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ORIGINAL ARTICLE

Mapping the Distribution and Conservation Status of Mature and Old Growth Forests Across Coastal Alaska and British Columbia

James E. Lamping,[1]* Melissa S. Lucash,[1] David M. Bell,[2] Daniel R. Irvine,[2] and Matthew J. Gregory[3]

[1]*Department of Geography, University of Oregon, Eugene, Oregon 97403, USA;* [2]*Pacific Northwest Research Station, USDA Forest Service, Corvallis, Oregon 97331, USA;* [3]*Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon 97331, USA*

Abstract

Old growth forests in coastal Alaska and British Columbia represent some of the most expansive temperate rainforests on Earth, supporting high biodiversity, substantial carbon stocks, and the cultural heritage of Indigenous communities. Despite their importance, spatially consistent information on the distribution of old growth and mature forests in this region remains limited. We addressed this gap by integrating data across two national forest inventory programs with remotely sensed predictors. Forest inventory plots were classified by forest type and successional status (old growth, mature, or other) and linked to Landsat imagery, disturbance history, climate variables, and topographic metrics. Using this data, forest type and successional status were spatially predicted at 30-m resolution using Gradient Nearest Neighbor imputation. Across the ~ 30 million ha study region, mountain and western hemlock were the most widespread forest types. We identified 1.2 million ha of old growth forest and 2.3 million ha of mature forests, representing ~ 12% of the total land area. Alaska yellow cedar and white spruce exhibited the highest proportions of mature and old growth forests (43% and 46%, respectively), while widespread species such as Sitka spruce had relatively low percentages (4.1%). More than 40% of mature and old growth forests occurred within Inventoried Roadless Areas (IRAs) and Old Growth Management Areas (OGMAs), which lack permanent legislative protection. OGMAs contained the highest aboveground C densities, while IRAs had the greatest total aboveground carbon. These findings highlight the vulnerability of mature and old growth forests to policy or management changes that could influence their long-term persistence at a regional scale.

Key words: Alaska; Biomass mapping; British Columbia; Forest conservation planning; Forest inventory data; Forest structure classification; Gradient Nearest Neighbor; Mature forests; Old growth forests; Protected areas.

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Corresponding author; e-mail: jlamping@uoregon.edu

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Highlights

- Mapped forest type and successional stages across 30 million hectares.
- Found 1.2 million hectares of old growth and 2.3 million hectares of mature forests.
- A quarter of all MOG forests have only administrative protection.

Introduction

Mature and old growth forests are vital to the ecological integrity, economic value, and cultural richness of many forested regions around the world. This is especially true in the temperate rainforests of North America, where ecologically their complex canopy layers, decaying wood, and varied microhabitats support a diverse range of plant and wildlife species, fostering unique ecosystems that promote stability and resiliency (Franklin 1981; Spies and Franklin 1996; Spies 2004). Culturally, these forests are deeply intertwined with the cultural identities, traditions, and histories of Indigenous communities, providing essential resources for food, building materials, and medicine (Turner and Hebda 1990; Crone and Mehrkens 2013; Gilhen-Baker and others 2022). Economically, these forests significantly contribute to local and global economies through timber harvesting, providing valuable raw materials for industries such as construction, pulp and paper production, and manufacturing, while supporting employment and economic growth in forest-dependent communities (Harris and Farr 1974; Veblen and Alaback 1996). More recently, however, these forests have gained increasing economic importance through carbon markets, reflecting their critical role in storing vast amounts of carbon both above and below ground to offset greenhouse gas emissions (Harmon and others 1990; Luyssaert and others 2008; Williams and Powers 2019; Lamping and others 2025).

Conservation efforts for old growth and mature forests have evolved over the past two centuries in response to shifting societal values, scientific insights, and environmental pressures. In North America, early landmark actions included the establishment of the first national parks, such as Yellowstone in 1872 and Banff in 1885, motivated by preserving outstanding natural landscapes and their ecological integrity. However, policies specifically protecting old growth forests were uncommon until the mid-to-late twentieth century, as public awareness of ecosystem science grew alongside the emergence of environmental movements (Beissinger and others 2019).

Conservation in the Temperate Rainforest

The temperate rainforests of the Pacific Northwest coast of North America, stretching from northern California through coastal British Columbia to southeast Alaska, have faced intense pressures from timber harvest and resource extraction since the mid-nineteenth century. Among the most carbon-rich forests in the world (Keith and others 2009; Buma and others 2016), their ecological, economic, and cultural importance has more recently fostered innovative landscape-scale conservation strategies, collaborative land-use agreements, and policies aimed specifically at protecting and enhancing mature and old growth characteristics in the forests that remain.

In the southern regions of the temperate rainforest, old growth conservation was catalyzed by concern over declining populations of old growth-dependent species, most notably the northern spotted owl, which triggered a series of legal and policy shifts in the late twentieth century. The Northwest Forest Plan (NWFP), implemented in 1994, was a landmark federal policy in the United States that reoriented management across 10 million hectares of federal land in Washington, Oregon, and northern California. It introduced long-term protections for old growth stands through Late-Successional Reserves and prioritized biodiversity, watershed health, and habitat connectivity in these areas, while limiting continued timber harvest to relatively younger stands (Spies and others 2018; Davis and others 2022). The plan marked a significant departure from stand-level management planning by using an interdisciplinary, landscape-level approach. As such, it's considered one of the first region-wide forest plans to explicitly consider cumulative impacts across ecosystems, ownership boundaries, and management jurisdictions.

In British Columbia, growing awareness of old growth forest loss, particularly highlighted during the Clayoquot Sound blockades of the 1990s, a series of high-profile protests opposing old growth logging on Vancouver Island, helped drive significant shifts in provincial forest policy (Clayoquot Sound Scientific Panel 1994; Parai and Esakin 2003). The establishment of the Great Bear Rainforest in 2016, for instance, culminated in the protection of approximately 6.4 million hectares of coastal temperate rainforest under an ecosystem-based management framework (Gorley and Merkel 2020; Government of Canada 2021). The Great Bear Rainforest agreements balanced conservation and economic development by protecting 85% of the region's forest ecosystems and prioritizing old growth conservation while supporting local economies through sustainable resource extraction and stewardship employment (Gorley and Merkel 2020; Dhari 2023). Today, these landmark agreements serve as global benchmarks for collaborative land-use planning, combining ecosystem-based management and Indigenous co-governance. Additionally, the province-wide establishment of Old Growth Management Areas (OGMAs) has sought to conserve representative ecosystems by explicitly limiting harvest in designated mature and old growth forests. Following a 2020 Old Growth Strategic Review, the British Columbia provincial government has deferred harvest on nearly 2.44 million hectares of old growth forests identified as at-risk (British Columbia 2024). Such deferrals provide temporary protection, allowing time for updated ecological inventories and collaborative, Indigenous-informed forest management plans to be developed.

In southeast Alaska, the Tongass National Forest has been central to discussions surrounding old growth forest conservation for decades. Following intensive timber harvesting during the mid-to-late twentieth century (Brackley and others 2009), conservation measures began to gain momentum through legislation such as the Alaska National Interest Lands Conservation Act (ANILCA) of 1980 (United States of America 1980), which significantly expanded wilderness designations and limited harvest in parts of the Tongass (USDA Forest Service 2010). Later, the Tongass Timber Reform Act of 1990 ended long-term timber contracts and reduced the allowable timber harvest, emphasizing habitat conservation and setting the stage for greater ecological protections (United States of America 1990). Since 2010, the U.S. Forest Service Tongass Forest Management Plan has focused on increasing the harvest of younger second-growth stands while reducing reliance on old growth harvest to support local timber economies. More recently, conservation efforts have led to the designation of Inventoried Roadless Areas (IRAs), limiting road constriction and timber harvest within ecologically intact portions of the forest. While the Roadless Rule remains a key mechanism for conservationists interested in protecting old growth forests in the Tongass, the administration of the Roadless Rule is subject to executive action; and thus, old growth forests within IRAs do not have the same legislative protections as other areas in the region. Considering the range of conservation strategies in place across the study area, effective regional- and landscape-level management plans depend heavily on clear and consistent definitions of what constitutes old growth and mature forests.

