfires in periods of intense drought have fewer limitations to fuel. In those regions, fuel breaks are the most successful solution. Information on the moisture content of CWD in local contexts provides vital information for managers or landowners considering climate-smart management strategies for their forests.

The two major regulating services associated with down wood are soil and slope formation and riparian development. Błońska et al. (2023) biochemically explores how soil formation is most heavily impacted by more decayed classes of down wood. The same study finds higher fractions of carbon in soils at lower elevations and warmer climates. Wohl et al. (2019) explores the ways by which large wood in stream channels can massively impact surrounding morphology. Down wood also contributes to ecosystem regeneration after wildfires by retaining high moisture volumes (Bombino et al., 2024). In the Puget Sound region, recruitment of down wood to the forest floor is an aeolian process and to a lesser extent a function of fire (Bahuguna et al., 2010). While the formation of down wood also contributes to tree-throw, it is not a direct result of down wood's presence. Mountainous climates experience lower decay rates than tropical ones (Lininger et al., 2016), positioning the Puget Sound as less productive for soil formation but better at retaining its down wood stock. Canopy composition above down wood can also impact moisture uptake (Tong et al., 2024), impacting decay and therefore soil creation (Błońska et al., 2023).

The Puget Sound region is ecologically defined by the lowland forests around its namesake, the Puget Sound, a glacial incision now occupied by an estuary and the major Seattle metropolitan area (Sorenson et al., 2012) (see Figure 1). The Puget Sound region's forests host particularly high structural complexity (Ehbrecht et al., 2021) with high resilience under more moderate climate change scenarios (Laflower et al., 2016). Structural complexity is a measure of diversity of elements within an ecosystem, where trees, down wood, rivers, and wildlife could each be considered individual elements (McElhinny et al., 2005). Structural complexity ensures that if disturbances damage one element catastrophically, other elements can persist or even enhance so that the ecosystem may survive. Simultaneously, Atlas et al. (2020) finds that poor management threatens subsistence practices and cultural survivance by degrading natural resources like the Pacific salmon (*Oncorhynchus spp.*) populations in the Sound and adjoining waterways. Threatened NTFPs include, at a glance, grasses, tree boughs, wild mushrooms, and berries (Alexander et al., 2001).

Down wood was sampled in three sites, Nisqually Community Forest (NCF), Island Center Forest (ICF), and H. F. Forest (HFF) (see Figure 1). NCF is a community forest near Ashford, WA, primarily used for timber extraction and community recreation under the Nisqually Land Trust. Major management actions taken in the sampling site include commercial thinning, fish-bearing stream buffering, which protects land surrounding the river from thinning, and the creation of a skid road for further extraction. The site is classified by larger down wood in a more remote context. ICF is a public forest on Vashon Island, WA, managed by King

County. Management activities include thinning for ecological purposes and the creation and maintenance of a trail network. The site is classified by frequent recreation use. HFF is a privately owned forest near Bucoda, WA. Management activities include pre-commercial and commercial thinning, as well as the maintenance of a trail system. The site is classified by a high variety of tree species and perhaps best captures the elements of ecological forestry.

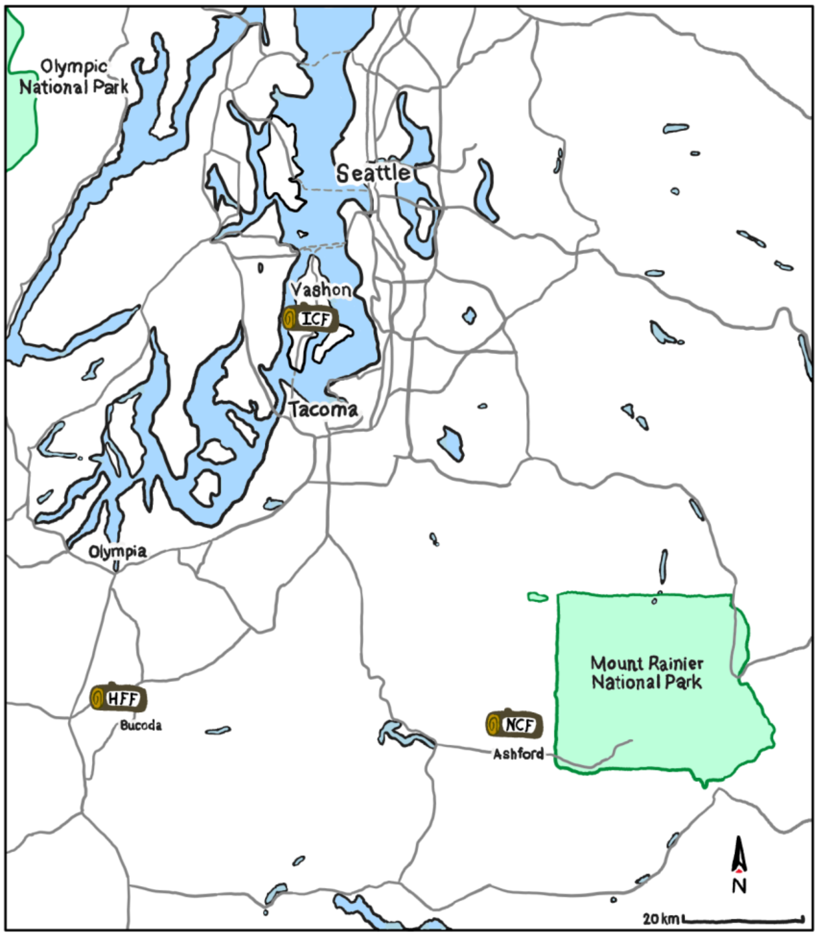

Figure 1: Map of Puget Sound Region, highlighting waterways, National Parks, relevant cities, roads, and community, public, and private study sites (Based on Google Earth, June 20, 2024)

The benefits to humans from a forest ecosystem can be nebulously diverse, and can span simple aesthetic pleasure to massive economic returns from clear cutting. The non-monetized portion of human valuation is difficult to compare to the raw extractive value, as per Costanza et al. (1997), but cannot be discounted due to its close relevance to cultural practice and nonextractive industries like recreation. In this study, cultural ecosystem services are assessed just as provisioning, supporting, and regulating services are, in many cases shaping how landowners choose to manage their forests. Juutinen et al. (2014) uses a willingness-to-pay index to determine what ecosystem characteristics are of what value in Finland, finding that the potential benefits from respondents greatly outweighed the existing benefits from industrial extraction. Eggers et al. (2018) finds that multi-use spaces for management and recreation are possible with relatively low capital investment. This is especially true under the USDA's Partnerships for Climate-Smart Commodities (CSC), which reduces costs for climate conscious forest management (USDA, 2022).

Despite any benefits to extractive resources, nutrient cycling, and forest morphology, down wood is not necessarily valued as highly by populations interested in recreation. A study conducted in Italy (Paletto et al., 2022) found that a majority of users felt that dead and down wood negatively impacted their recreation experience. Ribe (2003) found the same to be true of populations in Washington and Oregon, though in both cases the dislike stemmed mostly from evidence of logging or other industrial activity. This is in direct contention with Eggers et al.'s (2018) support for multi-use management, though the findings in Ribe require reassessment in a contemporary study. For instance, Janeczko et al. (2021) demonstrates how forests which allow the natural accumulation of woody debris provide greater value to recreational users than those in managed forests do, at least in forests which contain evidence of human management, like lop-and-scatter fine down wood, cut logs, and stumps. Up-to-date information should inform such perceptions from managers and community, public, and private landowner perspectives across the Puget Sound region.

Research Questions

This project seeks to learn how forest managers can estimate the ecosystem services of down wood in the Douglas fir (*Pseudotsuga menziesii*) forests of the Puget Sound region. To answer this question, surveys and interviews will measure how different management objectives, community, public, and private, affect various ecosystem service metrics, including down wood volume, species richness (provisioning), biomass, carbon and water content (supporting), river processes, slope, elevation, decay class (regulating), and human perception (cultural). The researcher hypothesizes that the richness provisioning metric will be highest in forests with larger logs with management objectives which emphasize retention of older trees. The supporting services should be highest under less accelerated decomposition. Higher moisture content should reduce respiration and thereby retain more carbon. Overall moisture and carbon findings should be consistently lower at lower elevations. The decomposition regulating services should be most pronounced in forests at lower elevations. Removed down wood across forests should be uniformly low due to shared ecological forestry management principles.

The project also aims to determine how human communities perceive down wood management in their Douglas fir (*P. menziesii*) forests. This element of the study will also be comparative across the three management contexts, highlighting community, public, and private perspectives on down wood. This research question should reveal the ways in which different stakeholders perceive and prefer aesthetic and functional aspects of down wood, and how managers familiar with the locality understand concepts of ecosystem services. Interviewing resident experts and stakeholders will also offset the biases of an outside researcher. The researcher hypothesizes that managers will prioritize ecological function and extraction obstacles while stakeholders will prioritize aesthetics.

Methods

The data collection methods used in this study can be divided broadly into four categories by ecosystem services. Provisioning services include down wood volume and species richness. Supporting services include biomass, carbon content, and water content. Regulating services include landform processes like rivers and slopes, elevation, and decay class. Cultural services include perceptions of forest managers and stakeholders. Quantitative metrics were statistically analyzed using one-factor ANOVA at an alpha-value of 0.05. Site selection was based on locations of Douglas Fir (*Pseudotsuga menziesii*) dominated forest in the Puget Sound Region which the researcher had access to in association with their practicum work with Northwest Natural Research Group (NNRG), an ecological forestry NGO based out of Seattle, WA. This was necessary for gaining access to plots that represented the variety of management scenarios considered in this study but also for having access to management objective information. The sampled sites include Nisqually Community Forest (NCF), a community owned forest near Ashford, WA, Island Center Forest (ICF), a public forest on Vashon Island, WA, and H. F. Forest (HFF), a privately owned forest near Bucoda, WA (see Figure 1). The name of the latter forest was abbreviated to preserve interviewees' identities. The sampling area for NCF was 3.73 hectares (ha), for ICF the area was 58.59 ha, and for HFF the area was 13.99 ha.

First, the researcher generated three scatter plots of ten random points using R, then superimposed each plot over the sampling area. The random points corresponded to ten geographic points, which were recorded in the GPS application Avenza, allowing access to precise locations even when in remote and disconnected portions of the survey plots. Initially, the plan called for fifteen separate down wood systems, but soon after beginning sampling it became clear that collecting more than fifty samples per day across ten systems was not feasible given set-up, travel, and measurement time. The final five points were removed from the NCF plot, potentially reducing spatial randomness between points at that site. At one point at ICF, the nearest down wood system was beyond an impassable thicket, so another down wood system was chosen at a slight distance (approximately ten meters). The spatial randomness at HFF, the private forest, was reduced due to a lack of high quality maps of the area, so the random points are arranged along a lower fidelity grid. Navigating from point to point required the Avenza application to refresh its location regularly. After reaching each point, the application was left on for around a minute to ensure that the point was correct. Upon reaching each individual point, the researcher sought the nearest down wood system, updated the geographic point accordingly, and began the research process. This process of random down wood selection allowed for a non-biased image of the variety of down wood in each forest management type.

Provisioning

To understand the volume of wood each measurement represents, length and diameter measurements using a 15.24 meter (m) ‘Spencer 50' Logger Tape - Model 950’ created a loose volume metric to apply findings onto. Log volume estimates were calculated assuming a rough cylinder shape in lieu of full shape renders.

Initially, the project plan called for a measurement of macro-species alpha diversity beyond species richness though it quickly became too difficult to count or differentiate the number of ants or mosses on any given log. Species richness can be used as a proxy for resource availability and an absence can evidence disturbance (Fridley & Palmquist, 2024). All visible species of animals, distinct plants including mosses, ferns, and flowering plants, and fungi including lichens were tallied as species richness across the entire survey duration. Spiderwebs, droppings, burrows, and markings were each adequate evidence to suggest the presence of at least one additional species. One aid used to determine whether something was one or more species was Seek, an application by iNaturalist which uses artificial intelligence to identify to the best of its ability the taxonomy of any species. This helped differentiate mushrooms from one another, though the application did not succeed easily with ambiguous plant species, where the tally could only include one new species, not two.

Supporting

The supporting services, including biomass, carbon, and water contents, were measured by extracting and processing one hundred and fifty down wood cores from thirty down wood systems across three forest types. Samples were drawn at even increments along the upward-facing wood, for which the tree was divided into five equal sections. Each sample was taken from the midpoint of each section. The researcher made these calculations in the field. Sampling along the up-facing side of the wood was standardized due to the advanced decay of many down wood systems, which would have reduced the researcher's ability to draw a sample.

This study's extractive methodologies are based most closely on the methodologies utilized in contemporary natural scientific research (Mantgem & Stephenson, 2011, Wu et al., 2022), namely wood coring using a 40.64 centimeter (cm) length, 0.43 cm diameter, 'Haglöf 2-Thread Increment Borer,' a standard tool in the field of ecological forestry with a sample volume of ~5.9 cubic meters (cm^3). The researcher placed the increment borer perpendicular to the log and applied pressure while spinning the apparatus until the device had reached the midpoint of the tree (see image in Appendix A). In one system (NCF2) with a diameter greater than the borer's length, the sample was taken to the maximum depth possible with the instrument. Further research would be required to understand the entire profile of this down wood system, whose advanced size returned some outlier results. The trees sampled in this study are non-living, therefore coring the down wood will have no impact on tree health.

Use of the increment borer requires a large amount of downward force for a sustained period while the borer gains purchase. Future researchers should consider their ability to maintain a squatted standing position for hours in a day for their own health and wellbeing before replicating methodologies. Additionally, in areas where vegetation overlapped with the increment borer's spinning radius, vegetation may interrupt successful application of this method. In those cases, all obstructive species should be tallied, carefully removed, and returned to their initial position post-sampling. Often the vegetation included stinging nettles (*Urtica dioica*) or Devil's club (*Oplopanax horridus*), which alongside the friction against one's hand, made the use of at least one sturdy work glove necessary to successful extraction. The primary obstacle to successful use of the increment borer is that its auger will become jammed easily with woody material. Whittled twigs were often too small or fragile to apply adequate force along the area of the 'plug,' though proved useful in a pinch. Rather, a whittled chopstick did a good job of clearing jams so long as no woody material from the plunging device contaminated the sample. Many times, the sample was stuck so firmly that a variety of methods had to be cycled through to fully clear the plug.

Upon extraction, any bark or cambium was delicately removed. The researcher then immediately weighed each core to eliminate evaporation losses. Masses were measured using a 'Superior Mini Digital Platform Scale' which measured in grams (g) to the nearest hundredth. The scale was, when possible, shielded from wind and precipitation to reduce error, though these conditions were also recorded where present. In NCF, rain persisted through sampling six of ten down wood systems and while the canopy mostly protected the scale, in instances near gaps along a river the researcher created an impromptu shelter out of a rain jacket, a backpack, and convenient nearby stones. In HFF, winds became so strong that measurements had to be taken between gusts, as the disturbance appeared to skew results. Before weighing, each sample was placed in a system-specific marked plastic bag. The plastic bags were weighed prior to adding samples, and all five samples from each down wood system were stored in the same bag to reduce waste.