Complexities in Definitions

Defining old growth in the temperate rainforest presents significant challenges due to the complexity and variability of forest ecosystems in the region as well as relatively sparse observational data (Gray and others 2023). Old growth forests are characterized by a combination of ecological, structural, and biological features, often characterized by large, mature trees, diverse species composition, and complex canopy structures (Franklin 1981; Alaback and Juday 1989; Spies and Franklin 1996; MacKinnon 2003; Spies and others 2018). However, the specific criteria used to define old growth can vary widely among scientists, land managers, and stakeholders, leading to inconsistencies in classification and management strategies. Varying criteria for stand age, tree size, species diversity, and disturbance history all influence various designations of old growth status. Additionally, the cultural value and historical significance of various forest attributes within these ecosystems varies across communities, further complicating efforts at a clear and consistent definition (Moyer and others 2008; Owen and others 2009; Crone and Mehrkens 2013).

Most definitions of old growth emphasize productive stands characterized by large, mature trees capable of attaining substantial height and diameter due to favorable soil conditions, climate, and nutrient availability (Franklin 1981; Spies 2004; Hilbert and Wiensczyk 2007). Such productive old growth stands are often prioritized in conservation frameworks because of their disproportionately large ecological and economic value, supporting diverse wildlife habitats, carbon storage potential, historical significance, and timber resources (Luyssaert and others 2008; Keith and others 2009). As a result, achieving consensus on old growth definitions and management approaches requires careful consideration of ecological principles and the diverse perspectives of multiple stakeholders.

In response to these challenges, the U.S. federal government issued Executive Order 14072 in 2022 (United States of America 2022), which was part of a broader policy to strengthen the nation's forests and advance climate-smart forest management that directed the Secretaries of Agriculture and the Interior to define, identify, and inventory old growth and mature forests on federal lands as a foundational step toward developing coordinated conservation and climate adaptation strategies. This effort resulted in the publication of old growth and mature definitions for each dominant forest type within the ten U.S. Forest Service management regions to standardize how these forests could be identified and managed across various jurisdictions (USDA Forest Service 2023). In the coastal Pacific Northwest, these standardized definitions emphasize productive stands thereby prioritizing forests that support large, ecologically significant trees and higher biomass density.

Despite the ecological, economic, and cultural significance of the Pacific coastal temperate rainforests of North America, there remains limited understanding of the current spatial distribution of mature and old growth (MOG) forests within this transboundary landscape (Pelz and others 2023; Price and others 2023, 2023). In particular, it is unclear which forest types support higher or lower frequencies of mature and old growth forests. Additionally, the extent to which these mature and old growth forests fall within protected areas has not been well quantified. This information is critical for informing forest policy and land-use decisions, including prioritization of conservation areas, evaluation of the permanence and vulnerability of existing protections, and development of climate adaptation strategies that account for forest structure, species composition, and carbon storage potential.

This study builds upon previously published Gradient Nearest Neighbor (GNN) mapping of forest structure and composition across coastal Alaska and British Columbia (Lamping and others 2025). That work used harmonized forest inventory data and satellite-derived environmental predictors to produce spatially continuous (30-m resolution) predictions of forest structural attributes (e.g., aboveground biomass, stand age, basal area, and snag density) and species-specific biomass. In this study, we used the previously developed inventory data and classified it by dominant species and successional status (mature, old growth, or other) based on U.S. Forest Service definitions. Using similar environmental predictors as Lamping and others (2025), we applied a Gradient Nearest Neighbor (GNN) imputation framework ($k = 5$, majority vote) to spatially map these categorical attributes of dominant species and successional status across the landscape. By quantifying where mature and old growth forests occur, which forest types most frequently support them, and how they intersect with protected and administratively designated lands, this analysis provides a region-wide basis for evaluating the effectiveness of current conservation strategies and identifying areas where policy changes could substantially influence the future persistence of mature and old growth forests.

Methods

Study Area

The study area encompasses nearly 29.9 million hectares along coastal British Columbia northward through Southeast Alaska to Kodiak Island (Figure 1), spanning substantial climatic, physiographic, and vegetative gradients (48°N to 61°N latitude and 121°W to 154°W longitude). Characterized by a maritime climate with mild temperatures, high humidity, and substantial annual precipitation, these forests support some of the highest biomass densities globally (Buma and others 2016; McNicol and others 2019). Winters are mild (0–10 °C) with increasing snowfall toward higher latitudes and elevations, while summers remain cool (15–25 °C) with persistent fog (Orians and Schoen 2013). The area was subdivided into five modeling regions reflecting climatic variations, administrative boundaries, and species composition (Figure 1). The western Kenai Peninsula represents a transitional zone into boreal forests, marked by cooler winters, warmer summers, and reduced precipitation compared to the maritime regions (Nowacki and others 2003). The remaining temperate coastal rainforest was segmented into Southcentral and Southeast Alaskan regions, and northern and southern coastal British Columbia regions separated by the northern range limit of Douglas-fir (Hermann and Lavender 1990).

Forest Inventory Data

To evaluate the spatial distribution and dominant species of mature and old growth forests, forest inventory data were sourced from the Forest Inventory and Analysis (FIA) program (Gray and others 2012) in the United States and the Forest Analysis and Inventory Branch (FAIB) in British Columbia (Bourgeois and others 2018). Plot measurements in FIA and FAIB were validated for consistency and corrected for duplicates (detailed methods in Lamping and others 2025). Plots were restricted to the most recent measurement, limited to fixed-radius designs to maintain consistency

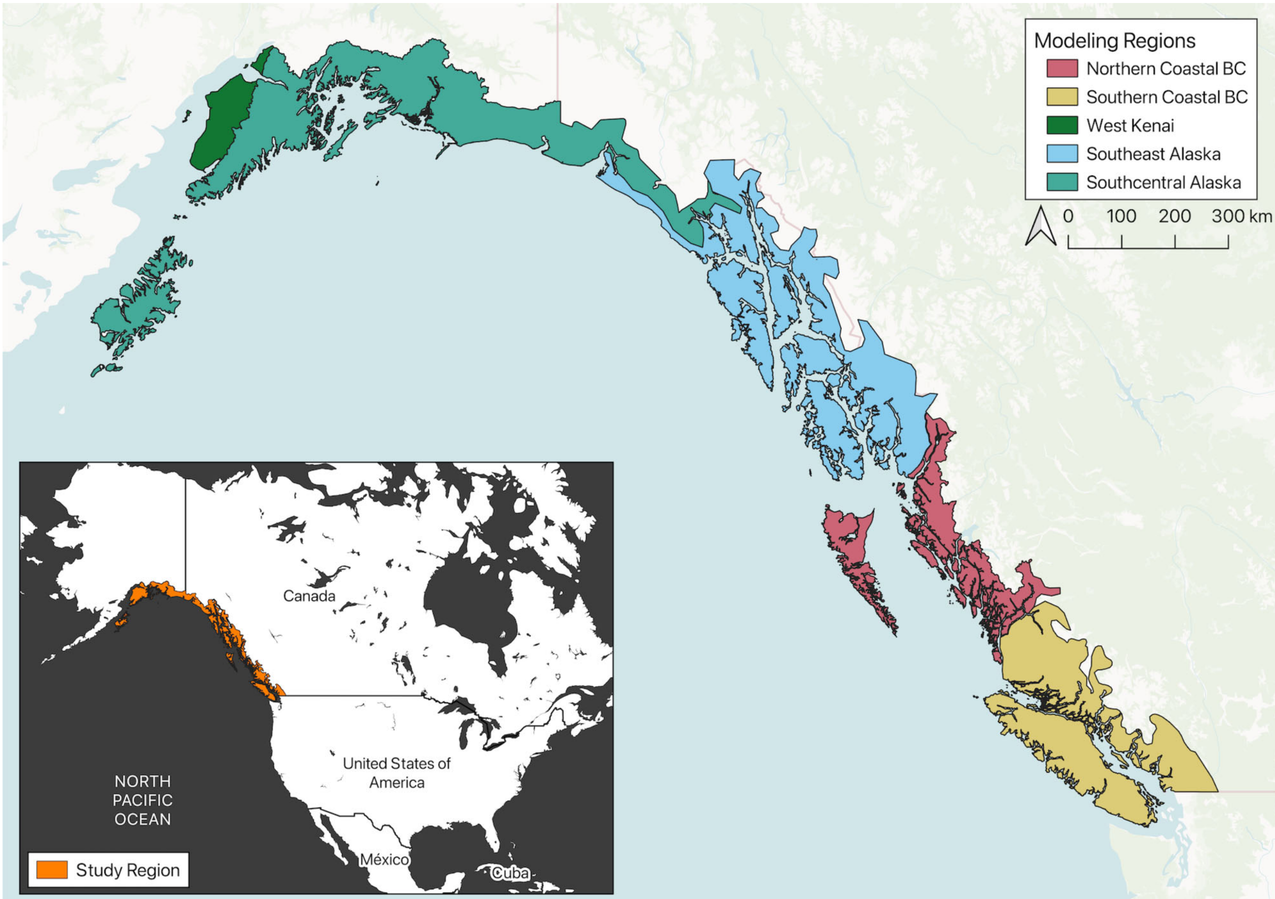

Figure 1. GNN modeling region of the temperate rainforests of North America separated into five sub-modeling regions.