Upon returning from the field, each down wood system sample cluster (five samples) was swiftly transferred to its own marked aluminum foil envelope, which had each also been weighed beforehand. The researcher placed each envelope, intentionally sculpted with breathable openings, inside a drying oven. The drying oven, a 'Nuwave Bravo Air Fryer Toaster Smart Oven,' also had a dehydration feature and probe-based temperature monitoring. The samples underwent exactly 48 hours of dehydration at 60° C. The researcher conducted regular check-ins to ensure that the oven temperature did not fluctuate. The electricity in the building shorted as a result once during the first batch of samples, though the researcher was checking in moments before and was able to resume the process without much trouble or temperature loss. Due to the risk of the drying oven catching fire, the machine had to be surveilled near-constantly to ensure that the probe was functional and that the foil did not touch the heating elements and combust. Upon completion, samples were immediately removed and weighed. The total mass of removed material consisted of only 56.69 g of biomass and 91.7 g of water, a benefit of the borer device. Managing and keeping track of numbers, samples, and bags was prioritized given the strenuity of extraction so that none of the samples became lost or unusable.

Dehydrating the samples provided both moisture and biomass measurements. Moisture was measured by the difference in the initial mass (minus the bag mass) and the dry mass (minus the envelope weight). The dry mass itself represents biomass, or the total organic mass remaining. Roach et al. (2021) finds the standard coefficient to estimate carbon content based on biomass in a Douglas Fir (*P. menziesii*) forest to be 0.5 in lieu of comparable destructive measurements. Harmon et al.'s (2013) measurements are near to this standard, but provide more information based on decay class and plant type in a proximal context at Andrews Experimental Forest near McKenzie Bridge, Oregon. That article finds that gymnosperms, the sole wood type measured in this study, have a slightly higher carbon content, at 0.506. That coefficient is used to calculate carbon content in each of the down wood systems surveyed.

Regulating

Regulating and miscellaneous metrics recorded at each down wood system included sampling-begin time, wood state as either sound, intermediate, or rotted based on ecological forestry standards, down wood slope at the system's midpoint along the log length, and a brief description of each down wood system. The brief descriptions included information like evidence of logging, dominant vegetation growing on the down wood system, evidence of erosion, surrounding tree species, an exact measurement of canopy cover using the application Canopy App, notable species present, severity of precipitation and wind, and any notable landscape features nearby including slopes and rivers. A photo was taken of each down wood system to be used in interviews and for organizational purposes, especially corroborating dominant species and logging evidence on several down wood systems.

Cultural

Each of the three site types corresponded to two interviews, one with a stakeholder and one with a forest manager, totalling six expected interviews. Interviewees were prioritized based on the availability and relevance of managers and stakeholders. For instance, the manager with the most experience and closest ties to the site was selected. For stakeholders, landowners were sought but where unavailable, as in the case of the public forest, a resident who uses the space regularly, recreationally was chosen. The researcher worked with NNRG staff to identify the best candidates for each interview. Interviewees were recruited via email. A sample recruitment letter can be found in Appendix B. In follow-up emails, the participants each received a participant informed consent form, an internal review-board approved document which ensures that the participant understands the potential processes and impacts associated with the interview. Meetings were conducted in locations agreed upon by both the interviewee and interviewer: on the land after sampling, in a public park, and in the NNRG office according to individual cases.

After greetings, interviewees received a physical copy, if requested, of the participant informed consent form, where they ultimately decided whether to opt in or out of the interview and whether they would be quoted in the final capstone paper. After that, the interviews began. The format was semi-structured and the language used was English. Throughout the process, the researcher answered questions about project objectives, processes, and concepts where needed. Example question sets for both the manager and stakeholder interviewee-types are included in Appendix C, although follow-up questions in line with existing objectives and research questions followed planned questions where appropriate. The researcher took hand-written notes to the best of their ability in a waterproof notebook. All interviews were under forty-five minutes in duration. Interviews serve to provide context and add human perspectives from four types of interviewees about down wood in management regimes relevant to the Puget Sound region.

Questions for land managers asked the interviewee to explain what ecosystem services are impacted in what ways by down wood, and how that management can ensure those services persist into the future. The managers explained how different management schemes and climate change regimes might impact down wood. Stakeholders were asked to explain how down wood impacted their work or time on the land, to share any stories or memories about down wood from their life, and what else they might like to learn about down wood. One of the questions for both the manager and stakeholder groups calls for each interviewee to comment on whether they feel positive, negative, or neutral about each of the down wood systems on their corresponding land and, if desired, to give a brief explanation as to why they feel any given way.

Interviewing managers and landowners proved educational both for project objectives and methodology. The primary obstacle to success was the speed at which the researcher could record quotes, though this steadily improved as interviews progressed. Accessing interviewees was also sometimes difficult, often requiring follow-up emails. Two interview candidates did not respond to email inquiries, leaving gaps in the data for the NCF Stakeholder and an ICF Manager roles. Future research should interview larger pools of managers and stakeholders to account for low response rates. The study did manage to include one respondent from each management zone, providing at least some cultural insights from each forest type. A number of interviewees offered to forgo signing the participant informed consent form, stating that they were happy to participate without prior knowledge of processes and impacts. They were informed that review of the form was an integral component of creating meaningful social science data.

Findings for other ecosystem resources were supported by or contrasted with the responses of managers and stakeholders alongside relevant scientific literature on the subject. In some instances, the interviews provided new avenues for post-sampling research according to metrics mentioned that were not gathered during the sampling phase. In other instances, perceptions were inconsistent with literature and findings, demonstrating the heterogeneity of down wood impacts across the Puget Sound region.

Reflections on Positionality and Ethical Concerns

As a non-resident researcher, I acknowledge that my project in the Puget Sound Region's forests impacts the individuals and landscapes I interface with. The complex and diverse realities of livelihoods in the region cannot be captured in the abbreviated format that this project's interviews take. Embracing my own positionality as a newcomer and acknowledging the potential connotations which an outside researcher garners was integral to the process of conducting this research. In many instances, insider-outsider identities exist on a spectrum (Nébié et al., 2021, Yip, 2023). By the time I engaged any residents, I had already demonstrated myself as less polarized on that spectrum and genuinely dedicated to the ecological management of forests to promote positive human-environment interaction, largely by my work with Northwest Natural Resource Group (NNRG). NNRG, the organization hosting my academic practicum simultaneously, had already exposed me to many of the ecological and interpersonal realities of forestry in the Puget Sound Region through forestry field work, land tours with smaller land-owners, and outreach events. NNRG helped to facilitate each of these connections as the interviewees were all NNRG staff or affiliates. This also holds a connotation, as these participants may feel obliged to participate due to their affiliation with my practicum organization. To alleviate any undue coercion to that effect, I made certain that potential participants understood their relationship to the organization would not be impacted in any way by opting out or individual responses.

The interviews took a maximum of forty-five minutes of the participants' time, averaging around thirty minutes, and offered no compensation and no direct benefits. Use of a participant informed consent form prior to beginning any interview ensured would-be participants had the ability to decide whether they were interested in undertaking such a time commitment, and just what the process might involve. These voluntary participants then offered up their words, experiences, and knowledge, each opting for the researcher to quote them directly in this report. The position of a participant is in many ways a vulnerable one, as the researcher may choose how these quotes are introduced, what text frames or mirrors their message, and what portions of their message are completely omitted. The researcher must take special care not to distort or dilute the initial message, ensuring that the participant's voluntary contribution to this process accurately expresses their perspectives without spinning it against them.

That said, each participant also is vulnerable for their connection to the field this report seeks to impact. Should the net impact of this report lead to an increase or decrease to down wood in managed forests in the area, the result is likely to go against the expertise or feelings of some or many of the interviewees. A drastic increase to down wood stocks for ecological benefit could conflict with valid concerns over fire risk, a dynamic explored in Halofsky et al. (2020). Alternatively, should this project find that the vast majority of participants dislike the aesthetic component of down wood during recreation, as is the case in Janeczko et al. (2021), spaces prioritizing recreation may be less likely to include down wood despite a minority of respondents focused on ecological benefits. The limited scope of this project calls for increased focus on the subject in future research, a long-term stress to those down wood stocks. In any case, this project has the potential to impact the many benefits and risks down wood systems bring to an ecosystem. Because the project aims to understand ecology across different management objectives, disagreement between cultural findings should be expected. The nuance between differing perspectives demonstrates the importance of generating robust datasets on down wood and those who deal with it.

One such instance of this dynamic is the importance of timber harvest to forest management. Seventy percent of the softwood harvested in Washington state occurs on private land, though poor management practices greatly increase habitat fragmentation and increases the risks associated with wildfires (Soulard et al., 2017). Aside from any beneficial ecosystem services associated with untouched forest lands, landowners engaging in harvest still seek to profit from extraction but the presence of down wood can obstruct the path of workers and machinery. Understanding the costs and benefits from a resident landowner or stakeholder whose experience extends far beyond the scope of this project can demonstrate some impacts from down wood that the selected methodologies might overlook.

In many ways, conducting these interviews constitutes a necessary step toward alleviating the bias of purely natural science methodologies. This study's methodologies are based on standard wood coring, applied to fallen trees in a variety of unique contexts but omitting several others due to its limited scope. The study does not include alternative methodologies, multiple researchers, or temporal measurements of the same sites. These methodologies were selected and employed to most efficiently cover a large diversity of Puget Sound Douglas fir (*Pseudotsuga menziesii*) forests in a comparatively short survey. Despite the researcher's best attempts, any scientific research with smaller sample sizes runs the risk of misrepresenting larger population trends. If that is the case, the expertise of various managers and landowners should provide dissenting perspectives which serve to challenge the data's singular understanding of down wood. Of course, this study does not include a wide variety of interviews and should not supersede the need for a wider, more intercontextual study of perspectives surrounding down wood across the Puget Sound region. Future studies with a larger scope will likely eliminate much of this uncertainty, though the results of this study still may have considerable bearing on the down wood regimes in the Puget Sounds' community, public, and private forests.

This project was conducted on the traditional lands of the Nisqually and Vashon Southern Coast Salish peoples and Chehalis peoples. The natural spaces and processes this project concerns itself with have in many cases close connections to cultures largely misunderstood by scientific institutions. Future studies concerning the ecological processes within these forests should place greater emphasis on consulting these perspectives in prior research and interview breadth to highlight perspectives and knowledge on down wood absent from existing scientific literature. Poe et al. (2016) extensively discusses the importance of maintaining a sense of place in reproducing several Puget Sound livelihoods. That study finds that above provisioning, supporting, and regulating services, the scenic beauty of a location is the highest priority for maintaining these spaces' sense of place. Poe et al. also demonstrates the importance of connecting conservation work to resident values in creating opportunities for the people who live in the Puget Sound region. Beyond this, there is little compelling research surrounding modern day livelihoods and cultural practices for the Southern Coast Salish or Chehalis peoples, a substantial blindspot for this paper and the field of down wood forestry as a whole.

In the interest of reducing negative cultural impacts to the people who use the Puget Sound's forests, this study was intentionally designed to reduce impacts on natural spaces. The increment borer, especially, greatly reduced the visibility of extraction. The total mass of extracted material was 120.39 grams (g) and the sample volume totaled 321.74 cubic meters (cm^3) across all 150 samples extracted. The data provided estimates for 28.7 m^3 of coarse woody debris (CWD), though the estimates are representative of a random sample of logs in three primary management purposes in the Puget Sound's Douglas fir (*P. menziesii*) forests as a whole, representing a much larger geographic context. Further, each of the sites contained some type of trail system, or a skid road in the case of Nisqually Community Forest. While the CWD systems were in random places throughout the forest, a route was picked along these trails prior to field work to reduce off-trail traversal. Larger forests with more useful trail systems supported a wider sampling area, most useful in the Island Center Forest.

Despite its smaller size, the Nisqually Community Forest plot took the longest time to sample due to its dense undergrowth and challenging terrain. In spaces across all three studied forests, the foliage surrounding the down wood systems was so dense that the researcher had to part and otherwise trample certain plants, in cases damaging the plant’s stems and leaves. While resilience to trampling is heterogenous between various plant communities, trampling intensity has less impact on resilience (Pescott & Stewart, 2014), which may improve the damage caused by this research. In the Pacific Northwest, trampling often impacts growth more than it does reproduction (Chardon et al., 2023), an unfortunate result of this research on understory plants. This more destructive work to access the down wood systems was reduced wherever possible, and special care was taken to avoid unique species including fauna and wildflowers. Images taken prior to sampling closely resembled the conditions of each site as the researcher was leaving. In a few instances where the down wood system was particularly thin in diameter or weak in integrity, the down wood split and additional destruction was caused. The researcher acknowledges that the ecological benefits this study seeks to understand are no longer possible in the removed biomass, though this hesitation was presented to the researcher’s institutional review board prior to the project’s commencement and ultimately deemed acceptable.

This project reduced its negative impacts in the pursuit of ecological data by using efficient, scientifically-informed methodologies. The total mass of extracted materials equalled only 148.39 g, of which about 91.7 g were water. This is one benefit of coring down wood rather than taking large destructive samples, as it allowed for a large majority of the down wood systems to continue their ecological processes, and the surface area removed only totalled around 87 square centimeters (cm^2).

Accessing all sites took three days of sampling, and the large distance between each site caused the researcher to travel a total of 518 kilometers by personal vehicle. At 2494.76 g of carbon per gallon of gasoline (U.S. Department of Energy, 2024) and an average 33 mpg in the researcher's personal vehicle, the travel burned a total of 243.43 kilograms (kg) of carbon. Accessing Island Center Forest did require two trips by ferry, though information on carbon emissions from that particular vessel are not publicly available. The total carbon estimated in this project, however, was 1.25 megagrams (Mg) across all fifteen logs. This study's implications, if applied to the entirety of each forest or all community, public, and private Douglas fir (*P. menziesii*) forests across the Puget Sound region, could preserve a substantial portion of the state's 157 Mg of carbon stored in down wood (Palmer et al., 2019).

The methodologies in this study were selected after careful examination of literature and experience under the direction of NNRG. The study's structure and procedures, including the participant informed consent form, recruitment emails (see Appendix B), and interview format (see Appendix C), were also each approved by an internal review board to ensure that the project would be rigorous without damaging the local environment or causing any harm to involved individuals. The results formed and conclusions drawn are inspired by the heterogenous livelihoods and knowledge systems of the residents I had the benefit of interacting with. This project anticipates the input of future research on any positionality or ethical oversights made by this study.

Results

The researcher took measurements, surveys, and interviews assessing ecosystem service metrics, including down wood volume, species richness (provisioning), biomass, carbon content, water content (supporting), landform processes like rivers and slopes, elevation, decay class (regulating), and perceptions of forest managers and stakeholders (cultural). A selection of metadata is available in Appendix D.

Provisioning

There was no significant difference in estimated volume of down wood in cubic meters (m^3) between NCF (0.68 m^3), ICF (0.13 m^3), and HFF (0.13 m^3) (one-factor ANOVA, $p>0.05$) (Figure 2a). The NCF average is particularly skewed by outliers of 1.57 m^3, 20 m^3, and 2.5 m^3 at down wood systems 1, 2, and 5, respectively. If treated as outliers and eliminated, the average becomes 0.3 m^3, still a higher value than the other two management types. In calculations involving estimated down wood volume, NCF system 2, with a volume estimated at 20 m^3, was considered a major outlier and removed from analysis.

There was a significant difference in average species richness between NCF (12.1) and ICF (6) (one-factor ANOVA, $p<0.05$) and between NCF and HFF (6.7) (one-factor ANOVA, $p<0.05$), but no significant difference in average species richness between ICF, and HFF (one-factor ANOVA, $p>0.05$) (Figure 2b). There was no significant difference between estimated species richness per m^3 of coarse woody debris (CWD) in NCF (38) and ICF (309.56), nor was there between ICF and HFF (183.67) (one-factor ANOVA, $p>0.05$), but HFF's estimates for species richness per m^3 were significantly higher than NCF's (one-factor ANOVA, $p<0.05$). Mosses were among the dominant vegetation types in twenty-four of the thirty down wood systems sampled. Of the other six systems, one in NCF had no dominant vegetation, in ICF two had no dominant vegetation and trailing blackberry (*Rubus ursinus*) was dominant in another, and in HFF trailing blackberry (*R. ursinus*) was dominant in one system and ferns were dominant in another (see Appendix D).

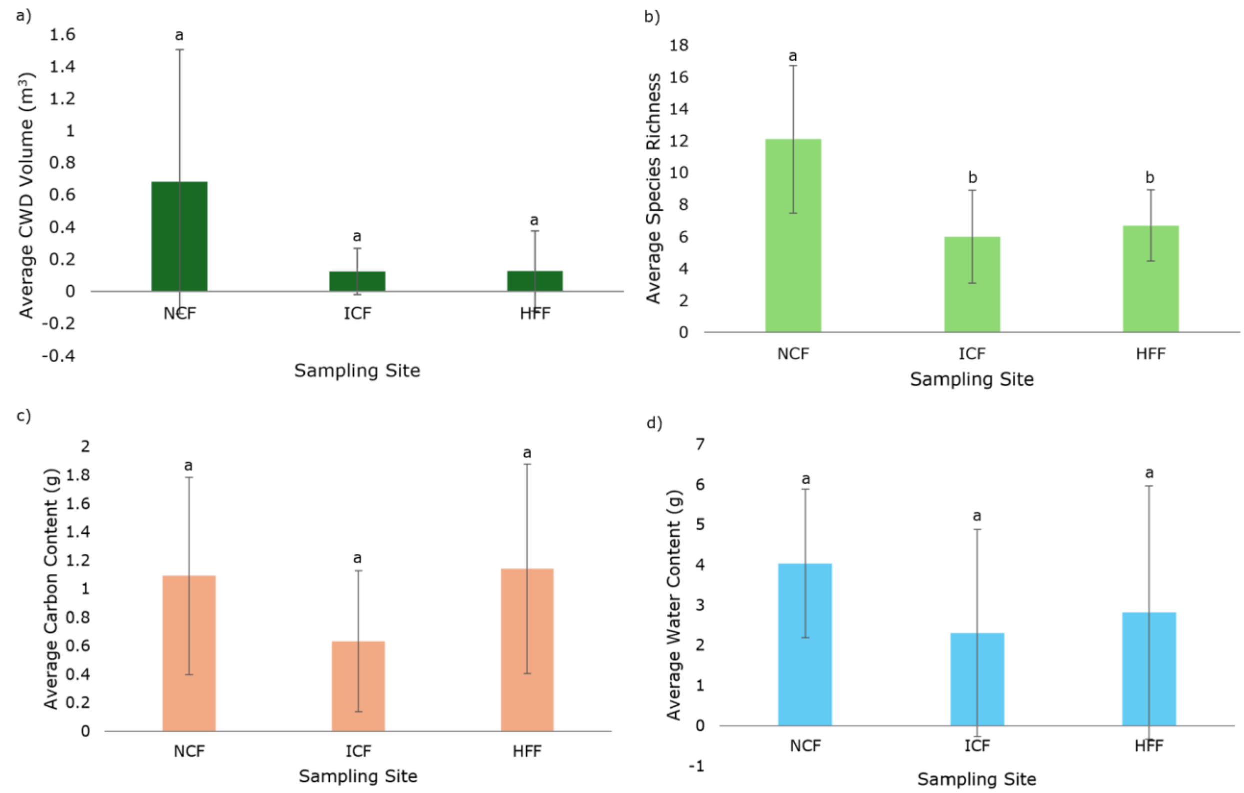

Figure 2. The effect of sampling site on a) average CWD volume (m^3), b) average species richness (g), c) average carbon content (g), and d) average water content (g) in the Puget Sound region, WA. Length and diameter measurements and species richness surveys were conducted on down wood systems in three management zones, Nisqually Community Forest (NCF) (n=9), Island Center Forest (ICF) (n=10), and H. F. Forest (HFF) (n=10), from the Puget Sound Region in May and June 2024. Five tree cores (maximum depth of 40.64 cm) were sampled from down wood systems in three management zones, NCF (n=10), ICF (n=10), and HFF (n=10), from the Puget Sound Region in May and June 2024. Error bars represent ±1 S.E.. One-factor ANOVA: Estimated CWD Volume ($p>0.05$), species richness between NCF and ICF, NCF and HFF ($p<0.05$), species richness between ICF and HFF ($p>0.05$), average carbon content ($p>0.05$), and average water content ($p>0.05$). Lower case letters denote significant differences between means.

Supporting

There was no significant difference in biomass (g) between any of the management zones, , NCF (2.16 g), ICF (1.25 g), and HFF (2.26 g), after 48 hours of drying at 60° C (one-factor ANOVA, $p>0.05$). Nor was there a significant difference in estimated biomass per log between any of the management zones, NCF (15.78 kg), ICF (45.76 kg), and HFF (45.76 kg) (one-factor ANOVA, $p>0.05$).

There was no significant difference between carbon mass (g), estimated by 50.6% of measured biomass, at any management zone, NCF (1.09 g), ICF (0.63 g), and HFF (1.14 g) (one-factor ANOVA, $p>0.05$) (Figure 2c). There was also no significant difference between estimated carbon mass per log (g) at any management zone, NCF (93.42 g), ICF (7.98 g), and HFF (23.16 g) (one-factor ANOVA, $p>0.05$).

There was no significant difference in average water content (g) between NCF (4.04 cm^3), ICF (2.31 cm^3), and HFF (2.82 cm^3) (one-factor ANOVA, $p>0.05$), nor was the difference between water content per log across management zones NCF (379.67 dm^3), ICF (21.37 dm^3), and HFF (104.71 dm^3) significant (one-factor ANOVA, $p>0.05$) (Figure 2d).

Regulating

The average elevation was significantly different between NCF (990.52 m) and ICF (103.69 m) (one way ANOVA, $p<0.05$) and between NCF and HFF (94.18 m) (one way ANOVA, $p<0.05$), but not between ICF and HFF (one way ANOVA, $p>0.05$). The average slope of down wood was 12.7° at NCF, 6.4° at ICF, and 9.1° at HFF. No significant difference existed between slopes at different management zones (one way ANOVA, $p>0.05$). At NCF, three sampled logs were of ‘sound’ decay class, six were intermediate, and one was rotted. At ICF, three logs were sound, two were intermediate, and five were rotted. At HFF, four logs were sound, five were intermediate, and only one was rotted. The average canopy cover was 67.22% in NCF, 61.77% in ICF, and 71.31% in HFF. Elevation had no significant impact on sound (373.11 m), intermediate (506.0846 m), and rotted (224.81 m) decay classes (one-factor

ANOVA, $p>0.05$). Slope also had no significant impact on sound (11.5°), intermediate (8.85°), and rotted (7.43°) decay classes (one-factorANOVA, $p>0.05$).

There was no significant difference in estimated volume of CWD between sound (0.32), intermediate (1.85), and rotted (0.2) decay classes (one-factor ANOVA, $p>0.05$). There was also no significant difference in species richness between sound (6.8), intermediate (9.54), and rotted (8) decay classes (one-factor ANOVA, $p>0.05$). Nor was there a significant difference between estimated species richness per m^3 of CWD across sound (289.93), intermediate (119.26), and rotted (98.64) decay classes (one-factor ANOVA, $p>0.05$).

There was a significant difference in biomass (g) between all three decay classes, sound (3 g), intermediate (1.6 g), and rotted (0.84 g) (one-factor ANOVA, $p<0.05$) (Figure 3a), though there was no significant difference in estimated biomass per down wood system (kg) across decay classes, sound (84.56 kg), intermediate (118.75 kg), and rotted (10.33 kg) (one-factor ANOVA, $p>0.05$). There was a significant difference in average carbon content between all decay classes, sound (1.52 g), intermediate (0.81 g), and rotted (0.43 g) decay classes (one-factor ANOVA, $p<0.05$) (Figure 3b). There was no significant difference in estimated carbon content per down wood system (kg) between any decay class: sound (42.79 kg), intermediate (60.09 kg), and rotted (5.23 kg) (one-factor ANOVA, $p>0.05$). There was no significant difference in water content (g) between sound (3.88), intermediate (2.56), and rotted (2.81) decay classes (one-factor ANOVA, $p>0.05$) (Figure 3c). There was no significant difference in estimated water content per down wood system (kg) between sound (147.61 kg), intermediate (260.82 kg), and rotted (27.25 kg) decay classes (one-factor ANOVA, $p>0.05$).

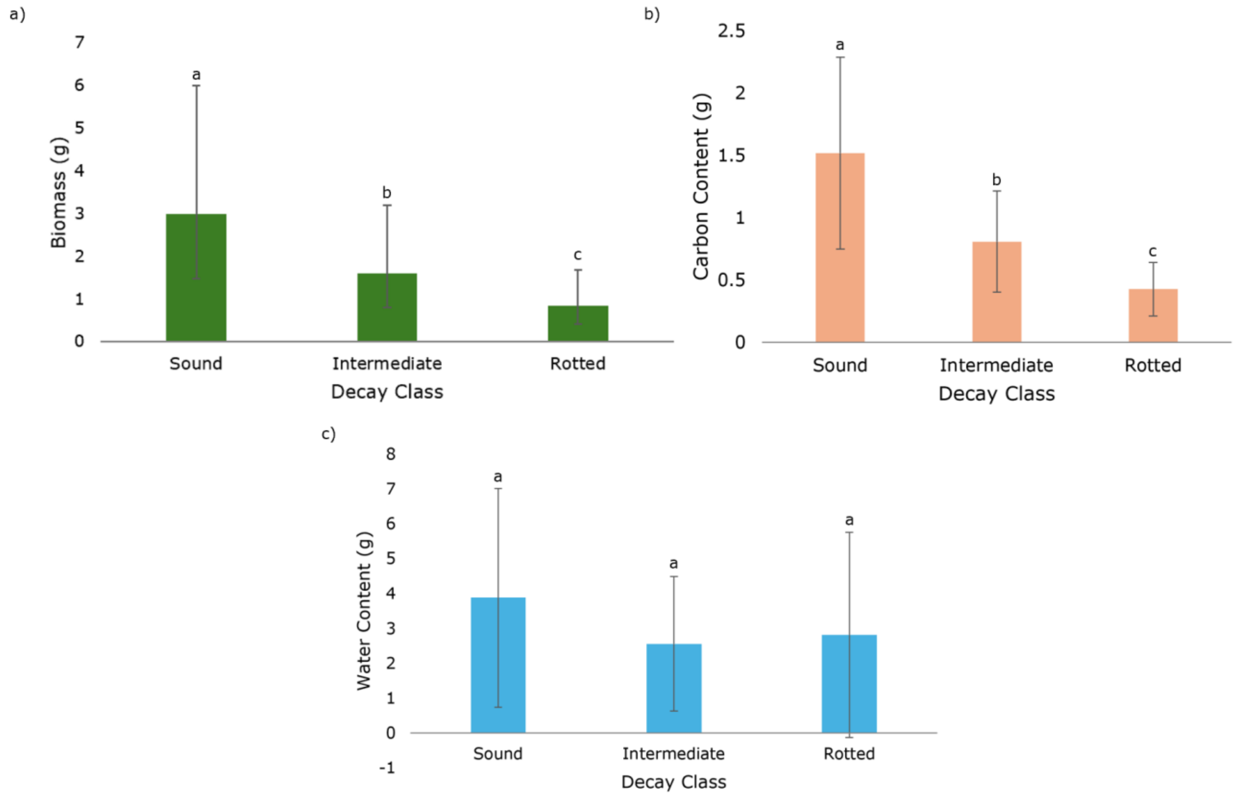

Figure 3. The effect of decay class (sound, intermediate, rotted) on a) biomass (g), b) carbon content (g), and c) water content (g) in the Puget Sound region, WA. Five tree cores (maximum depth of 40.64 cm) were sampled to estimate carbon and water contents (g), and a species richness survey was taken from down wood systems across three decay classes, sound (n=10), intermediate (n=13), and rotted (n=7), from the Puget Sound Region in May and June 2024. Error bars represent ±1 S.E.. One-factor ANOVA: Average biomass content ($p<0.05$), average carbon content ($p<0.05$), and average water content ($p>0.05$). Lower case letters denote significant differences between means.

Cultural

At NCF, the interviewed manager, henceforth referred to as the NCF Manager, emphasized the importance of down wood as nurse logs, especially for western hemlock (*Tsuga heterophylla*), surface and subsurface biodiversity, and moisture retention within CWD. The NCF Manager noted that biodiversity enabled by CWD could also be invasive, and destructive to surrounding timber. Seeing a hole in one down wood system (NCF7), they explained how that might be a burrow or other microhabitat. The manager highlighted specific wildlife:

> There’s nurse logs, which seem to be especially good for western hemlock. There are small mammals, amphibians, we’ve seen pikas using slash piles. Squirrels and small birds all use down wood. Then there’s the ones we forget about, that’s insects, decomposers and fungi. Y’know, not as cute but still important (Interviewee #3, July 2, 2024).

Their management priority was large down wood, for which they described two ways of influencing to create larger diameters: growing larger trees by increasing time between harvest and simulating large down wood with constructed down wood. The NCF Manager identified leading climate risks to down wood as wildfire, for which they prescribed even burns across managed forest ecosystems, and drought stress, for which they prescribed gap cutting and thinning. They did worry that heavy thinning could increase solar intensity and actually be damaging to ecosystem survival. The NCF Manager also chose to provide a non-climate change to down wood, that being increased recreation. They mentioned that recreation increases societal will to preserve larger trees and would therefore increase the size of recruited down wood. They perceived a societal will for a more “pristine” recreation environment, though they also noted that large down wood had a positive impact on recreation.

The NCF Manager’s response to each sampled log (Figure 4) was generally positive with one exception. Large down wood was emphasized. When down wood was particularly rotted, they discussed how its future benefits would be lower but only because of how much those down wood systems had already contributed to the ecosystem, namely soil creation. The manager did mention the importance of these down wood systems to subsurface biodiversity: “That is from a surface-dweller perspective. If I was an insect or a fungi [sic], I’m sure I’d have a different feeling about it (Interviewee #3, July 2, 2024).” The interviewees’ attitudes toward each sampled down wood system, as well as specific comments about ecosystem services and disadvantages, are summarized in Figure 4.