between inventory systems, and filtered to include only trees ≥ 12.7 cm diameter at breast height. For the FIA data, internally accessed plot coordinates with precise locations were used rather than the publicly available, spatially offset plot locations, enabling accurate spatial correspondence between plot observations and spatial predictor variables. To create estimates of stand age, individual tree ages were calculated using regionally developed site index equations (Hegyi 1981). This process ensured robust integration of datasets across the political and ecological gradients of the study area.

Dominant Forest Type

Existing old growth forest definitions used in this study rely on information about the dominant tree species in order to apply the correct definition to any given forest area. All observations in the plot inventory were filtered for only living trees, and diameter values were converted to basal area (Avery and Burkhart 1983). For each plot, the species with the maximum basal area was calculated and assigned (Table A1).

Successional Classification

To classify forests as either old growth, mature, or other, we utilized the dominant forest type classification described above to determine the seral status of each plot in the observational data. The definitions used in this analysis came from the recent publication of nationwide definitions of old growth and mature forests by the U.S. Forest Service (USFS) in the United States. In this report, the USFS Alaska Region adopted old growth forest criteria outlined by Boughton and others (1992a, 1992b) and translated these criteria into measurable attributes using available data from FIA plots. Plots were considered old growth if they met specific thresholds of tree density and stand age (Table 1).

These definitions were used in this analysis based on the calculated plot characteristics of stand age and density of dead standing trees. To determine if a plot matched the definition for mature forests, the diameter diversity index (DDI), basal area of standing dead snags (BA dead), and standard deviation of tree height (SD HT) were also calcu-

Table 1. Definitions for Old Growth and Mature Classification Based on Dominant Species Forest Type (USDA Forest Service 2023) with Metrics Including Diameter Diversity Index (DDI), Basal Area of Standing Dead Snags (BA Dead), and Standard Deviation of Tree Height (SD HT) (Grayed Cells Indicate Attributes that Were not Used in Determining old growth or Mature Status Because No Species-Specific Criteria Were Defined for those Variables)

Species	Old growth		Mature		
	Stand age	TPH dead	DDI	BA dead	SD HT
Abies amabilis	170	4	21.3	4.5	
Abies grandis	170	4	40.1		14.3
Abies lasiocarpa	170	4	27.8		12.5
Chamaecyparis nootkatensis	150	3		14.2	6.9
Picea glauca	150	22		1.6	6.4
Picea mariana	200	10		1.6	2.5
Picea sitchensis	160	1	42.8		12.1
Pinus albicaulis	170	4	21.3	4.5	
Pinus contorta	170	2			
Pinus monticola	170	4	21.3	4.5	
Pseudotsuga menziesii	150	4	32.6		12.9
Thuja plicata	170	12	63.8	4.2	17.3
Tsuga heterophylla	150	2	21.3	4.5	
Tsuga mertensiana	160	2		1.6	10.2
Acer macrophyllum	80	6			
Alnus rubra	80	6			
Betula papyrifera	80	6			
Populus tremuloides	80	6			
Populus trichocarpa	80	6			

lated. Stands were classified as mature forests if they met the criteria for maturity but did not meet the old growth criteria for their respective dominant forest type. For certain species, classification as mature did not require meeting all three criteria, whereas other species lacked defined maturity criteria altogether. In cases where no maturity criteria existed for a species, plots were not assigned a mature forest classification.

Gradient Nearest Neighbor Imputation

A Gradient Nearest Neighbor (GNN) imputation method was used to classify forest structure across the landscape within the five different modeling regions. The GNN approach combines canonical correspondence analysis (CCA) with nearest neighbor imputation to map forest attributes (Ohmann and Gregory 2002; Ohmann and others 2011). CCA captures relationships between plot data and environmental gradients by ordinating plot attributes directly against measured predictors (Ter Braak 1986). Each 30-m pixel received an imputed value based on the mean of the five nearest neighbor plots ($k = 5$), determined by minimizing weighted Euclidean distances within a multivariate gradient space defined by plot and environmental data. This method is well-suited for vegetation modeling due to its ability to handle nonlinear responses and datasets with missing values (McCune and others 2002) and is a common method for multivariate forest attribute mapping using the FIA program of the U.S. Forest Service (Ohmann and Gregory 2002; Davis and others 2022; Bell and others 2023). To enhance model stability and regional representation, modeling regions incorporated plot data from adjacent areas when local sample sizes were limited. Specifically, modeling utilized 693 plots for the western Kenai region, 1831 for Southcentral Alaska, 2066 for

Southeast Alaska, and 2053 each for the northern and southern regions of coastal British Columbia.

To predict spatial patterns of dominant forest type and mature and old growth forest status across the study region, we related forest inventory observations to a suite of remotely sensed, climatic, topographic, and disturbance-related explanatory variables. Explanatory variables included Landsat 8 satellite imagery, topographic features, climate data, and disturbance history (Table A2). Landsat reflectance data were processed into a cloud-free, terrain-corrected composite using Google Earth Engine (Gorelick and others 2017; Hurni and others 2017), prioritizing high-quality pixels from 2018–2021. In addition to raw spectral bands, indices such as NDVI and Tasseled Cap transformations (brightness, greenness, and wetness) were calculated as additional explanatory variables (Crist and Cicone 1984). Temporal disturbance data from 1985 to 2021 were derived from the LandTrendr algorithm (Kennedy and others 2010, 2018) and combined with harvest boundary data (USDA 2022; Forest Analysis and Inventory Branch 2023) to create an accurate time since disturbance layer. Climate data were sourced from CHELSA v2.1 (Karger and others 2017), while topographic data such as elevation and slope were derived from the ALOS digital elevation model (JAXA EORC 2024). For each 30-m pixel, dominant forest type and successional status (old growth, mature, or other) were assigned using a majority vote (mode) of the five nearest neighbor plots in multivariate gradient space, resulting in spatially continuous categorical maps across the landscape.

Validation

To validate our classification of dominant overstory species, old growth, and mature forest status, we constructed confusion matrices to compare the observed field classifications against predicted map classifications for both the successional stage (old growth, mature, or other) and dominant species categories. Overall classification accuracy scores were calculated to quantify the reliability and agreement of our classification results.

To evaluate how well landscape conditions were represented by the forest inventory data used in the GNN imputation, we examined the mean nearest neighbor distance in environmental gradient space. Following Ohmann and Gregory (2002) and Lamping and others (2025), we calculated the mean Euclidean distance between each 30-m pixel and its five nearest neighbor plots used in the imputation. This metric reflects the similarity between the environmental conditions of a given pixel and those represented by the training dataset. Although this measure does not represent statistical uncertainty, higher distances indicate areas where modeled conditions are less well represented by available plot data and where predictions should therefore be interpreted with greater caution.

Management and Conservation Extents

To better quantify the amount of productive mature and old growth forest located within different land-use allocations, we utilized existing GIS layers that delineated areas of different levels of statutory protections (Figure 2). The most recently released datasets of protected areas from Canada and the U.S., the Canadian Protected and Conserved Area Database for British Columbia (Canada 2021) and the USGS Protected Area Database for Alaska (Gergely and McKerrow 2013), contained maps of the IRAs and the OGMAs. Both datasets were reclassified into shared categories based on the type of land-use restriction (i.e., wilderness area, national parks and monuments, wildlife habitat reserve, indigenously managed, IRA, and OGMA) and then rasterized to the same extent and resolution as the GNN predictions (Figure 2).