	Manager					Stakeholder				
Log ID	Attitude	Provisioning	Supporting	Regulating	Cultural	Attitude	Provisioning	Supporting	Regulating	Cultural
NCF1	+	Nurse Log								
NCF2	+			Soil Formation						
NCF3	+	**Small**		River Proximity	Aesthetic					
NCF4	+	Fungi, Insects		Field Proximity						
NCF5	+		Moist					N/A		
NCF6	+/0	Large, **invasives**			**Logged**					
NCF7	+	Biodiversity, **small**		River Proximity						
NCF8	++	Biodiversity		River Inclusion	Aesthetic					
NCF9	+	**Small**								
NCF10	+			Soil Formation						
ICF1						+	Biodiversity			
ICF2						+				
ICF3						++	Biodiversity			Aesthetic
ICF4						0				
ICF5			N/A			+	Biodiversity, large			
ICF6						0				
ICF7						+				
ICF8						0				
ICF9						+				
ICF10						+	Large			Aesthetic
HFF1	-			**Wildfire Fuel**		-				**Branches**
HFF2	+			Soil Formation		+			Decomposition	
HFF3	+			Decomposition		+			Decomposition	
HFF4	+					+				
HFF5	+					+	Biodiversity			
HFF6	+	Large				++	Firewood		Decomposition	
HFF7	+					+			Decomposition	
HFF8	+	Large				-				**Logged**
HFF9	+					+				
HFF10	++	Biodiversity		Decomposition		+				

Figure 4. Perceived down wood ecosystem services and disadvantages by community, public, and private forest managers and stakeholders. Four interviews about down wood were conducted with forest managers and stakeholders across three management types. Interviewees expressed overall feelings (positive, neutral, negative) and identified ecosystem services and disadvantages associated with ten down wood systems in the pertaining management zone. Detrimental aspects of down wood are highlighted in red and bolded. Systems prioritized by interviewees are highlighted in yellow. Two interviewee roles went unfilled due to lack of reachout response.

Down wood systems nearer to the major river at the sampling site were emphasized for their importance to wildlife. A down wood system (NCF8) directly within the stream channel was “very, very high priority (Interviewee #3, July 2, 2024)” as habitat for fish (see image in Appendix A). Similarly, the NCF Manager mentioned the importance of down wood near to fields, where recruitment of down wood would otherwise be lower. Smaller down wood was less important and if moved during management operations would not be considered a major loss. One down wood system (NCF3, see image in Appendix A) was described positively for its aesthetically pleasing lichen cover. A particularly large piece of down wood was viewed positively, though was too moist to sit on and eat lunch. One down wood system (NCF6) was positive for its width, but its sawed sides were not aesthetically pleasing and invasive species growing on it made the valuation more neutral. The NCF Manager was curious to learn more:

> I'm curious about down wood size. Some say that a fifteen inch diameter is the cutoff, that anything greater than fifteen inches is beneficial and anything less is a fire risk. But is a twelve inch tree that much less valuable? Is a twenty inch log any less of a fire risk? I also don't know if anyone's created a constructed log and come back to see, later, if it's mushed together into something like some of the larger rotted logs you have there. I'd be curious to see that (Interviewee #3, July 2, 2024).

Multiple candidates for the community forest stakeholder and the public forest manager failed to respond to interview inquiries in a timely manner, ultimately reducing the data from those unique positions. These absent perspectives are listed as "N/A" in Figure 4.

The ICF Stakeholder distinguished between logs on trails, which were a "mild inconvenience (Interviewee #4, July 12, 2024)" to recreation, and logs in the forest. They asserted that wood on trails was regularly cleared from the path by ICF's trail crews. The landowner also benefited from non-timber forest products (NTFP), specifically oyster mushrooms (*Pleurotus ostreatus*). The stakeholder regularly harvests, cooks, and consumes these mushrooms found on red alder (*Alnus rubra*), a common hardwood species in Douglas fir (*Pseudotsuga menziesii*) forests. The ICF Stakeholder noted that the shorter decomposition time for red alder (*A. rubra*) was beneficial for that particular NTFP. The ICF Stakeholder understood the ecosystem benefits of down wood, but discussed more extensively the aesthetic benefits of down wood in a natural context and the benefit of having a platform on which to eat lunch. They recounted experiences with down wood internationally and at a nearby National Park, stressing aesthetic and recreation benefits and exception:

> I was traveling in Czechoslovakia, after the Berlin Wall came down. We went to a forest there that was totally clean of down wood. It was only pine needles and twigs the size of a pencil, no down wood. It just felt sterile. I went on a backpacking trip in the Olympics… There were just massive logs. Eight foot logs. You had to climb over or even

> go around. There they were obstacles. On the one hand, those were more than mildly inconvenient. But they were also part of the grandeur of the forest. There's another type. When they have a windstorm, it can form a big tangle which is more of a pain in the neck and doesn't look as good (Interviewee #4, July 12, 2024).

The ICF Stakeholder's preferences surrounding individual down wood systems (Figure 4) was mostly positive, especially regarding CWD displaying strong moss colonies. ICF3 was a particular favorite for its near-perfect moss cover. Many systems were perceived as positive, even if the stakeholder felt the system (ICF2) was just "okay, kind of nondescript (Interviewee #4, July 12, 2024)." The stakeholder particularly liked down wood which contributed to the naturalistic look of the forest, though made no comment about logging evidence. ICF10 was also favored, the stakeholder describing it as *wabi-sabi*, an aesthetic term of Japanese origin which celebrates imperfection and asymmetry (see image in Appendix A). The ICF Stakeholder stated that they would like to learn more about what kinds of animal wildlife existed on down wood.

The HFF Manager emphasized carbon sequestration, wildlife habitats and food-sources, moisture retention, and soil creation. The manager worried that the down wood could be a source of carbon, and that down wood with a diameter of four inches or less was fuel for wildfires. The manager also mentioned that "Aesthetically, well it doesn't meet my aesthetic criteria if I'm looking at that (Interviewee #2, June 11, 2024)." The HFF Manager felt down wood could increase either by allowing the natural recruitment of down wood or by manually constructing down wood. They explained a few ways that climate change will impact down wood in the area:

> Mechanically, climate change will accelerate mortality and therefore recruitment. That'll be mostly from drought intolerant trees. You can combat recruitment through proactive thinning to keep residual trees healthier. If there's excess buildup of down wood, chipping, extraction, lop and scatter (Interviewee #2, June 11, 2024).

The HFF Manager responded positively to all down wood systems (Figure 4) but one, discussing the benefits of more accelerated decay stages and large down wood, especially for its lower fire risk. The manager particularly liked the site's only 'rotted' down wood system

(HFF10), citing benefits to wildlife habitats and food sources. The one down wood system which the HFF Manager viewed negatively (HFF1) was a high wildfire risk due to its intact upright branches, or "fine down wood" (Interviewee #2, June 11, 2024) (see image in Appendix A).

The HFF Stakeholder explained that the only impact down wood had on their activity on the land was as obstacles to maneuvering around the space. The HFF Stakeholder recalled how down wood was managed differently in their home state: "we cleared most of the downed trees and sold firewood. That allowed seedlings to be planted underneath it. That was the downside, but there's light underneath (Interviewee #1, June 11, 2024)." The HFF Stakeholder felt positively about all but two down wood systems (Figure 4), prioritizing the down wood they felt would rot faster and the down wood which might be used as wildlife habitat. The stakeholder decided that one down wood system (HFF6) was rotting adequately, but could also be a good piece of wood for a fireplace. The HFF Stakeholder felt negatively about one down wood system (HFF8) aesthetically, for its evidence of sawing. The HFF Stakeholder also felt negatively about HFF1's branches, stating that they detracted from the surrounding ferns rather than the HFF Manager's issue of fire risk. When asked about their overall thoughts on down wood, the stakeholder said:

> Previously, down wood was usable, we didn't think about how it affected habitat where I'm from. Out here, there are many other uses for it and it decays so fast, not like in [my home state]. Down wood is especially important in a big woods like this, but maybe not in a yard. Maybe not in a smaller area. I say, just leave it! If it's marketable for pulp, let's use it. Take some, don't leave it all (Interviewee #1, June 11, 2024).

In NCF and ICF, estimated CWD volume (m^3) correlated positively with species richness under linear regression, with CWD volume explaining 63.85% of NCF's species richness values and 22.95% of ICF's. CWD volume only explained 2.1% of HFF's species richness values (Figure 5a). In NCF and HFF, carbon content (g) correlated positively with water content (g) under linear regression, with carbon content explaining 52.52% of NCF's water content values and 31.55% of HFF's. Carbon content only explained 0.18% of ICF's water content values (Figure 5b). In sound and intermediate CWD, carbon content correlated positively with water content under linear regression, with carbon content explaining 21.16% of sound CWD water content and 59.5% of intermediate CWD water content. Carbon content only explained 0.15% of water content in rotted CWD (Figure 5c).

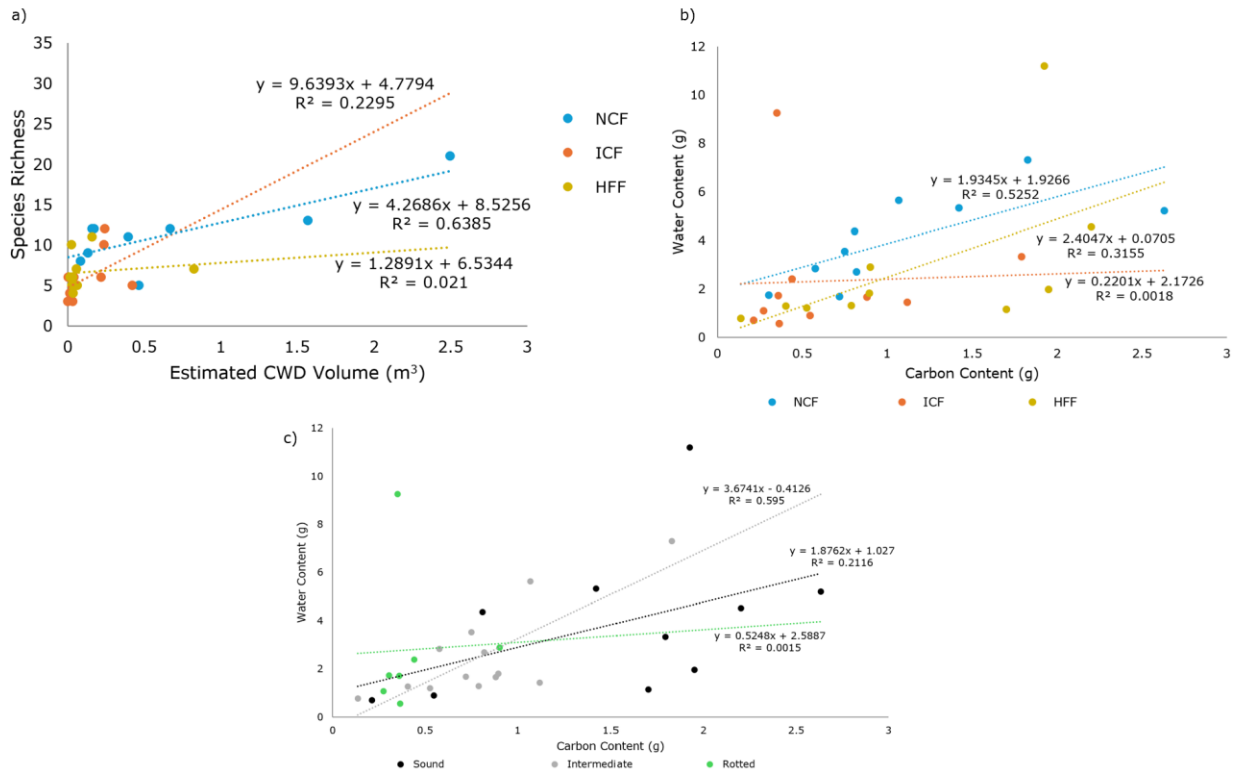

Figure 5. a) The effect of CWD volume (m^3) on species richness across management scenarios and the effect of carbon content (g) on water content (g) across b) management scenarios and c) decay classes in the Puget Sound region, WA. Length and diameter measurements and species richness surveys were conducted on down wood systems in three management zones, Nisqually Community Forest (NCF) (n=9), Island Center Forest (ICF) (n=10), and H. F. Forest (HFF) (n=10), from the Puget Sound Region in May and June 2024. Five tree cores (maximum depth of 40.64 cm) were sampled from down wood systems in three management zones, NCF (n=10), ICF (n=10), and HFF (n=10), from the Puget Sound Region in May and June 2024.

Discussion

Findings in this study are often best explained across ecosystem service types, consulting the results from all sectors of study. Schröter et al. (2014) critiques the ambiguity between ecosystem services as they are presented in modern scientific assessment. The major distinctions between service classes are based upon the Millennium Ecosystem Assessment Board synthesis (MA 2005), which does little to delineate which ecosystem services fit into which category. Schröter et al. does acknowledge how the ambiguity is often construed as intentional, benefiting analyses which span disciplines and consider diverse dialogues. This study takes a similarly interdisciplinary approach, using the classifications of ecosystem services loosely to structure findings within tangible results for humans and ecosystems.

The significant differences in provisioning metrics between management sites were in species richness and estimated species richness per m^3, where Nisqually Community Forest (NCF) had significantly higher species richness than Island Center Forest (ICF) and H. F. Forest (HFF), and HFF had significantly higher estimated species richness per m^3 than NCF. Despite a higher average volume of down wood estimated in NCF than ICF and HFF, the difference was not statistically significant. While NCF sampling elevations were substantially higher than the other sampling sites, elevation generally correlates negatively with species richness in Washington (Brockway, 1998) and cannot explain the significantly higher biodiversity at NCF. Assuming 123.55-345.94 down logs per hectare (ha) in undisturbed forests (Malone et al., 2023) and around 139.93 cubic meters (m^3) per ha in mature stands (Spies & Cline, 1988), NCF's down wood volume is 0.6 to 1.68 times the volume of undisturbed, mature forests, while ICF's down wood volume is only 0.15 to 0.32 times that expected volume and HFF is 0.12 to 0.32 times the expected volume. The higher, though not significantly higher, volume at NCF suggests a high enough variation between volumes around the site to eliminate the difference between all sites. This implies that the size classes across all three sites are highly variable, though the size classes monitored at NCF are more comparable to natural conditions. The lower volume at ICF and HFF may be explained by those sites' less developed stand characteristics, with lower complexity.

There was a significantly higher species richness in down wood at NCF than at ICF and HFF. The increased species richness may be a result of NCF's rainy climate. Species richness generally increases with precipitation (Hu et al., 2022) and the sampling day at NCF itself was characterized by high precipitation. According to NOAA (2024), annual precipitation roughly totals 162.56 cm at NCF, 101.6 cm at ICF, and 124.46 cm at HFF. Despite not significantly impacting down wood retention, that higher precipitation could be causing the higher species richness in NCF's sampled down wood systems. The higher species richness per cubic meter of down wood in HFF is best attributed to consistently higher lengths and diameters of down wood at NCF, which, while not significantly greater than ICF or HFF, created a smaller species to down wood ratio and lower quotients as a result.

A linear correlation between the estimated volume of down wood and species richness only represented 2.1% of the data at a slight positive correlation in HFF, while it explained a more substantial 22.95% of ICF's volume-richness relationship on a strong positive slope, and a substantial 63.85% of NCF's data with a somewhat shallower slope. The volume of down wood appears to influence provisioning services more substantially under multivariate analysis, a potential future direction for down wood studies. Hekkala et al. (2023) found log volume as the best indicator of biodiversity in down wood, supported by the far larger average log volume at NCF and the site's significantly higher species richness. This trend may also be less strong at

HFF due to an outlier, HFF1. Both the manager and stakeholder disliked HFF1 due to its branches' aesthetic detraction from surrounding biodiversity and potential fire risk, a likely risk to biodiversity. Eliminating this point, the regression accounts for a stronger 35.08% of data. Lower species richness at ICF may be a result of the frequent human use of that site, or even biodiversity removal for non-timber forest products (NTFPs) that the ICF Stakeholder discussed.