Protected areas within our study region were grouped into classes reflecting varying levels of administrative protection and permanence. National parks, monuments, and wilderness areas generally offer the highest levels of legal protection, typically requiring legislative or similarly robust processes to modify or rescind these protections. Conversely, Inventoried Roadless Areas (IRAs), wildlife habitat refuges, ecological reserves, and Old Growth Management Areas (OGMAs) provide critical protections but rely primarily on administrative designations. These administrative protections are more susceptible to modification or repeal through policy decisions or governmental changes, making forests within these categories potentially vulnerable to future harvesting and development.

Results

Classification Accuracy

The accuracy assessment showed that our classification of dominant forest type achieved an overall accuracy of 67.1% across all species categories (Table A3). Misclassification was most common among ecologically similar conifer species that frequently co-occur in mixed stands (e.g., western hemlock, mountain hemlock, Sitka spruce), while

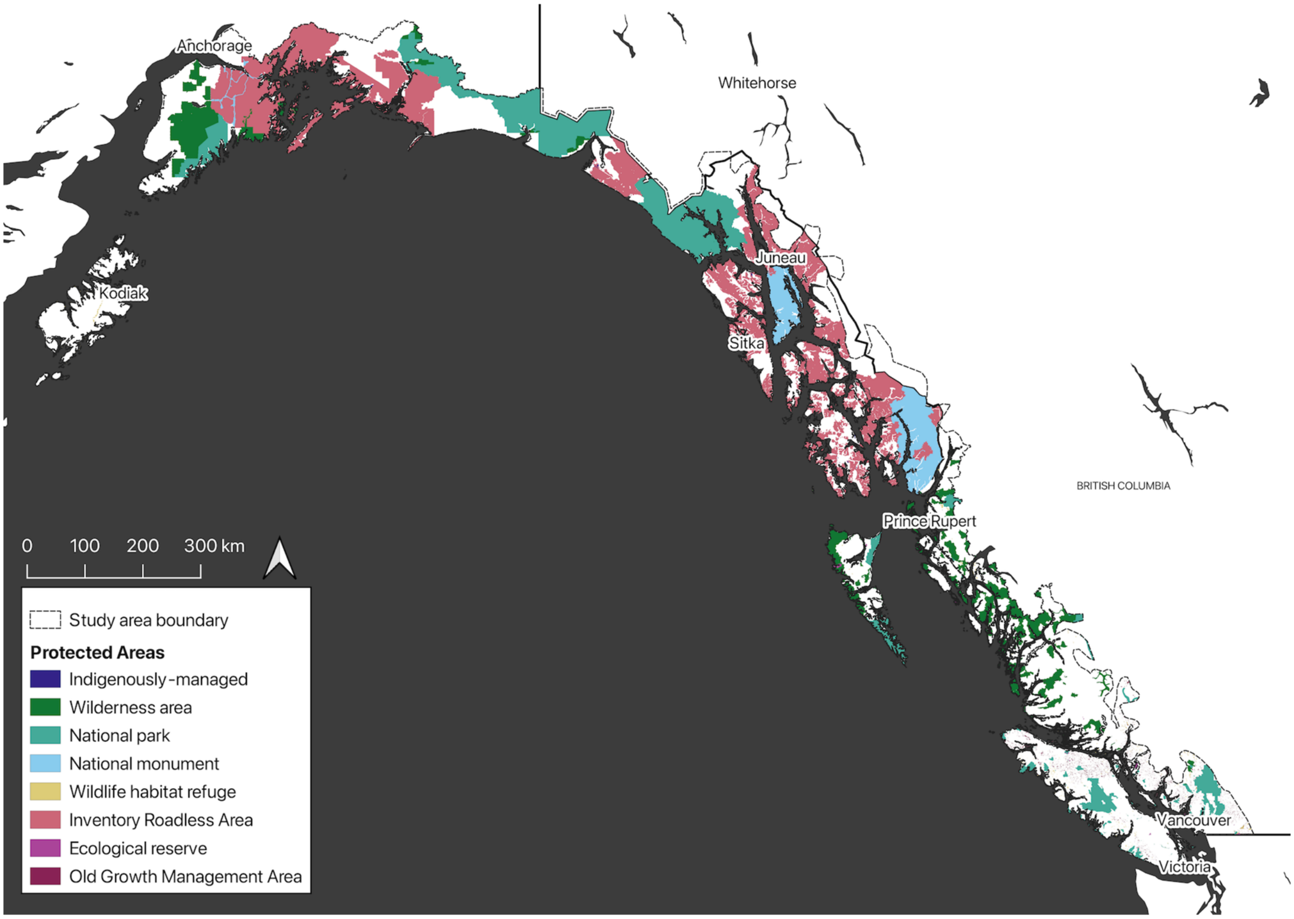

Figure 2. Protected areas of the northern temperate rainforests in Alaska and coastal British Columbia.

less common or more geographically restricted forest types showed higher agreement with observed plot data. The successional stage classification had an overall accuracy of 78.9% (Table A4). The accuracy ranged between 77.4% and 80.5% at a 95% confidence interval, indicating a moderate agreement between observed and classified successional stages. Misclassification primarily occurred between mature and old growth classes, likely reflecting overlap in structural characteristics near classification thresholds, while forests classified as ''other'' showed substantially higher agreement with observed plot data.

Spatial patterns of mean nearest neighbor distance revealed clear geographic structure in the representation of environmental conditions across the study area (Figure 3). Lower distances were observed in low-elevation, productive forests of southeast Alaska and portions of the boreal transition zone on the western Kenai Peninsula, where forest inventory plot density was highest. Higher distances occurred primarily at higher elevations and in remote wilderness areas, reflecting combinations of climatic and topographic conditions that were less frequently sampled by inventory plots. These patterns suggest that predictions in well-sampled coastal lowlands are strongly supported by field data, whereas classifications in high-elevation and sparsely inventoried regions should be interpreted more cautiously.

Dominant Overstory Species Distribution

Dominant overstory species patterns matched regional descriptions and observational datasets for expected distributions for these species on the landscape. The primary tree species found throughout this region commonly co-occur in various mixed species assemblages. Forest typing based on dominant basal area by species revealed that an area over 5 million hectares (25% of the region) is dominated by *Tsuga heterophylla* (Table 2, Figure 4). *Tsuga heterophylla* stands tended to be found in low-elevation areas nearest to the coastline. This coastal area was also interspersed with forests dominated by *Picea sitchensis* in the north,