Management regimes can have substantial impacts on species richness within a forest, especially with more intense land-use, land-use change, and forestry (LULUCF). Chaudhary et al. (2016) finds more substantial impacts from forestry management that retains fewer trees, like clear-cutting, than selection-and-retention focused management. The management styles that caused the most species loss, however, were non-timber LULUCF operations like agroforestry. None of the forests considered in this report are used for clear-cutting or agroforestry, but the management plans do differ in thinning, buffering, and use. The NCF Manager expressed concerns over the greater solar intensity associated with thinning and gap-cutting potentially reducing soil moisture though no measurement of water content differed across management objectives or decay class in this study.

The findings at NCF support the prioritization of high-biodiversity forests, particularly areas of high elevation and high biodiversity like the Pacific Northwest. These ecosystems consistently provide more services and exhibit climate change resilience with lower mortality and vulnerability (Law et al., 2021). Gaines et al. (2022) asserts that the success of preserved lands will be threatened by shifting climate and wildfire patterns, reducing viable habitat within preserved spaces. A priority for maintaining biodiversity is retaining or constructing down wood, especially for the microclimate habitats it supports despite external climate factors (Bunnell & Houde, 2010). This trend is more true of the higher elevations and moister climates of Western

Washington, including much of the Puget Sound region, where wildfires are lower intensity and down wood is not contextualized as fuel (Halofsky et al., 2020).

The dominant vegetation types associated with twenty-three down wood systems sampled were mosses (Appendix D). In sixteen of the down wood systems, mosses were the only dominant vegetation present. Trailing blackberry (*Rubus ursinus*) was dominant in four down wood systems, twice simultaneously with mosses, and no vegetation was dominant in another four systems. Thomas et al. (2001) finds that silvicultural thinning in Washington's forests can negatively impact moss colonies. Along the lines of the NCF Manager's discussion of the impacts of over-thinning, more intense management could lead to decreased prevalence of these species, a loss to biodiversity. Alternatively, decreasing the dominance of mosses could create new niches for other plant colonies and further diversity. Mosses are primary colonizers whose richness increases over time, while early colonizers like lichens peak in richness earlier (Rudolphi, 2007). While thinning actions at all sites could damage future moss richness, it could create more species evenness with other lichens, which had a noted positive aesthetic value to one interviewee. The effect of moss colonies on forest ecosystem services varies contextually (Glime, 2024), so specific prescriptions for moss-conscious thinning would depend heavily upon site characteristics and management objectives.

Perhaps the most overwhelming argument in favor of moss dominance of coarse woody debris (CWD) was the responses from the ICF Stakeholder. The stakeholder spoke positively about that ecosystem and aesthetic characteristics in several down wood systems, with curiosities existing around what other wildlife exists across down wood in the region. In fact, biodiversity and size, both provisioning metrics, were the only ecosystem services identified by all interviewees across all management scenarios. The ICF Stakeholder also discussed their experiences harvesting a NTFP, oyster mushrooms (*Pleurotus ostreatus*). Hoa et al. (2015) finds that *P. ostreatus* yields correspond heavily with carbon:nitrogen ratios. In the sampled forests, *P. ostreatus* NTFPs should produce the highest yields in trees in the ‘sound’ decay class, though further research would be required to corroborate this finding.

Many participants discussed how down wood could be beneficial as food and habitat for wildlife, with a common suggested management option being simulated down wood. Placed wood in stream channels had low rates of structural failure and positive impacts on fish populations, especially in its creation of habitat, according to Roni et al. (2015). The study did highlight the underemphasis on watershed processes in scientific literature surrounding placed wood, including sedimentation and water quality. Down wood can also be a disturbance contributing to habitat complexity, especially when natural movement of down wood is allowed by managers (Wohl et al., 2023). Ultimately, the benefits to wildlife provisioning likely outweighs the fringe conception and complicated logistics of extracting down wood for biofuel production (Barrette et al., 2015, Riffell et al., 2011). An exception might exist in the instance of small down wood with lower aesthetic value, as is the case with down wood HFF6, which the HFF Stakeholder decided “would also be nice for a fireplace (Interviewee #1, June 11, 2024).”

There was no significant difference in measured nor estimated biomass, carbon, and water content across all sites, implying that management objectives had low impact on nutrient and hydrological cycling in down wood systems. The trend in biomass is supported by Brown et al. (2018), which finds that harvest scenarios played less of a role than climate did. One explanation for biomass “over-yielding,” is the tree diversity in a forest (Augusto & Boča, 2022). The tree canopy across all ten tree systems included an identified four species in all three sites, loosely supporting the similarity seen in estimated biomass per m^3. Assuming 123.55-345.94

logs per ha (Malone et al., 2023) and 32.12 megagrams (Mg) of biomass per ha (Spies & Cline, 1988), the biomass at NCF is 0.73 to 2.05 times the biomass of a mature, undisturbed forest, 0.08 to 0.22 times that standard at ICF, and 0.19 to 0.54 times the standard at HFF. This trend demonstrates higher biomass storage, consistent with undisturbed, mature forests, at NCF, though variation in log biomasses was great enough that the difference was not significant. This trend likely also relates to the generally higher sizes measured at NCF, though the biomass content at NCF was also consistently higher than ICF and HFF, if not significantly so.

As biomass and carbon content are proportional (Harmon et al., 2013), management action that enhances biomass should simultaneously improve carbon content, and forests with no major difference in biomass should not have significant differences in carbon. Assuming 123.55-345.94 logs per ha (Malone et al., 2023) and 100 Mg of carbon per ha (Means et al., 1992), the carbon storage at NCF is 0.12 to 0.32 times that of a mature, undisturbed forest, 0.01 to 0.03 times the standard at ICF, and 0.03 to 0.08 times the standard at HFF. The Means et al. estimate of 100 Mg carbon/ha is likely too high, higher than the Spies & Cline (1988) estimate for biomass content, likely due to the closer approximation of mature to old growth forest at Andrews Experimental Forest, the sole site considered in the carbon study.

Law et al. (2021) finds the Pacific Northwest's forest carbon stock and biodiversity under threat, particularly from logging activity. This finding is supported by Domke et al.'s (2013) finding that the Pacific Northwest hosts the highest CWD carbon stocks. Domke et al. also discusses obstacles to measuring and monitoring CWD, citing a 9% overestimation by leading modeling technology. The study offers the option of sustainable recreation in preserved forests as an alternative to extractive management. Augusto & Boča (2022) finds that carbon sequestration can be enhanced by increasing standing biomass, species richness, and functional forest composition, synergizing tree physiology including root, leaf, and wood proportions. Despite these findings, there was no significant difference in stored carbon between management zones in this study. With Waterman-Hoey's (2022) estimated emissions associated with LULUCF, it is important to understand how down wood and management activities factor into carbon sequestration and emissions.

The NCF and HFF Managers both discussed one option for enhancing down wood ecosystem services, by allowing for the natural recruitment of down wood. The NCF Manager explored this further, stating that increasing time between harvesting would allow for the recruitment of larger down wood, and therefore higher biomass and carbon content, to the forest floor. HFF is managed by multiple rotations of thinning, while the NCF study site had fewer, and a large portion of the site was within the stream buffering zone, increasing down wood size and density. Down wood recruitment is largely a function of wind (Bahuguna et al., 2010) in the Puget Sound region, though Sailor et al. (2008) finds a likely wind speed decrease in the region as a result of climate change. The ICF Stakeholder remarked negatively about windstorm-driven recruitment of multiple trees, noting the eyesore and obstruction to recreation activities. The acceleration of climate change will likely decrease wind recruitment, an aesthetic improvement.

Down wood concentration is particularly high across the Pacific Northwest, but proportionally more carbon is stored in secondary forests than old growth forests, demonstrating the priority that down wood should garner in even earlier stages of management (Sillett et al., 2019). Zhang et al. (2023) finds substantial carbon storage decreases in heavily-cut forests across nearly all carbon pools, but also found that CWD played an important role in the transfer of carbon and nitrogen into the soil. CWD exhibits higher carbon storage with stand age, though is also subject to salvage during harvest and more intense fire where CWD is already sparse (Gray et al., 2016). This relates to the NCF Manager's discussion of beneficial CWD size and the fine down wood the HFF Manager identified at HFF1. After decomposition time, diameter was a strong predictor of down wood decomposition rate in logs 20-40 cm, with larger diameters decomposing more slowly (Herrmann et al., 2015). Of course, smaller diameters correlate with lower carbon storage and therefore have fewer ecosystem benefits.

Under no management style and under no decay class was a significant difference in water content recorded, although averages in water content and water content per down wood system were higher if insignificantly so in NCF logs. This slight difference may be attributable, again, to the higher precipitation experienced at NCF, the proximity of a river to several of the sampled down wood systems, or the rain experienced on the actual sampling date. Assuming 123.55-345.94 logs per ha (Malone et al., 2023) and 559-10,700 liters (L)/log of water per ha (Means et al., 1992), the water storage at NCF is 4.38 to 234.96 times that of a mature, undisturbed forest, 0.25 to 13.25 times the standard at ICF, and 1.21 to 64.8 times the standard at HFF. Water content did trend strongly with carbon content at both NCF and HFF, but the trend did not persist at ICF. This site experienced the lowest precipitation, with consistently lower moisture content and carbon content. ICF had by far the most logs in the rotted decay class. As the NCF Manager argued, much of the ecosystem benefits of more accelerated decay had already been felt and are now more prominent in the soil than the wood, potentially explaining this trend. The comparatively high water storage in down wood around the Puget Sound region supports Halofsky et al.'s (2020) findings that the forests of Western Washington are more equipped to resist climate-driven wildfire than the fueling CWD in more eastern contexts.

In one study (Kwak et al., 2015), soil water content was unaffected by proximity to CWD, a potentially lower impact to local hydrology than other studies (Dhar et al., 2022, Goldin

& Hutchinson, 2014) suggest. Pichler et al. (2011) found that down wood rapidly lost its water content after recruitment but with more advanced stages of decay was able to retain more water. This trend was unsupported by the data in this study, although this study's measurements were taken on several different logs of different decay classes at the same time and not monitored across a down wood system's life cycle. Nevertheless, both the NCF and HFF managers identified moisture retention as an ecosystem service associated with down wood, specifically discussing the impact of drought stress on forest ecosystems. Cartwright et al. (2020) discusses the impacts of climate-driven drought stress in the Pacific Northwest, attributing the highest resilience to forests with valley bottoms, low soil bulk density, and more available water. But if Pichler et al.'s findings apply to the Puget Sound region's Douglas fir (*Pseudotsuga menziesii*) forests, as they did in temperate European forests, down wood will have a reduced ability to improve drought conditions. One strong option for drought resilience is allowing seedlings to colonize CWD, as per Halofsky et al. (2020). The microclimates in down wood provide ample moisture and nutrients for seedlings, even at lower latitudes more impacted by climate change and resulting drought severity.

The slopes of each measured down wood system were not significantly different from those in other management zones. Webster & Jenkins (2005) and Sena et al. (2023) find that slope and even slope position can impact accumulated and sloughed CWD, especially when in proximity to river systems. This study can provide no insights to further this trend, with no significant difference in slope or CWD volume. The study also found no impact on slope across decay classes.

The elevation of NCF was significantly higher than the elevations of ICF and HFF, though this was unlikely to support higher species richness measurements in the same site.

Higher elevation sites in the Pacific Northwest were found to host more ecosystem services and better climate adaptations, especially when coupled with higher biodiversity (Law et al., 2021). This trend was supported by this study's species richness findings. Halofsky et al.'s (2020) discussion of wildfire dynamics describes the benefits of moisture in down wood at higher altitudes. Elevation had no significant impact on decay class, implying that the management strategies employed produced enough variation in decay classes to ensure even decomposition benefits even at lower altitudes.

No significant difference in any provisioning service metric was found across decay classes. Decay appears to be a function of regional temperature and weather dynamics (Yuan et al., 2017), as well as the impact by particular species, mostly fungal communities (Yamashita et al., 2015). Progar et al. (2000) and Yamashita et al. (2015) find respiration higher in down wood with lower moisture and higher colonization by certain biodiversity, specifically fungi, and fungi colonization accelerated by decay stage. None of the down wood systems measured experienced dominant fungal colonies (Appendix D) though systems ICF3, in the rotted decay class, and HFF1, in the intermediate decay class, both had notable mushroom colonies present. Further study of down wood systems highlighting fungal species and extent would be required to assess the impact of mushrooms on decomposition in CWD in the Puget Sound region. Measurements of in- and out-fluxes of carbon surrounding down wood systems could contribute to greater understanding of biodiversity-emissions dynamics, but were beyond the scope of this study's methodology. As the NCF Manager explained, the surface ecosystem services associated with down wood are mostly exhausted by the time the tree reaches the rotted decay class, though to decomposers and soil dynamics, subsurface services will continue.

Leverkus et al. (2020) finds support for low variation in regulating service impacts by logging across harvest scenarios, but does suggest that increasing time between harvests could amplify those services. This finding is consistent with the NCF Manager’s recommendation for increasing the size and benefit of down wood and the conditions in the less thinned NCF. The most notable significant differences between decay classes were biomass content and carbon content, both found to be highest in sound, then intermediate, then rotted CWD. Pringle et al. (2021) discusses the importance of decomposition rates when calculating carbon emissions, as relatively long decay times in Queensland’s CWD create more reliable carbon sinks for longer periods. Harmon et al. (1986) discusses the same processes by which CWD is reduced, including by way of stream processes, substrate type, and internal gaseous composition. More decomposed wood, decomposition being a function which expels carbon, had resulting lower carbon storage, a logical outcome.

The trend did not continue for estimated biomass or carbon measurements across the entire down wood system, nor did it for water content or water content per log. This trend implies relative uniformity of biomass and carbon across down wood decay classes. As each measurement per down wood system represents five equally-spaced wood cores extracted along the entire length of the down wood system, the measurements should be somewhat representative of the entire system. One area of error is the position at which each sample was taken. The corer was entered into the top of the down wood system, and therefore does not necessarily represent trends along the base or even sides of the system. If higher water or carbon contents exist at different locations of the down wood system profile, this study would not successfully identify that distinction. Taking measurements around the entire log, or even conducting destructive measurements along the entire length of the CWD could be useful avenues for future research to account for this source of error.

Down wood has perhaps the widest range of potential values when considered as a cultural resource. To some stakeholders, it will constitute an eyesore, an obstruction to management activities, or the threat of wildfire. Others will perceive its aesthetic and ecological values as incredibly valuable, an integral component of any forest ecosystem. The unwritten importance of down wood to the Puget Sound region is reflected in many public parks around the Seattle area, where placed down wood or concrete statues of down wood attempt to capture the benefits of this environmental feature, even in landscapes incapable of natural recruitment. These artificial down wood systems prevail in forest management, where constructed down wood can reproduce some of the benefits to wildlife that natural systems can.

Studies like Paletto et al. (2022) and Ribe (2003) find general distaste for down wood, especially when as a result of logging, during recreation. Two of the ten down wood systems at NCF had evidence of logging, while at ICF there was only one logged system, and at HFF there were five instances of logging. Despite the higher proportion of logged wood at HFF, that forest had a higher average canopy cover (71.31%) than NCF (67.22%) and ICF (61.77%). This may explain the generally positive reaction that the HFF Stakeholder and Manager had toward much of the down wood on their property. The two down wood systems they decided were more negative than positive (HFF1, HFF8) both evidenced logging, but the other three systems at HFF with logging evidence were still received as positive. In the case of HFF8, the HFF Stakeholder particularly disliked the way the log had been “manhandled (Interviewee #1, June 11, 2024),” a clear indication of the negative aesthetic value Paletto et al. and Ribe find associated with logging.

Neither the NCF Manager nor the HFF Manager reported that logging evidence was detracting from the aesthetic value of their plots. Both managers were generally more influenced by the ecological ramifications of CWD, namely fire risk and invasive species, when they felt less positively about a down wood system. This trend likely stems from the managers' background in forestry and deeper understanding of the purpose of logging in management activities. For the NCF Manager, the most frequently promoted ecosystem services in specific contexts were soil formation through decomposition and wildlife habitat, closest related to log diameter. The HFF Manager was also most interested in soil formation related to decay class. The HFF Stakeholder most frequently promoted down wood systems in which decomposition was likely. The ICF Manager was particularly fond of moss and its aesthetic values.

The importance of decompositional processes to all interviewees with the exception of the ICF Stakeholder reflects the importance of decay class in biomass and carbon storage, while the NCF Manager's interest in habitat was best explained by management scenarios. The community-managed forest, NCF, had significantly higher species richness, another metric which promotes cultural services. Rozario et al. (2023) finds a strong correlation between short-term mental wellbeing and perceived biodiversity. Community forests are uniquely suited to achieve this goal for their promotion of recreation and environmental services (Hajjar et al., 2024). The benefits to wildlife in down wood systems experienced in the community forest management scenario demonstrates how one scenario can promote multiple uses while emulating ecological processes. The similarity in other metrics across all management scenarios, however, shows the viability of ecological forestry across management objectives and use types.

Janeczko et al.'s (2021) study demonstrates another way down wood can be perceived through ecological forestry. By allowing for the natural recruitment of down wood, as per the climate adaptation suggestions of the NCF and HFF Managers, Janeczko et al. finds recreation stakeholders benefit from the CWD's presence. Eggers et al. (2018) also calls for multi-use management such that harvest and recreation can coexist. This is made more viable in the present day with small landowners' improved access to funding for ecological forestry through the Partnerships for Climate-Smart Commodities (CSC) program (USDA, 2022). Reduced cost to resources which promote ecologically sound and forward-thinking management also promotes a more cohesive direction for forest management in Western Washington. Soulard et al. (2017) finds severe inconsistency in Washington's private forest management leading to environmental degradation. This trend can be reversed through coordinated action toward sustainability through programs like CSC and ecological forestry organizations like NNRG.

Down wood elicited particular reactions for the ICF and HFF Stakeholders, each comparatively recalling down wood in other locations they had visited or lived. The impact on recreation was minimal to both stakeholders, and was accepted as part of the naturalistic grandeur in many instances by the ICF Stakeholder. The ICF Stakeholder preferred down wood in their yard while the HFF Stakeholder said they would not. General aesthetic benefits were high for stakeholders, especially ICF's "*wabi-sabi* (Interviewee #4, July 12, 2024)" ICF10.

The ecosystem services provided by down wood are amplified by forest management types which exemplify them, as NCF demonstrates by provisioning high biodiversity for NTFPs. While all study sites supported comparatively low carbon, very high moisture contents in each forest type should resist climate-driven fire and drought. Down wood regulates carbon release in forests with less accelerated decay, though more rotten logs have greater impacts below the forest floor. The cultural value of down wood generally illustrates how detrital services enrich human stakeholders, especially if managed with ecosystem services in mind.

Conclusions and Recommendations

The future of forest management will depend heavily upon synergizing management objectives, including timber extraction and recreation, with ecological processes, including nutrient cycling and climate adaptation. The role of non-tree forest features, specifically down wood, cannot be understated. Down wood represents the end of a tree's life cycle, but also can enable the creation of further life, whether as new trees in the form of a nurse log or as vertical diversity in the form of plant and animal communities. The ecosystem services model is a useful tool to analyze the many dimensions of coarse woody debris (CWD). Different management objectives handle this ecosystem element differently though ecological forestry, a management system championed by organizations like Northwest Natural Resource Group (NNRG) which promotes managing forests by replicating natural processes. The results of this study find much support for this style of forest management and provide new insights which might accelerate the field of ecological forestry.

Works of scientific literature focusing on CWD tend to overlook a few facets of detrital services and can neglect understudied regions. The Puget Sound region was convenient for the selection of proximal literature from which to build a base understanding of CWD dynamics but also in its relative lack of precise measurements in a landscape dominated by extractive industry. This study works most intently to produce findings which fill these gaps while also identifying future avenues for study beyond the scope of this project.

The provisioning resources associated with CWD are most apparent in each system's biodiversity. The significantly higher species richness recorded in the community forest informs management objectives. This trend should be corroborated across multiple community-managed forests, for the trend could stem from either unique management activities (i.e., stream buffering, fewer thinnings) or a more natural characteristic of the community forest (i.e., higher elevation). Additionally, the importance of fungal communities to decomposition and respiration within down wood systems needs further research in the Puget Sound region to assess how specific species accelerate respiration and feed residents. The community forest experienced the strongest positive trend between CWD volume and species richness. This project's findings suggest that using CWD as biofuel, a sometimes cited provisioning option for down wood, would likely detract from biodiversity and other ecosystem services.

Supporting services did not significantly vary between management zones, though this trend should be assessed between forests in more contexts, including tribal lands and non-ecologically managed forests. The main differences between biomass and carbon content masses were across decay classes. With more advanced stage, this study found significantly lower biomass and carbon content. Comparatively lower carbon content in all management zones implies that down wood will not be a major carbon source under accelerated climate change. Water content was very high across management zones, also contributing to fire and drought resistance. A positive interaction between carbon and water content masses was most prominent in the community forest and in intermediate decay classes of down wood. Destructive measurements which map down wood profiles would also better explain the distribution of nutrients and water within the CWD, as the data collected in this study best represents the very top of each system. In lieu of such measurements, this study provides a low-disturbance methodology for basic CWD core measurements.

Decay class was, again, most useful for understanding biomass and carbon dynamics, while proportions of CWD in each decay class helped to explain further ecosystem dynamics. The characteristics of down wood in slope dynamics was less useful due to the insignificant variety of slopes across measured systems. CWD life cycle assessments may also explain more than these ‘snapshot’ measurements can in terms of specific soil creation and retention properties. Recorded fluvial dynamics were corroborated by extensive scientific literature on down wood in water systems and insights from one interviewee. Only one sampling plot had a significant river channel, though that system was of extremely high value to the site manager.

Down wood cultural services are particularly conflicting across scientific literature, but the interviews conducted in this study mostly favored the presence of CWD. In certain contexts, particularly those which increased fire risk, down wood was perceived less favorably by managers. Stakeholders, instead, ranked down wood lower when it detracted from the scenic beauty of a space, somewhat along the lines of logging evidence. The positive findings emphasized morphological benefits to soil creation, decomposition processes, and wildlife habitat. Stakeholders identified certain instances they imagined using in domestic life, as lawn decor and fireplace wood. Anticipated climate impacts were increased mortality due to drought stress and more severe wildfires, which would increase down wood recruitment but also exhaust existing carbon pools. The context of down wood, including diameter, presence of fine down wod, and moisture retention, determined whether a down wood system was more likely to fuel wildfires or increase adaptation by storing water. A larger pool of stakeholders would provide a more diverse take on valuation, which in turn could inform management strategies for community and public forest management. Future studies should also prioritize equitable inclusion of perspectives from diverse populations across the Puget Sound.

Sustainable forest management is of growing importance given the rapid acceleration of climate change impacts like wildfire and drought as well as the emissions associated with land-use, land-use change, and forestry (LULUCF). Densely forested regions like the Puget Sound region are typified by greater ecosystem services but often suffer from more extensive resource extraction which ignores the ecological realities of forest processes. The findings in this study imply that down wood in the region will be resilient against climate change, likely retaining these services long into the future if ecologically managed. Recent sustainable natural resource management systems, especially ecological forestry, promote responsible extraction and use to reduce LULUCF and enhance value to resident communities. Any solution which works for environmental protection must also work for human use, and vice versa.

The dead and dying components of a forest are as much a part of the landscape as thriving trees. Intermediate disturbances decrease tree health or increase mortality but create resilience through vertical complexity and down wood recruitment. Successful, sustained management of forests must include down wood, not as an obstacle but as an enabling hub of biodiversity, nutrient cycling, soil formation, and aesthetic value. Findings in this report best support community management styles which facilitate species richness. Such forests ultimately provide more wellbeing benefits to stakeholders and provisioning services by stocking wildlife. Retaining down wood throughout its life cycle from sound to rotted will allow for the propulsion of supporting services like nutrient cycling. Retention of down wood across all management scenarios will enhance ecosystem resilience as the Puget Sound region morphs and shapes under an accelerated-recruitment climate scenario. Humans must learn not to overlook down wood for its blatant exhibition of the gorey reality of ecosystem services, instead marveling in the extant beauty and rife facilitative value that death brings to life.

Bibliography

Ahirwal, J., & Maiti, S. K. (2018). Carbon sequestration and Soil Co 2 flux in reclaimed coal mine lands from India. *Bio-Geotechnologies for Mine Site Rehabilitation*, 371–392. https://doi.org/10.1016/b978-0-12-812986-9.00021-x

Alexander, S. J., McLain, R. J., & Blatner, K. A. (2001). Socio-economic research on non-timber forest products in the Pacific Northwest. *Journal of Sustainable Forestry*, *13*(3–4), 95–103. https://doi.org/10.1300/j091v13n03_09

Atlas, W. I., Ban, N. C., Moore, J. W., Tuohy, A. M., Greening, S., Reid, A. J., Morven, N., White, E., Housty, W. G., Housty, J. A., Service, C. N., Greba, L., Harrison, S., Sharpe, C., Butts, K. I., Shepert, W. M., Sweeney-Bergen, E., Macintyre, D., Sloat, M. R., & Connors, K. (2020). Indigenous systems of management for culturally and ecologically resilient Pacific salmon (*oncorhynchus*spp.) fisheries. *BioScience*, *71*(2), 186–204. https://doi.org/10.1093/biosci/biaa144

Augusto, L., & Boča, A. (2022). Tree functional traits, forest biomass, and tree species diversity interact with site properties to drive Forest Soil Carbon. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-28748-0

Ausmus, B. S. (1977). Regulation of Wood Decomposition Rates by Arthropod and Annelid Populations. *Ecological Bulletins*, *25*, 180–192. http://www.jstor.org/stable/20112579

Bahuguna, D., Mitchell, S. J., & Miquelajauregui, Y. (2010). Windthrow and recruitment of large woody debris in riparian stands. *Forest Ecology and Management*, *259*(10), 2048–2055. https://doi.org/10.1016/j.foreco.2010.02.015

Barrette, J., Thiffault, E., Saint-Pierre, F., Wetzel, S., Duchesne, I., & Krigstin, S. (2015). Dynamics of dead tree degradation and shelf-life following natural disturbances: Can salvaged trees from boreal forests “fuel” the forestry and bioenergy sectors? *Forestry*, *88*(3), 275–290. https://doi.org/10.1093/forestry/cpv007

Błońska, E., Prażuch, W., & Lasota, J. (2023). Deadwood affects the soil organic matter fractions and enzyme activity of soils in altitude gradient of temperate forests. *Forest Ecosystems*, *10*, 100115. https://doi.org/10.1016/j.fecs.2023.100115

Bombino, G., D’Agostino, D., Marziliano, P. A., Pérez Cutillas, P., Praticò, S., Proto, A. R., Manti, L. M., Lofaro, G., & Zimbone, S. M. (2024). A nature-based approach using felled burnt logs to enhance forest recovery post-fire and reduce erosion phenomena in the Mediterranean area. *Land*, *13*(2), 236. https://doi.org/10.3390/land13020236

Brockway, D. G. (1998). Forest plant diversity at local and landscape scales in the Cascade Mountains of southwestern Washington. *Forest Ecology and Management*, *109*(1–3), 323–341. https://doi.org/10.1016/s0378-1127(98)00266-7

Brown, M. L., Canham, C. D., Murphy, L., & Donovan, T. M. (2018). Timber harvest as the predominant disturbance regime in northeastern U.S. forests: Effects of harvest intensification. *Ecosphere*, *9*(3). https://doi.org/10.1002/ecs2.2062

Bunnell, F. L., & Houde, I. (2010). Down Wood and biodiversity — implications to forest practices. *Environmental Reviews*, *18*(1), 397–421. https://doi.org/10.1139/a10-019

Campbell, J. L., Green, M. B., Yanai, R. D., Woodall, C. W., Fraver, S., Harmon, M. E., Hatfield, M. A., Barnett, C. J., See, C. R., & Domke, G. M. (2019). Estimating uncertainty in the volume and carbon storage of downed coarse woody debris. *Ecological Applications*, *29*(2). https://doi.org/10.1002/eap.1844

Cartwright, J. M., Littlefield, C. E., Michalak, J. L., Lawler, J. J., & Dobrowski, S. Z. (2020). Topographic, soil, and climate drivers of drought sensitivity in forests and shrublands of the Pacific Northwest, USA. *Scientific Reports, 10*(1). https://doi.org/10.1038/s41598-020-75273-5

Chardon, N. I., Stone, P., Hilbert, C., Maclachlan, T., Ragsdale, B., Zhao, A., Goodwin, K., Collins, C. G., Hewitt, N., & Elphinstone, C. (2023). Species-specific responses to human trampling indicate alpine plant size is more sensitive than reproduction to disturbance. *Plants*, *12*(17), 3040. https://doi.org/10.3390/plants12173040

Chaudhary, A., Burivalova, Z., Koh, L. P., & Hellweg, S. (2016). Impact of forest management on species richness: Global meta-analysis and economic trade-offs. *Scientific Reports, 6*(1). https://doi.org/10.1038/srep23954

Chazdon, R. L., Brancalion, P. H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I. C., & Wilson, S. J. (2016). When is a forest a forest? forest concepts and definitions in the era of forest and landscape restoration. *Ambio, 45*(5), 538–550. https://doi.org/10.1007/s13280-016-0772-y

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and Natural Capital. *Nature*, *387*(6630), 253–260. https://doi.org/10.1038/387253a0

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of Ecosystem Services. *Global Environmental Change*, *26*, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Dhar, A., Forsch, K. B., & Naeth, M. A. (2022). Effects of coarse woody debris on soil temperature and water content in two reconstructed soils in reclaimed boreal forest. *Soil Systems*, *6*(3), 62. https://doi.org/10.3390/soilsystems6030062

Domke, G. M., Woodall, C. W., Walters, B. F., & Smith, J. E. (2013). From models to measurements: Comparing downed dead wood carbon stock estimates in the U.S. Forest Inventory. *PLoS ONE*, *8*(3). https://doi.org/10.1371/journal.pone.0059949

Dungait, J. A., Hopkins, D. W., Gregory, A. S., & Whitmore, A. P. (2012). Soil Organic matter turnover is governed by accessibility not recalcitrance. *Global Change Biology*, *18*(6), 1781–1796. https://doi.org/10.1111/j.1365-2486.2012.02665.x

Eggers, J., Lindhagen, A., Lind, T., Lämås, T., & Öhman, K. (2018). Balancing landscape-level forest management between recreation and wood production. *Urban Forestry & Urban Greening*, *33*, 1–11. https://doi.org/10.1016/j.ufug.2018.04.016

Ehbrecht, M., Seidel, D., Annighöfer, P., Kreft, H., Köhler, M., Zemp, D. C., Puettmann, K., Nilus, R., Babweteera, F., Willim, K., Stiers, M., Soto, D., Boehmer, H. J., Fisichelli, N., Burnett, M., Juday, G., Stephens, S. L., & Ammer, C. (2021). Global Patterns and climatic controls of forest structural complexity. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-020-20767-z

Ehrlich, P.R. and Ehrlich, A.H. (1981) Extinction: The Causes and Consequences of the Disappearance of Species. Random House, New York, 72-98.