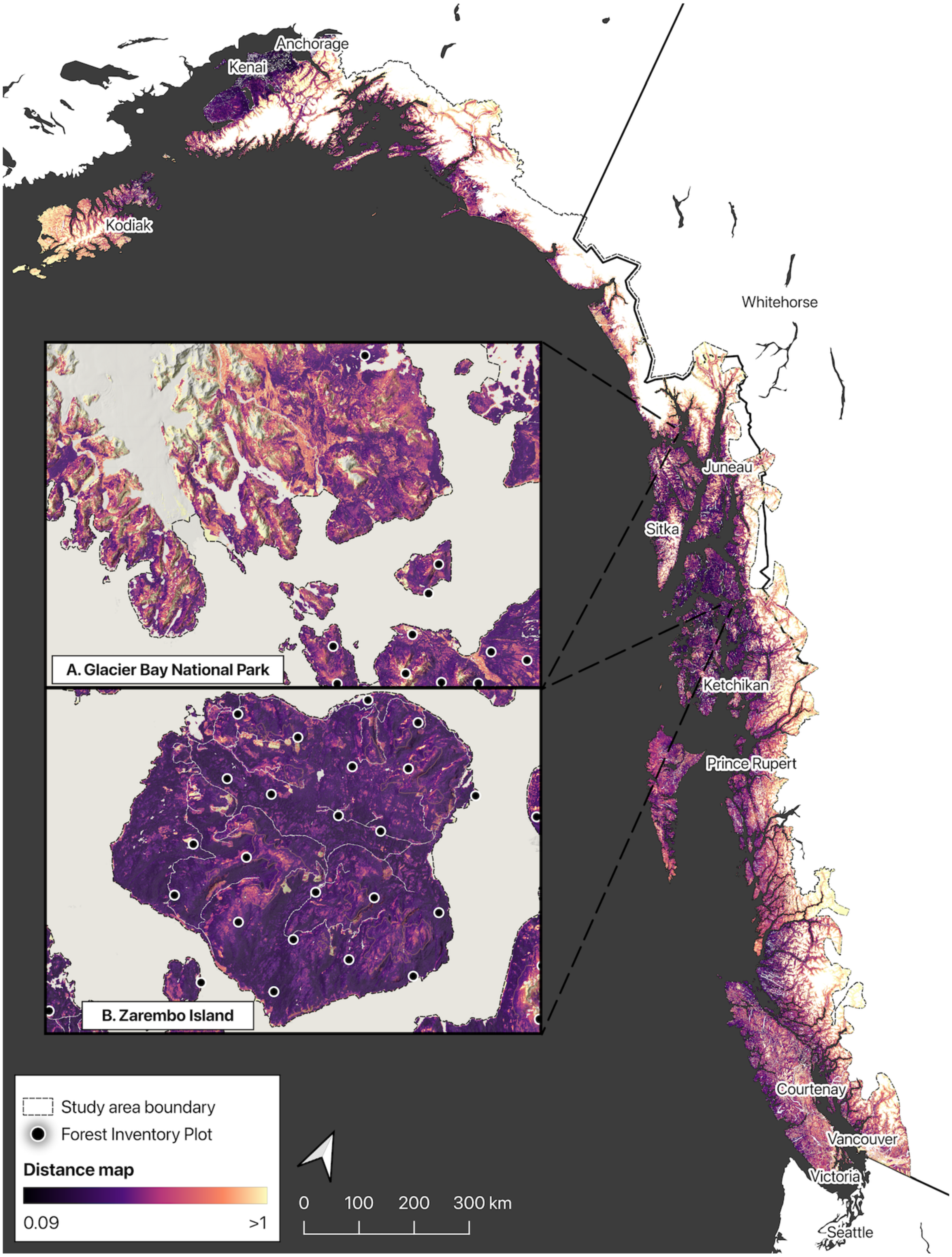

Figure 3. Mean nearest neighbor distance in environmental gradient space derived from the Gradient Nearest Neighbor (GNN) imputation. Lower values indicate pixels whose environmental conditions are well represented by forest inventory plots, whereas higher values represent areas with limited representation in the training dataset. Inset maps illustrate contrasting levels of plot support and environmental complexity: (A) Glacier Bay National Park, Alaska, characterized by steep terrain and sparse inventory coverage, resulting in higher nearest neighbor distances; and (B) Zarembo Island, Alaska, a low-relief landscape with relatively dense plot coverage, exhibiting lower nearest neighbor distances.

Table 2. Dominant Overstory Species Extent, Percent Cover of Total Study Region, and Total Area and Percent Classified as Mature and Old Growth (MOG) Forests Within Each Dominant Forest Type

Species	Total area (ha)	% of landscape	MOG area (ha)	% classified as MOG
Tsuga heterophylla	5,206,934	25	1,313,747	25
Tsuga mertensiana	4,805,966	23	1,017,792	21
Thuja plicata	3,046,853	14	85,920	2.8
Picea sitchensis	2,883,049	14	117,534	4.1
Pseudotsuga menziesii	1,405,777	6.6	150,197	11
Chamaecyparis nootkatensis	1,215,076	5.7	518,622	43
Pinus contorta	731,461	3.4	10,014	1.4
Betula papyrifera	499,956	2.4	22,206	4.4
Abies amabilis	347,135	1.6	78,357	23
Picea glauca	293,468	1.4	135,883	46
Picea mariana	285,372	1.3	7507	2.6
Populus trichocarpa	205,429	1.0	4220	2.1
Alnus rubra	164,933	0.8	1696	1.0
Acer macrophyllum	96,010	0.5	4194	4.4
Populus tremuloides	27,706	0.1	176	0.6
Pinus monticola	8112	0.04	468	5.8
Abies lasiocarpa	2164	0.01	15	0.7

and *Thuja plicata* in the mid and southern parts of the study region, although at lower frequencies (14 percent for both species). The second most common forest type in the region was *Tsuga mertensiana*, which can be seen at higher elevations up to tree line but also down to sea level in the northern extent of its range and covers more than 4.8 million hectares (23 percent) of southeast Alaska and coastal British Columbia. *Pseudotsuga menziesii*, an important commercial species in the Pacific Northwest (Brackley and others 2009), covers over 1.4 million hectares but was mostly constrained to the southeastern areas of Vancouver Island and more inland forests north of Washington state.

Less common forest types included *Pinus contorta*, *Chamaecyparis nootkatensis*, *Abies amabilis*, *Picea glauca*, and *Picea mariana*. *Pinus contorta* tended to dominate in low-lying areas near the coast that were associated with waterlogged soils (muskegs) or areas of low productivity. *Picea glauca* and *Picea mariana* were dominant forest types only in the boreal transition zone of the western Kenai Peninsula (1.4 and 1.3 percent). Hardwood species had relatively low dominance, commonly comprising relatively minor components of the coniferous forests of the region, with all hardwood species representing less than 3 percent total area as a dominant forest type. However, the spatial arrangement of hardwood forest types aligns with the expected distributions. For example, *Acer macrophyllum* made up large components of forested riparian areas to the south while *Populus trichocarpa* occurred in similar areas to the north.

Mature and Old Growth Extent by Dominant Species

Analysis of mature and old growth forest distribution by dominant species revealed notable variability among species (Table 2). Alaska yellow cedar (*Chamaecyparis nootkatensis*) and white spruce (*Picea glauca*) showed particularly high proportions of their total extent classified as mature or old growth forests (43% and 46%, respectively), suggesting these species frequently occur in older stands across the landscape. In contrast, other widespread species such as Sitka spruce (*Picea sitchensis*) and western redcedar (*Thuja plicata*) exhibited notably lower percentages of mature and old growth forests (4.1% and 2.8%, respectively) relative to their overall extent. Together, western hemlock (*Tsuga heterophylla*) and mountain hemlock (*Tsuga mertensiana*) forests accounted for more than 67% of the total mature and old growth forest area, covering over 2.3 million hectares. It is important to recognize the biogeographic delineation between temperate and boreal regions when interpreting these mature and old growth forest extents, as ecological and disturbance dynamics differ significantly between these zones.

Old Growth and Mature Forest by Protected Status

The classification of forests into seral states showed that a total of 1,176,903 hectares were classified as old growth forests while 2,291,309 hectares can be