Frey, G. E., Chamberlain, J. L., & Schmidt, J. P. (2019). Estimating the value of forests for provisioning non-timber forest products to market: Concepts, approaches, and case studies. *Agricultural and Resource Economics Review*, *49*(1), 91–116. https://doi.org/10.1017/age.2019.17

Fridley, J. D., & Palmquist, K. A. (2024). Herbaceous vegetation, species richness in. *Encyclopedia of Biodiversity*, 711–718. https://doi.org/10.1016/b978-0-12-822562-2.00109-2

Gaines, W. L., Hessburg, P. F., Aplet, G. H., Henson, P., Prichard, S. J., Churchill, D. J., Jones, G. M., Isaak, D. J., & Vynne, C. (2022). Climate change and forest management on federal lands in the Pacific Northwest, USA: Managing for dynamic landscapes. *Forest Ecology and Management*, *504*, 119794. https://doi.org/10.1016/j.foreco.2021.119794

Glatthorn, J., Appleby, S., Balkenhol, N., Kriegel, P., Likulunga, L. E., Lu, J., Matevski, D., Polle, A., Riebl, H., Rivera Pérez, C. A., Scheu, S., Seinsche, A., Schall, P., Schuldt, A., Wingender, S., & Ammer, C. (2023). Species diversity of forest floor biota in non-native douglas-fir stands is similar to that of native stands. *Ecosphere*, *14*(7). https://doi.org/10.1002/ecs2.4609

Glime, J. M. (2024). Roles of bryophytes in forest sustainability—positive or negative? *Sustainability*, *16*(6), 2359. https://doi.org/10.3390/su16062359

Goldin, S. R., & Hutchinson, M. F. (2014). Coarse woody debris reduces the rate of moisture loss from surface soils of cleared temperate Australian Woodlands. *Soil Research*, *52*(7), 637. https://doi.org/10.1071/sr13337

Gray, A. N., Whittier, T. R., & Harmon, M. E. (2016). Carbon stocks and accumulation rates in Pacific Northwest Forests: Role of stand age, plant community, and Productivity. *Ecosphere*, *7*(1). https://doi.org/10.1002/ecs2.1224

Hajjar, R., McGinley, K., Charnley, S., Frey, G. E., Hovis, M., Cubbage, F. W., Schelhas, J., & Kornhauser, K. (2024). Characterizing community forests in the United States. *Journal of Forestry*, *122*(3), 273–284. https://doi.org/10.1093/jofore/fvad054

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, *16*(1). https://doi.org/10.1186/s42408-019-0062-8

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromack, K., & Cummins, K. W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research*, *15*, 59–234. https://doi.org/10.1016/s0065-2504(03)34002-4

Harmon, Mark E., Fasth, B., Woodall, C. W., & Sexton, J. (2013). Carbon concentration of standing and downed woody detritus: Effects of tree taxa, decay class, position, and tissue type. *Forest Ecology and Management*, *291*, 259–267. https://doi.org/10.1016/j.foreco.2012.11.046

Hekkala, A.-M., Jönsson, M., Kärvemo, S., Strengbom, J., & Sjögren, J. (2023). Habitat heterogeneity is a good predictor of boreal forest biodiversity. *Ecological Indicators*, *148*, 110069. https://doi.org/10.1016/j.ecolind.2023.110069

Hoa, H. T., Wang, C.-L., & Wang, C.-H. (2015). The effects of different substrates on the growth, yield, and nutritional composition of two oyster mushrooms (*pleurotus ostreatus* and *pleurotus cystidiosus*). *Mycobiology*, *43*(4), 423–434. https://doi.org/10.5941/myco.2015.43.4.423

Herrmann, S., & Bauhus, J. (2018). Nutrient retention and release in coarse woody debris of three important central European tree species and the use of NIRS to determine deadwood chemical properties. *Forest Ecosystems*, *5*(1). https://doi.org/10.1186/s40663-018-0140-4

Herrmann, S., Kahl, T., & Bauhus, J. (2015). Decomposition Dynamics of coarse woody debris of three important central European tree species. *Forest Ecosystems*, *2*(1). https://doi.org/10.1186/s40663-015-0052-5

Hu, Y., Li, X., Guo, A., Yue, P., Guo, X., Lv, P., Zhao, S., & Zuo, X. (2022). Species diversity is a strong predictor of ecosystem multifunctionality under altered precipitation in desert steppes. *Ecological Indicators*, *137*, 108762. https://doi.org/10.1016/j.ecolind.2022.108762

Janeczko, E., Bielinis, E., Tiarasari, U., Woźnicka, M., Kędziora, W., Przygodzki, S., & Janeczko, K. (2021). How dead wood in the forest decreases relaxation? the effects of viewing of Dead Wood in the forest environment on psychological responses of Young Adults. *Forests*, *12*(7), 871. https://doi.org/10.3390/f12070871

Juutinen, A., Kosenius, A.-K., & Ovaskainen, V. (2014). Estimating the benefits of recreation-oriented management in state-owned commercial forests in Finland: A choice experiment. *Journal of Forest Economics*, *20*(4), 396–412. https://doi.org/10.1016/j.jfe.2014.10.003

Krohs, U., & Zimmer, M. (2023). Do ecosystems have functions? *Ecology and Evolution*, *13*(9). https://doi.org/10.1002/ece3.10458

Kwak, J.-H., Chang, S. X., Naeth, M. A., & Schaaf, W. (2015). Coarse woody debris increases microbial community functional diversity but not enzyme activities in reclaimed oil sands soils. *PLOS ONE*, *10*(11). https://doi.org/10.1371/journal.pone.0143857

Laflower, D. M., Hurteau, M. D., Koch, G. W., North, M. P., & Hungate, B. A. (2016). Climate-driven changes in forest succession and the influence of management on Forest Carbon Dynamics in the puget lowlands of Washington State, USA. *Forest Ecology and Management*, *362*, 194–204. https://doi.org/10.1016/j.foreco.2015.12.015

Law, B. E., Berner, L. T., Buotte, P. C., Mildrexler, D. J., & Ripple, W. J. (2021). Strategic forest reserves can protect biodiversity in the western United States and mitigate climate change. *Communications Earth & Environment*, *2*(1). https://doi.org/10.1038/s43247-021-00326-0

Leverkus, A. B., Gustafsson, L., Lindenmayer, D. B., Castro, J., Rey Benayas, J. M., Ranius, T., & Thorn, S. (2020). Salvage logging effects on regulating ecosystem services and fuel loads. *Frontiers in Ecology and the Environment*, *18*(7), 391–400. https://doi.org/10.1002/fee.2219

Lininger, K. B., Wohl, E., Sutfin, N. A., & Rose, J. R. (2016). Floodplain downed wood volumes: A comparison across three biomes. *Earth Surface Processes and Landforms*, *42*(8), 1248–1261. https://doi.org/10.1002/esp.4072

MA. (2005) *Ecosystems and human well-being: synthesis report*. Island Press, Washington D.C., USA.

Malone, L., David, Wolf, L., Erin, Outreach, & Jean. (2023, February 23). *Keeping dead wood and creating wildlife habitat piles: Some guidance for forest owners - Northwest Natural Resource Group*. Northwest Natural Resource Group - Leaders in Ecological Forestry. https://www.nnrg.org/habitat-piles/

Mantgem, P. J., & Stephenson, N. L. (2011). Does coring contribute to tree mortality? *Canadian Journal of Forest Research*, *34*(11), 2394–2398. https://doi.org/10.1139/x04-120

McElhinny, C., Gibbons, P., Brack, C., & Bauhus, J. (2005). Forest and woodland stand structural complexity: Its definition and measurement. *Forest Ecology and Management*, *218*(1–3), 1–24. https://doi.org/10.1016/j.foreco.2005.08.034

Means, J. E., MacMillan, P. C., & Cromack Jr., K. (1992). Biomass and nutrient content of Douglas-fir logs and other detrital pools in an old-growth forest, Oregon, U.S.A. *Canadian Journal of Forest Research*, *22*(10), 1536–1546. https://doi.org/10.1139/x92-204

Nébié, E. K. I., West, C. T., & Crane, T. A. (2021). Participatory Mapping with Herders in a Climate Adaptation Research Project. Practicing anthropology, 43(1), 25–29. https://doi.org/10.17730/0888-4552.43.1.25

NOAA, US Department of Commerce. (2024). *Seattle/Tacoma, WA*. National Weather Service. https://www.weather.gov/sew/

Paillet, Y., Bergès, L., Hjältén, J., Ódor, P., Avon, C., Bernhardt-Römermann, M., Bijlsma, R.-J., De Bruyn, L., Fuhr, M., Grandin, U., Kanka, R., Lundin, L., Luque, S., Magura, T., Matesanz, S., Mészáros, I., Sebastià, M. -Teresa, Schmidt, W., Standovár, T., … Virtanen, R. (2010). Biodiversity differences between managed and unmanaged forests: Meta-analysis of species richness in Europe. Conservation Biology, 24(1), 101–112. https://doi.org/10.1111/j.1523-1739.2009.01399.x

Paletto, A., Becagli, C., & De Meo, I. (2022). Aesthetic preferences for Deadwood in Forest Landscape: A case study in Italy. *Journal of Environmental Management*, *311*, 114829. https://doi.org/10.1016/j.jenvman.2022.114829

Palmer, M., Kuegler, O., & Christensen, G. (2019). *Washington's Forest Resources, 2007–2016: 10-Year Forest Inventory and Analysis Report*. https://doi.org/10.2737/pnw-gtr-976

Parisi, F., Innangi, M., Tognetti, R., Lombardi, F., Chirici, G., & Marchetti, M. (2021). Forest stand structure and coarse woody debris determine the biodiversity of beetle communities in Mediterranean Mountain Beech forests. *Global Ecology and Conservation*, *28*. https://doi.org/10.1016/j.gecco.2021.e01637

Pescott, O. L., & Stewart, G. B. (2014). Assessing the impact of human trampling on vegetation: A systematic review and meta-analysis of experimental evidence. *PeerJ*, *2*. https://doi.org/10.7717/peerj.360

Piaszczyk, W., Lasota, J., Błońska, E., & Foremnik, K. (2022). How habitat moisture condition affects the decomposition of fine woody debris from different species. *CATENA*, *208*, 105765. https://doi.org/10.1016/j.catena.2021.105765

Pichler, V., Homolák, M., Skierucha, W., Pichlerová, M., Ramírez, D., Gregor, J., & Jaloviar, P. (2011). Variability of moisture in coarse woody debris from several ecologically important tree species of the temperate zone of Europe. *Ecohydrology*, *5*(4), 424–434. https://doi.org/10.1002/eco.235

Poe, M. R., Donatuto, J., & Satterfield, T. (2016). “sense of place”: Human Wellbeing Considerations for Ecological Restoration in Puget sound. *Coastal Management*, *44*(5), 409–426. https://doi.org/10.1080/08920753.2016.1208037

Pringle, M. J., Bray, S. G., & Carter, J. O. (2021). Modelling the disappearance of coarse woody debris, following a land clearing event. *Carbon Balance and Management*, *16*(1). https://doi.org/10.1186/s13021-021-00199-y

Progar, R., Schowalter, T., Freitag, C. et al. Respiration from coarse woody debris as affected by moisture and saprotroph functional diversity in Western Oregon. *Oecologia* 124, 426–431 (2000). https://doi.org/10.1007/PL00008868

Ribe, Robert. (2003). Aesthetic perceptions of New Forestry and the retention of green trees and down wood in timber harvests.

Riffell, S., Verschuyl, J., Miller, D., & Wigley, T. B. (2011). Biofuel harvests, coarse woody debris, and biodiversity – a meta-analysis. *Forest Ecology and Management*, *261*(4), 878–887. https://doi.org/10.1016/j.foreco.2010.12.021

Roach, W. J., Simard, S. W., Defrenne, C. E., Pickles, B. J., Lavkulich, L. M., & Ryan, T. L. (2021). Tree Diversity, site index, and carbon storage decrease with aridity in Douglas-fir forests in Western Canada. *Frontiers in Forests and Global Change*, *4*. https://doi.org/10.3389/ffgc.2021.682076

Roni, P., Beechie, T., Pess, G., & Hanson, K. (2015). Wood placement in river restoration: Fact, fiction, and future direction. *Canadian Journal of Fisheries and Aquatic Sciences*, *72*(3), 466–478. https://doi.org/10.1139/cjfas-2014-0344

Rozario, K., Oh, R. R., Marselle, M., Schröger, E., Gillerot, L., Ponette, Q., Godbold, D., Haluza, D., Kilpi, K., Müller, D., Roeber, U., Verheyen, K., Muys, B., Müller, S., Shaw, T., & Bonn, A. (2023). The more the merrier? Perceived Forest Biodiversity promotes short-term mental health and Well-being—a multicentre study. *People and Nature*, *6*(1), 180–201. https://doi.org/10.1002/pan3.10564

Rudolphi, J. (2007). *Bryophytes, lichens, and dead wood in young managed boreal forests*. Swedish University of Agricultural Sciences.

Rutledge, A., & Brandt, L. (2023). *Puget sound region: Tree species vulnerability assessment*. U.S. Department of Agriculture, Northern Forests Climate.

Sailor, D. J., Smith, M., & Hart, M. (2008). Climate change implications for wind power resources in the northwest United States. *Renewable Energy*, *33*(11), 2393–2406. https://doi.org/10.1016/j.renene.2008.01.007

Sandström, J., Bernes, C., Junninen, K., Lõhmus, A., Macdonald, E., Müller, J., & Jonsson, B. G. (2019). Impacts of dead wood manipulation on the biodiversity of temperate and boreal forests. A systematic review. *Journal of Applied Ecology*, *56*(7), 1770–1781. https://doi.org/10.1111/1365-2664.13395

Schröter, M., van der Zanden, E. H., van Oudenhoven, A. P. E., Remme, R. P., Serna-Chavez, H. M., de Groot, R. S., & Opdam, P. (2014). Ecosystem Services as a contested concept: A synthesis of critique and counter-arguments. *Conservation Letters*, *7*(6), 514–523. https://doi.org/10.1111/conl.12091

Schumacher, E. F. (1973) Small is beautiful; economics as if people mattered. Harper & Row, New York.

Sena, K. L., Flynn, J. K., Leuenberger, W., Kolka, R., & Barton, C. D. (2023). Long-term changes in coarse woody debris abundance in three Appalachian headwater streams with differing best management practices. *Frontiers in Forests and Global Change*, *6*. https://doi.org/10.3389/ffgc.2023.1242878

Shapchenkova, O. A., Loskutov, S. R., & Kukavskaya, E. A. (2023). Alteration of organic matter during wildfires in the forests of southern Siberia. *Fire*, *6*(8), 304. https://doi.org/10.3390/fire6080304

Sillett, S. C., Van Pelt, R., Carroll, A. L., Campbell-Spickler, J., Coonen, E. J., & Iberle, B. (2019). Allometric equations for Sequoia sempervirens in forests of different ages. *Forest Ecology and Management*, *433*, 349–363. https://doi.org/10.1016/j.foreco.2018.11.016

Sorenson, G. S., Sleeter, B.M., Wilson, T.S., and Acevedo, W., eds., 2012, Status and trends of land change in the Western United States—1973 to 2000: U.S. Geological Survey Professional Paper 1794–A, 324 p. (Available at https://pubs.usgs.gov/pp/1794/a/.)

Soulard, C., Walker, J., & Griffith, G. (2017). Forest harvest patterns on private lands in the Cascade Mountains, Washington, USA. *Forests, 8*(10), 383. https://doi.org/10.3390/f8100383

Spies, T. A., & Cline, S. P. (1988). *Coarse woody debris in forests and plantations of coastal Oregon*. USDA.

Stein, A., Gerstner, K., & Kreft, H. (2014). Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecology Letters*, *17*(7), 866–880. https://doi.org/10.1111/ele.12277

United Nations. (n.d.). *Goal 15 | Department of Economic and Social Affairs*. https://sdgs.un.org/goals/goal15

Thomas, S. C., Liguori, D. A., & Halpern, C. B. (2001). Corticolous bryophytes in managed Douglas-fir forests: Habitat differentiation and responses to thinning and fertilization. *Canadian Journal of Botany*, *79*(8), 886–896. https://doi.org/10.1139/cjb-79-8-886

Thorn, S., Seibold, S., Leverkus, A. B., Michler, T., Müller, J., Noss, R. F., Stork, N., Vogel, S., & Lindenmayer, D. B. (2020). The living dead: Acknowledging life after tree death to stop forest degradation. *Frontiers in Ecology and the Environment*, *18*(9), 505–512. https://doi.org/10.1002/fee.2252

Tong, R., Ji, B., Wang, G. G., Lou, C., Ma, C., Zhu, N., Yuan, W., & Wu, T. (2024). Canopy Gap impacts on soil organic carbon and nutrient dynamic: A meta-analysis. *Annals of Forest Science*, *81*(1). https://doi.org/10.1186/s13595-024-01224-z

USDA. (2022). *Partnerships for climate-smart commodities*. https://www.usda.gov/climate-solutions/climate-smart-commodities

U.S. Department of Energy. (2024). *Alternative fuels data center fuel properties comparison*. Alternative Fuels Data Center. https://afdc.energy.gov/files/u/publication/fuel_comparison_chart.pdf

Washington Department of Natural Resources, Christensen, G. A., Gray, A. N., Kuegler, O., & Siemann, D., Washington Forest Ecosystem Carbon Inventory: 2002-2016. Retrieved October 13, 2020, from https://www.dnr.wa.gov/publications/em_wa_carbon_inventory_final_111220.pdf.

Waterman-Hoey, S. (2022, December). *Ecology Publications & Forms*. Washington State Greenhouse Gas Emissions Inventory: 1990–2019. https://apps.ecology.wa.gov/publications/SummaryPages/2202054.html

Webster, C. R., & Jenkins, M. A. (2005). Coarse woody debris dynamics in the southern Appalachians as affected by topographic position and anthropogenic disturbance history.

Forest Ecology and Management, *217*(2–3), 319–330. https://doi.org/10.1016/j.foreco.2005.06.011

Wohl, E., Kramer, N., Ruiz-Villanueva, V., Scott, D. N., Comiti, F., Gurnell, A. M., Piegay, H., Lininger, K. B., Jaeger, K. L., Walters, D. M., & Fausch, K. D. (2019). The Natural Wood regime in Rivers. *BioScience*, *69*(4), 259–273. https://doi.org/10.1093/biosci/biz013

Wohl, E., Uno, H., Dunn, S. B., Kemper, J. T., Marshall, A., Means-Brous, M., Scamardo, J. E., & Triantafillou, S. P. (2023). Why wood should move in Rivers. *River Research and Applications*. https://doi.org/10.1002/rra.4114

Woodall, C. W., Monleon, V. J., Fraver, S., Russell, M. B., Hatfield, M. H., Campbell, J. L., & Domke, G. M. (2019). The downed and Dead Wood Inventory of Forests in the United States. *Scientific Data*, *6*(1). https://doi.org/10.1038/sdata.2018.303

Woods, C. L., Maleta, K., & Ortmann, K. (2021). Plant–Plant Interactions Change during succession on nurse logs in a northern temperate rainforest. *Ecology and Evolution*, *11*(14), 9631–9641. https://doi.org/10.1002/ece3.7786

Wu, L., Shi, Y., Zhang, F., Zhou, Y., Ding, Z., Lv, S., & Xu, L. (2022). Estimating carbon stocks and biomass expansion factors of urban greening trees using Terrestrial Laser Scanning. *Forests*, *13*(9), 1389. https://doi.org/10.3390/f13091389

Yamashita, S., Masuya, H., Abe, S., Masaki, T., & Okabe, K. (2015). Relationship between the decomposition process of coarse woody debris and fungal community structure as detected by high-throughput sequencing in a deciduous broad-leaved forest in Japan. *PLOS ONE*, *10*(6). https://doi.org/10.1371/journal.pone.0131510

Yip, S. Y. (2023). Positionality and reflexivity: Negotiating insider-outsider positions within and across cultures. *International Journal of Research & Method in Education*, *47*(3), 222–232. https://doi.org/10.1080/1743727x.2023.2266375

Yu, K., Smith, W. K., Trugman, A. T., Condit, R., Hubbell, S. P., Sardans, J., Peng, C., Zhu, K., Peñuelas, J., Cailleret, M., Levanic, T., Gessler, A., Schaub, M., Ferretti, M., & Anderegg, W. R. (2019). Pervasive decreases in living vegetation carbon turnover time across forest climate zones. *Proceedings of the National Academy of Sciences*, *116*(49), 24662–24667. https://doi.org/10.1073/pnas.1821387116

Yuan, J., Hou, L., Wei, X., Shang, Z., Cheng, F., & Zhang, S. (2017). Decay and nutrient dynamics of coarse woody debris in the Qinling Mountains, China. *PLOS ONE, 12*(4). https://doi.org/10.1371/journal.pone.0175203

Zhang, J., Page-Dumroese, D. S., Jurgensen, M. F., Busse, M., & Mattson, K. G. (2023). Coarse woody debris and carbon stocks in pine forests after 50 years of recovery from harvesting in northeastern California. *Forests*, *14*(3), 623. https://doi.org/10.3390/f14030623

Appendix A:

Below is a series of photos from the field sampling days including, in order, an image of the researcher using the increment borer and logging tape to sample NCF3, sampling materials on NCF8, the *wabi-sabi* ICF10, and HFF1 with fine down wood branches.

Appendix B:

Below is a sample recruitment letter for interview participants:

Hello, my name is Forrest Becker from the School for International Training (SIT) in Brattleboro, Vermont. I am pursuing my Master's degree in Climate Change and Global Sustainability. I am conducting a study on down wood ecosystem services in the Puget Sound region. Northwest Natural Resource Group (NNRG) is recruiting landowners and management experts for interviews on my behalf. If you volunteer to participate, your participation will take up to forty-five minutes. There is no compensation for participation in the study.

If you would like to participate or ask any questions about this study, please email me at forrest.becker@mail.sit.edu or contact my cell phone number at +1 (973) 222-0971.

Thank you for your consideration,

Forrest Becker

Appendix C:

Below is an interview guide for forest management experts.

- Which services, if any, do down wood systems provide in the forests you manage?
- *If any are listed:* What can be done to ensure those services continue?
- How would you expect changes to management and climate regimes might impact down wood?
- How do you feel about down wood in these contexts (referencing photographs from survey sites)?

Below is an interview guide for forest stakeholders.

- How do downed trees impact activities on your land?
- Do you have any experiences interacting with downed trees (recreation, cultural practice, memories) on your land?
- How do you feel about downed trees in these two contexts (photographs from survey sites)?
- What would you like to know about downed trees?

Appendix D:

Below is a table of selected metadata taken at each sample site transcribed from field notes, highlighting dominant vegetation type:

Plot	Date	Time	Elevation (m)	State	Slope (°)	Species Richness	Notes
NCF1	5/24/2024	8:48 AM	996.4	Sound	6	13	Logged Douglas fir, straight cuts on either side, starting side sinking into root mat, still sound, surrounded by elders and hemlock, mosses, ant burrow around Weight 3, 66.154% canopy, no precipitation, no wind
NCF2	5/24/2024	10:06 AM	990.7	Intermediate	2	18	No visible signs of logging, massively decaying into earth, some areas of stronger integrity, surrounded by true firs and hemlock, no dominant vegetation, mosses and needles, near a steeper cliff, 56.996% canopy, no precipitation, no wind, hardwood sticks across beginning
NCF3	5/24/2024	10:50 AM	985.8	Sound	49	8	Laying on intense slope, below seasonal trickle, mostly sheltered by a stump, no evidence of logging, more decay at base, true firs, hemlocks, and huckleberries, 64.837% canopy, mosses and lichens, no precipitation, no wind
NCF4	5/24/2024	11:36 AM	989	Intermediate	18	12	On slope, noble fir canopy = 67.507%, heavy decay on sides, mosses, needles, little plants, no precipitation, <10% wind

NCF5	5/24/2024	12:19 PM	989.2	Intermediate	3	21	No evidence of logging, Douglas fir + true fir, 77.680% canopy, mosses, plants, insects, devil's club, no wind, 10% precipitation
NCF6	5/24/2024	1:08 PM	995.3	Intermediate	4	5	Old logged fir, cut on both sides, strong erosion at center, situated in a thicket, mosses and vine maple, 70.267% canopy from nearby Douglas fir, <10% precipitation, <10% wind
NCF7	5/24/2024	1:51 PM	993.6	Sound	11	12	Stumpy, no logging evidence, on streambank, 90.645% cover from aspens (?), ferns, mosses, huckleberries, 30% rain, no wind, rocky substrate
NCF8	5/24/2024	2:34 PM	998.3	Intermediate	3	11	Mostly fallen into creek, no evidence of logging, 44.868% cover from noble fir, mosses and plants, laying in debris, 30% rain, 10% wind, bird evidence
NCF9	5/24/2024	3:22 PM	986.9	Intermediate	15	9	Thin, no evidence of logging, on cusp of a steep slope, supported by a stump, canopy of Douglas fir and noble fir, 64.760% canopy, 30% rain, no wind, mosses
NCF10	5/24/2024	3:59 PM	980	Rotted	16	12	Plump, rotting log, no evidence of logging, 68.482% canopy of Douglas fir and hemlock, mosses and plants, cusp of a steep slope, 30% rain, no wind
ICF1	6/4/2024	9:23 AM	111.1	Rotted	5	5	A tiny remaining hunk of Douglas fir, mostly rotted away into mosses, 63.587% canopy of Douglas fir, ferns, thorns, and salal, 0%

							precipitation, light wind, earthworm
ICF2	6/4/2024	10:08 AM	111.3	Rotted	2	6	Very rotty log on an old game trail, heavily reclaimed by trailing blackberry, 23.096% canopy, broadleaf maple and blackberry, 0% wind, 0% precipitation
ICF3	6/4/2024	10:59 AM	109.2	Rotted	13	6	Rotty deadfall, covered in moss and other fallen wood, very loose consistency, 77.225% canopy of hazelnut, alder, and ferns, flat millipede, mushrooms, 0% wind, 0% precipitation
ICF4	6/4/2024	11:39 AM	101.1	Sound	9	6	Douglas fir branch, no dominant vegetation, somewhat fresh, 54.371% canopy of Douglas fir and alder, some little insects, 0% wind, 0% precipitation
ICF5	6/4/2024	12:16 PM	107.6	Sound	5	5	Logged Douglas fir with clean cuts on both sides, coated in moss, one banana slug, 71.038% canopy of hemlock, Spanish mosses
ICF6	6/4/2024	1:36 PM	90.9	Rotted	13	12	Extremely rotty, part of the "Forestry Loop," on slope overlooking a stream, covered in mosses and needles with growths of salal and low oregon grape, 81.104% canopy of hazelnut and Douglas fir, 10% wind, 0% precipitation
ICF7	6/4/2024	2:21 PM	96.4	Rotted	1	4	Old hunk of Douglas fir, reclaimed by mosses and trailing blackberries, 72.317% Douglas fir canopy, 0% precipitation,

							10% wind
ICF8	6/4/2024	2:55 PM	99.8	Sound	9	3	Douglas fir branch in fern grove, 68.025% canopy of hazelnut, Douglas fir, and ferns, little mites, 10% wind, 0% precipitation, no dominant vegetation
ICF9	6/4/2024	3:28 PM	102	Intermediate	0	10	A long, intermediate Douglas fir, mostly covered in mosses and trailing blackberries, under a canopy of 79.769% Douglas fir, 0% wind, 0% precipitation
ICF10	6/4/2024	4:03 PM	107.5	Intermediate	7	3	Dry, barkless Douglas fir, in a sunny clearing, no dominant vegetation, little cover from moss, mushrooms, and blackberries, 27.171% canopy from Douglas firs, 10% wind, 0% precipitation
HFF1	6/11/2024	8:27 AM	124	Sound	4	7	Large, still branched, Douglas fir, pre-commercially thinned on one side, laying in a fern grove, mosses, 76.290% Douglas fir canopy, small evidence of insect burrowing, 0% wind, 0% precipitation
HFF2	6/11/2024	9:03 AM	124	Intermediate	14	10	Thin log, bent just past its midpoint around a large fern, 64.467% Douglas fir canopy, mosses, 0% wind, 0% precipitation
HFF3	6/11/2024	9:35 AM	73.2	Intermediate	27	6	A short, twice cut Douglas fir log, 84.953% canopy of fir and rose, mosses, 0% wind, 0% rain, slight slope

HFF4	6/11/2024	10:04 AM	73.2	Intermediate	14	6	Thin, mossy log, 66.959% canopy of firs and elders, among blackberry thicket, 0% wind, 0% precipitation
HFF5	6/11/2024	10:32 AM	75	Intermediate	0	6	Straight log, situated across a slope, half covered by dead ferns, banana slug, 81.168% canopy from alders, elders, and ferns, 0% wind, 0% precipitation
HFF6	6/11/2024	11:15 AM	124	Sound	4	5	A cut Douglas fir on both sides, light moss, mixed surrounding underbrush, 52.691% canopy of firs, 10% wind, 0% rain
HFF7	6/11/2024	11:49 AM	124	Sound	7	5	Short, twice-cut Douglas fir with a third, diagonal, intermediate cut and a few branches, somewhat mossy, 68.924% canopy of firs and alder, 20% wind, 0% precipitation
HFF8	6/11/2024	12:29 PM	74.8	Sound	11	4	Recently twice-cut, short log along maintained trail, some moss, 69.764% canopy of alder and fir, 30% wind, 0% precipitation
HFF9	6/11/2024	1:01 PM	74.8	Intermediate	8	7	A long Douglas fir in an area of low buttercups and blackberries, some moss, 72.912% canopy of bigleaf maple and alder, 30% wind, 0% precipitation
HFF10	6/11/2024	1:29 PM	74.8	Rotted	2	11	Old and rotty Douglas fir, in a thicket of elder and vine maple, trailing blackberry, flowers and lichens, banana slug, 74.928% canopy from alder and a fir stump, 30% wind, 0% precipitation