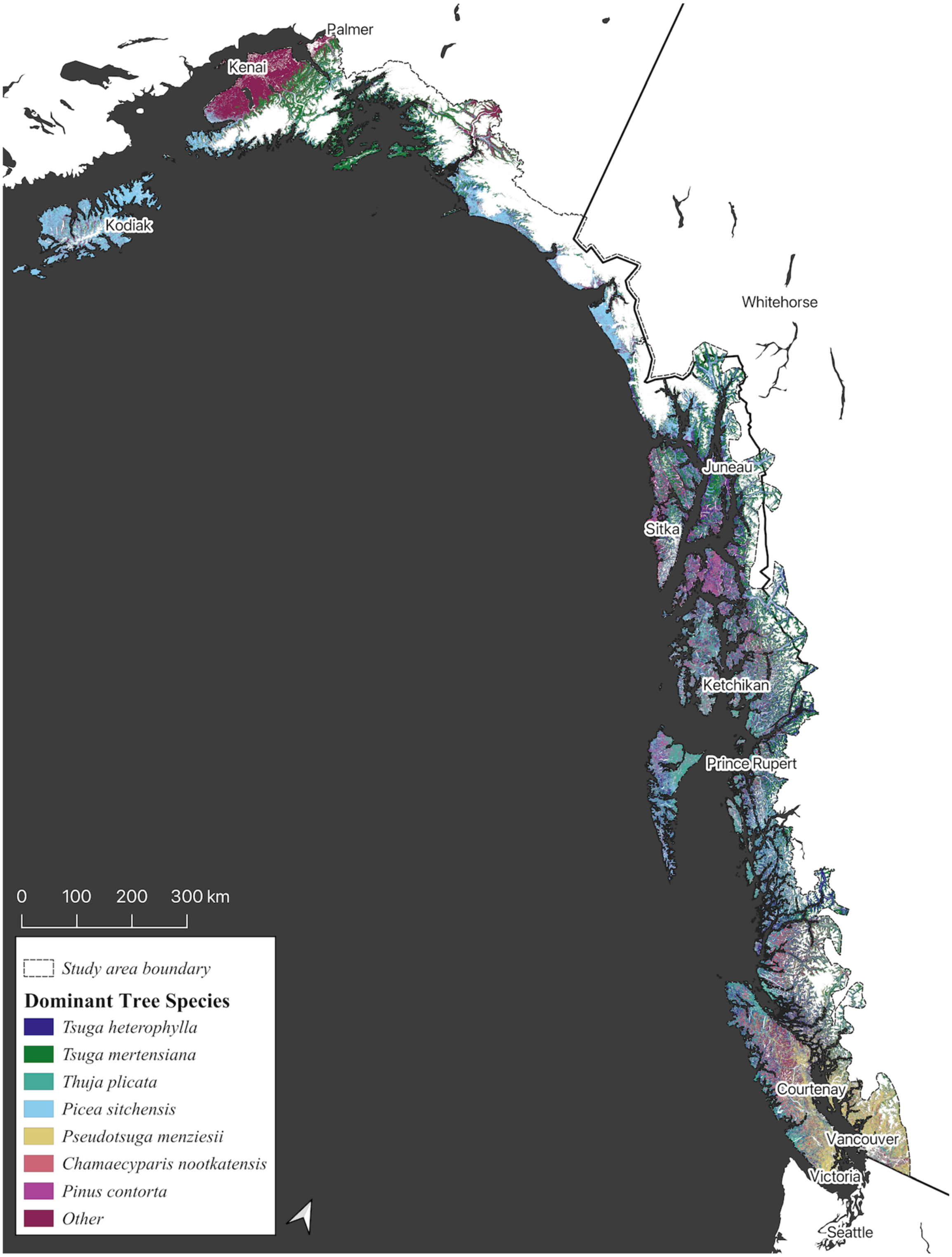

Figure 4. Dominant species classification map showing the seven most common forest types by extent. Forest types that comprise less than 3% of the total study are shown as ''other.''

classified as mature forests (Figure 5). In southeast Alaska, old growth and mature stands comprise nearly 23 percent of all forests within the Tongass National Forest boundary not designated as wilderness, IRA, or national monument. Within legislatively protected areas, National Parks and

Monuments throughout southeast Alaska and British Columbia cover a combined area of over 5.9 million hectares of forested land. Of these, our analysis shows 230,345 hectares of old growth and 309,949 hectares of mature forests (Table 3). Designated wilderness areas, while having a slightly smaller footprint on the landscape at over 2.3 million hectares, also contain large amounts of productive old growth. By far, the largest areas of mature and old growth forest across the study area fall outside of legislatively protected areas. In British Columbia, OGMAs contain higher proportions of older forests, despite their fragmented nature and relatively small spatial coverage, with over 20 percent of the forests classified as either old growth or mature. The largest areas of mature and old growth forests in the region reside within IRAs in southeast Alaska, with a combined total of 832,500 hectares.

Carbon Density and Stocks by Protected Status

Mean aboveground carbon density varied among land-use and protection categories. The highest mean carbon densities occurred in OGMAs in British Columbia, followed by national monuments, wilderness areas, and ecological reserves. Areas without administrative protection had the lowest mean carbon density, averaging 13,666 g m^{-2} (Figure 6). In contrast to density patterns, total aboveground carbon stocks were highest in IRAs in Alaska and National Parks across the region, which together store over 1583 Tg C. Substantial carbon stocks were also present in unprotected lands (684 Tg C).

Discussion

Our analysis provides insights into the distribution of mature and old growth forests across coastal Alaska and British Columbia, highlighting the varied impacts of historical management and ecological constraints on different species across the region. Although hemlock-dominated forests (*Tsuga heterophylla* and *Tsuga mertensiana*) cover about 48% of the region, only about one-quarter are currently classified as mature or old growth stands. Extensive past logging practices preferentially targeted these economically valuable forests, significantly reducing their mature and old growth extents (Table 2). Conversely, less abundant forest types, such as Alaska yellow cedar (*Chamaecyparis nootkatensis*), exhibited notably higher proportions of mature and old growth stands (43%), possibly because of lower economic demand or inherent resilience to disturbance. On the other hand, species like western redcedar (*Thuja plicata*) and Sitka spruce (*Picea sitchensis*) have relatively low percentages of mature and old growth areas (3% and 4%, respectively), potentially indicating higher susceptibility to disturbances or intensive historical harvest pressures. Understanding the spatial pattern of mature and old growth forests are essential, as it allows resource managers to identify and prioritize forest types where conservation efforts could significantly enhance biodiversity and ecosystem functions like carbon storage. Rare, high-value mature and old growth forest types may warrant targeted protection to ensure their continued ecological contribution to the landscape.

Approximately 39% of all mature and old growth forests in the study region occurred within in Alaska, which are administratively designated areas whose protections can be modified through policy or management decisions without legislative action (Table 3). Although administratively designated areas in B.C. such as OGMAs occupied only a small area (only 150,220 ha), almost 21% of their land was identified as mature and old growth. Policy changes that relax harvest restrictions or shift management priorities could result in disproportionate impacts on these highly valued forests. Mature and old growth forests store large amounts of carbon, support structurally complex habitat critical for late-successional and old growth associated species, and contribute to landscape connectivity that enhances ecological resilience. In addition, these forests hold significant cultural importance for Indigenous communities and provide ecosystem services that are not readily replaced on management-relevant timescales. By explicitly identifying where mature and old growth forests occur, which forest types most frequently support them, and the protection frameworks under which they fall, this analysis provides information needed to evaluate the potential ecological and climatic implications of future administrative or policy decisions.

Innovative conservation strategies, collaborative land-use agreements, and policies aimed specifically at protecting mature and old growth stands in the region have tried to strike a balance between preserving ecological integrity and sustainable resource management. IRAs are a significant component of protected old growth forests in the United States, particularly within the Tongass National Forest where they contain the largest area of late-successional forests (Table 3). IRAs restrict road construction and timber harvests, thereby

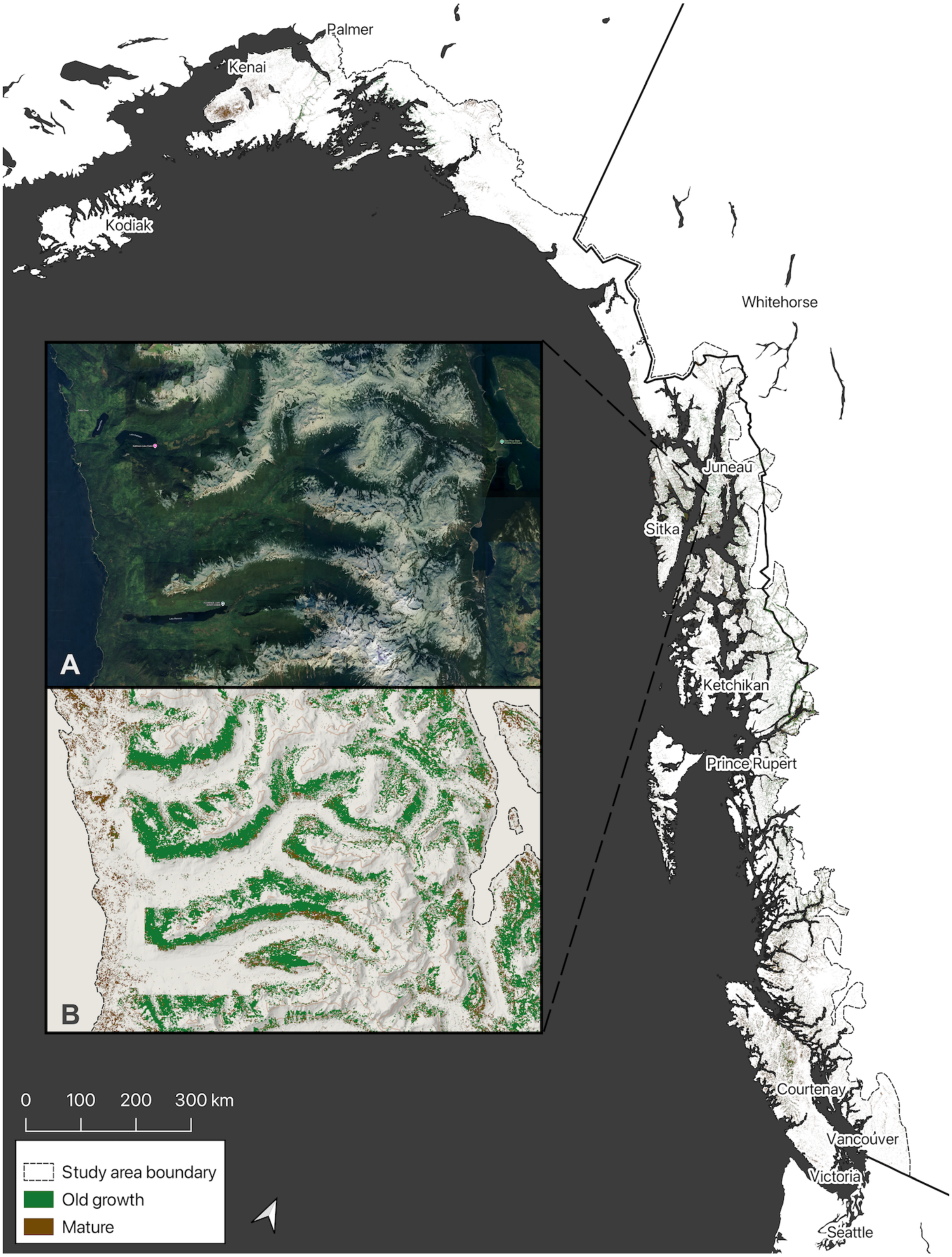

Figure 5. Predicted distribution of old growth and mature forests across the study region. Inset panels highlight Admiralty Island National Monument in Alaska, a landscape with a history of intensive logging prior to its designation as a national monument, showing (**A**) satellite imagery and (**B**) corresponding mature and old growth classifications generated through this study's modeling framework.

Table 3. Administrative Protective Areas with the Total Area (ha), Area Classified as Either old Growth or Mature (ha), and Percent of Old Growth and Mature Forest (MOG) Contained Within Each

Land-use category	Total land area	Old growth	Mature	% protected area classified as MOG
Administratively protected areas				
Inventoried Roadless Areas *	5,511,216	372,290	460,210	15%
OGMA †	150,220	7398	23,725	21%
Wildlife Habitat Refuge ‡	68,917	2143	6047	12%
Ecological Reserve ‡	28,096	388	2056	9%
Indigenously managed ‡	11,461	553	805	12%
Legislatively protected areas				
National Park ‡	3,625,641	73,682	162,190	7%
Wilderness Area ‡	2,304,321	82,744	175,588	11%
National Monument ‡	1,318,337	156,663	147,759	23%
No protections				
No administrative protection ‡	5,007,818	136,258	336,298	9%

*U.S.-only designation
†B.C.-only designation
‡Found in both U.S. and B.C

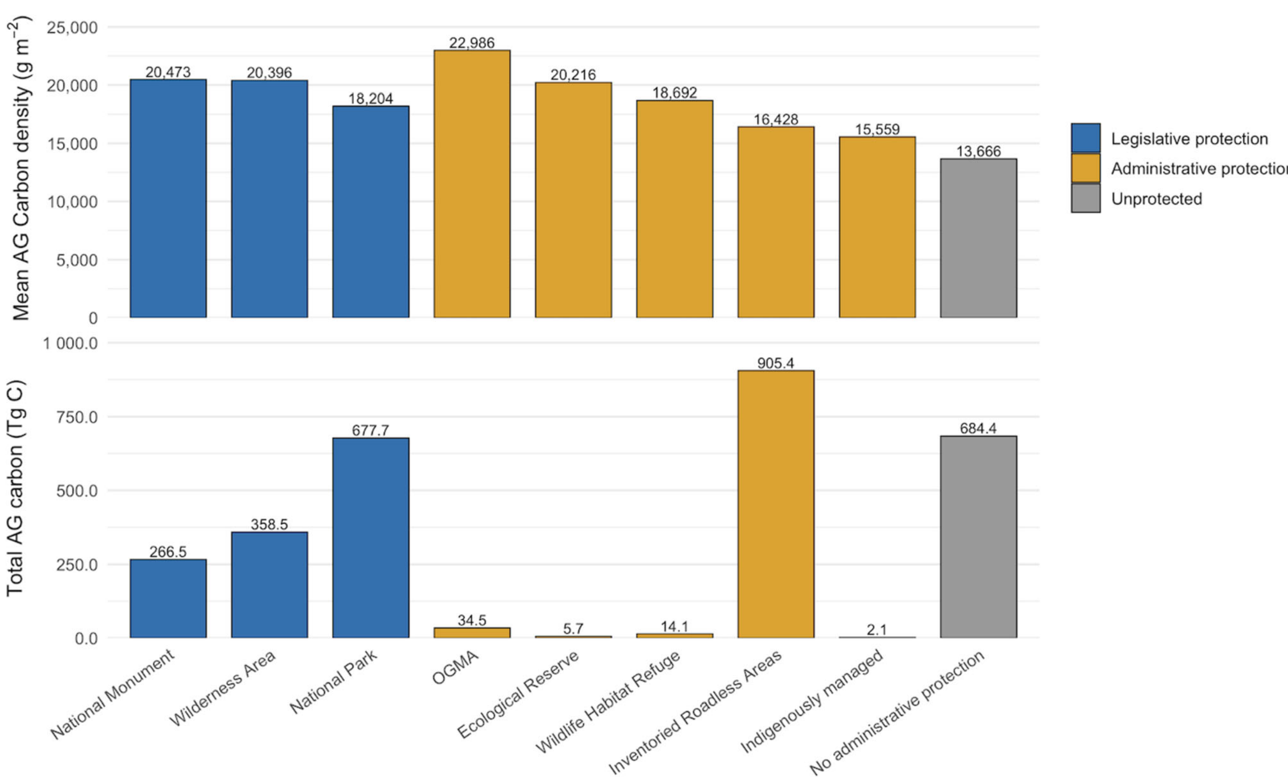

Figure 6. Mean aboveground carbon density (g m^{-2}; top) and total aboveground carbon stocks (Pg C; bottom) by land-use and protection category in coastal Alaska and British Columbia. Colors denote legislative protection, administrative protection, and unprotected lands. Categories are ordered within protection groups by descending carbon density.

preserving large tracts of undeveloped land. DellaSala and others (2022) highlight the critical role of IRAs in maintaining biodiversity, ecological functions, and carbon storage in the Tongass, noting that an estimated 1.06 million hectares of productive old growth are held within IRAs. However, the predictions in this study show 65% lower extents of old growth in IRAs, with only 372,290 hectares classified as old growth. This discrepancy might be attributed to the broader definition of productive old growth used in DellaSala and others (2022) (wood standing volume > 46.6 m^3/ha and stand age > 150 years) and the inclusion of a mature forest classification in this analysis (Table 3). When combining our estimates of old growth and mature forests within IRA boundaries, the two estimates are more closely aligned, with our models suggesting a total of 832,500 hectares classified as being in a late-successional stage, only 20% lower than DellaSala and others (2022).

Recent national-scale analyses provide important context for interpreting these regional patterns. Birdsey and others (2025) showed that across conterminous U.S. forests, the majority of forest carbon (58%) is stored in mature forests, while only ~ 15% resides in old growth forests, and that less than one-fifth of carbon in mature and old growth forests is afforded any level of protection. These findings show that mature forests represent a dominant and often underprotected component of the national forest carbon pool. Our results mirror this broader pattern at a regional scale. While old growth forests hold the highest carbon densities, mature forests account for a substantial fraction of total late-successional area and carbon stocks, much of which remains only weakly protected or entirely unprotected.

Different types of protective designations offer varying degrees of security for old growth forests. Some protections are more permanent, such as national parks, monuments, and wilderness areas, which typically require legislative action to alter their status. In contrast, other protections, such as administrative designations like IRAs and OGMAs, can be more easily modified or revoked by government agencies and comprise 40% of the late seral forest found in the region. These areas are also shown to have some of the highest densities of aboveground carbon in the region (Figure 6). Administratively protected areas, particularly IRAs, also contain the largest total aboveground carbon stocks in the region, meaning that potential policy changes affecting these designations would have disproportionate consequences for regional carbon storage (Dietz and others 2021; Price and others 2021; DellaSala and others 2022; Dhari 2023). The recent repeal and subsequent reestablishment of the Roadless Rule in Alaska, which governs IRAs and has been subject to multiple legal challenges and administrative changes, illustrate this vulnerability. Notably, a substantial portion of mature and old growth forests, approximately 472,556 hectares, currently lacks these more formal administrative protections (Table 3). These unprotected areas represent roughly 22% of the total mature and old growth forests identified in this study.

The management and conservation of old growth forests are complicated by varying definitions across different jurisdictions, which creates significant challenges in mapping, policy implementation, ecological conservation, and forest management. Over large, cross-jurisdictional areas such as coastal Alaska and British Columbia, these inconsistencies, combined with variability in data sources and inventory methodologies, complicate accurate estimations of old growth forests. A critical issue highlighted in recent literature is the discrepancy between defining old growth forests by tree age versus structural characteristics (Price and others 2021), such as their capacity to support large, ecologically significant trees. In British Columbia, for example, the provincial government often defines old growth forests primarily based on the age of the trees, typically those older than 140 years in interior regions and 250 years in coastal regions (Gorley and Merkel 2020). While age is a straightforward criterion, it does not necessarily capture the ecological, structural complexity nor productivity of these forests. Some recent studies argue that an age-based definition alone can be misleading because it includes large areas of low-productivity forests, such as subalpine and bog forests, that do not support large, ecologically significant trees (Davis and others 2015; Spies and others 2018). To mitigate these issues, this study adopted recently published U.S. Forest Service definitions, which explicitly incorporate both stand age and structural characteristics for specific forest types, offering a comprehensive and standardized approach. While definitional challenges persist, this unified methodology provides robust cross-jurisdictional vegetation mapping suitable for comprehensive landscape analysis and informed decision-making.

While this study provides a consistent, region-wide assessment of mature and old growth forest distributions, the spatial coverage of plots was uneven (Figure 3) and coverage of some environmental predictors was incomplete. As with other imputation-based vegetation maps, these products are most appropriate for regional- and landscape-scale assessments of forest structure and condition, rather than for interpretation at the individual pixel scale. Mature and old growth forests represent a relatively small and spatially clustered fraction of the landscape for some forest types. Given that classification outcomes are influenced by the density and spatial distribution of inventory plots capturing these conditions, predictions are more sensitive to sampling bias in regions where late-successional forests are underrepresented. Areas with higher nearest neighbor distances in environmental gradient space, particularly high-elevation and remote landscapes, reflect combinations of climate and topography that are less frequently sampled by inventory plots, rather than reduced model performance (Figure 3). Accordingly, classifications in well-sampled low-elevation coastal forests are most strongly supported by field data, while predictions in sparsely inventoried regions should be interpreted with appropriate caution.

In summary, our analysis suggests that approximately 3.5 million hectares, or about 12% of the total forested land in the region, can be classified as mature and old growth forests. Hemlock forests had the largest land area denoted as mature and old growth ($\sim$ 2.3 million ha), while Alaska yellow cedar and white spruce had the highest percent of their land area designated as mature and old growth, ranging from 43 to 46%. Approximately 37% of mature and old growth forests are located within areas of legislative protection, and 22% have no protections at all. Approximately 40% are situated in administrative designations that offer fewer permanent forms of protection, such as IRAs and OGMAs. Carbon density was also highest in OGMAs while IRAs have the greatest stocks of aboveground carbon, suggesting a substantial portion of the carbon in this region is vulnerable to shifts in policy and administrative decisions. By providing detailed and harmonized maps of old growth that cross-jurisdictional boundaries, this study offers a comprehensive view of mature and old growth forests that is crucial for effective transboundary conservation and forest management. The detailed spatial data on dominant species and old growth forests can inform targeted management practices aimed not only at preserving biodiversity, enhancing carbon storage, and maintaining ecosystem functions, but also at supporting economic sustainability and other land management priorities. Additionally, understanding the distribution of carbon across different protected areas helps prioritize regions for more comprehensive and balanced conservation and resource use strategies.

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DATA AVAILABILITY

All derived data products used to generate the results of this study are publicly available via Zenodo (https://doi.org/10.5281/zenodo.17055325). The dataset includes modeled maps of dominant forest types and mature and old growth forest classifications. Forest inventory data were obtained from the U.S. Forest Service Forest Inventory and Analysis (FIA) Program and the British Columbia Forest Analysis and Inventory Branch (FAIB) and are available through their respective data access portals.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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REFERENCES

Alaback PB, Juday GP. 1989. Structure and composition of low elevation old-growth forests in research natural areas of Southeast Alaska. Natural Areas Journal 9:27–39.

Avery TE, Burkhart HE. 1983. Forest measurements. McGraw-Hill Book Company.

Beissinger SR, Ackerly DD, Doremus H, Machlis GE. 2019. Science, conservation, and national parks. University of Chicago Press https://www.degruyter.com/document/doi/https://doi.org/10.7208/9780226423142/html. Last accessed 18/04/2025

Bell DM, Gregory MJ, Palmer M, Davis R. 2023. Guidance for forest management and landscape ecology applications of recent gradient nearest neighbor imputation maps in California, Oregon, and Washington. Gen Tech Rep PNW-GTR-1018 Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station 41 1018. https://research.fs.usda.gov/treesearch/67105.

Birdsey RA, DellaSala DA, Walker W, Gorelik S. 2025. How much more carbon could be protected in mature and old-growth forests of the United States? Biological Conservation 306:111114.

Boughton J, Copenhagen M, Faris T, Flynn R, Fry L, Huberth P, Lidholm G, Loiselle R, Martin J, Samson F, Shea L, Williamson D (1992a) Definitions for old-growth forest types in southcentral Alaska. U.S. Department of Agriculture, Forest Service, Alaska Region, Anchorage, AK. Old-growth definition task group technical report, 52 p.

Boughton J, Copenhagen M, Faris T, Flynn R, Fry L, Huberth P, Lidholm G, Loiselle R, Martin J, Samson F, Shea L, Williamson D (1992b) Definitions for old-growth forest types in southeast Alaska. U.S. Department of Agriculture, Forest Service, Alaska Region, Anchorage, AK. Old-growth definition task group technical report R10TP-28, 67 p.

Bourgeois W, Brinley C, LeMay V, Moss I, Reynolds N. 2018. British Columbia Forest Inventory Review Panel Technical Background Report. Office of the Chief Forester Division, British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/brp_technical_document_final.pdf.

Brackley AM, Haynes RW, Alexander SJ. 2009. Timber harvests in Alaska: 1910–2006. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station https://www.fs.usda.gov/treesearch/pubs/31910.

British Columbia. 2024. Old Growth Deferrals - FAQ. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/old-growth-forests/deferral-maps/og_deferral_faq.pdf.

Buma B, Krapek J, Edwards RT. 2016. Watershed-scale forest biomass distribution in a perhumid temperate rainforest as driven by topographic, soil, and disturbance variables. Can J for Res 46:844–854.

Clayoquot Sound Scientific Panel. 1994. Report of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound. Clayoquot Sound Scientific Panel https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/land-use-plans-and-objectives/westcoast-region/clayoquotsound-lud/clayoquot_lud_scientificpanelrpt_tor_principles.pdf.

Crist EP, Cicone RC. 1984. A physically-based transformation of Thematic Mapper data—The TM Tasseled Cap. IEEE Transactions on Geoscience and Remote sensing:256–63.

Crone LK, Mehrkens JR. 2013. Indigenous and commercial uses of the natural resources of the north pacific rainforest with a focus on southeast Alaska and Haida Gwaii. In: North Pacific temperate rainforests: ecology and conservation. University of Washington Press Seattle. pp 89–126.

Davis RJ, Bell DM, Gregory MJ, Yang Z, Gray AN, Healey SP, Stratton AE. 2022. Northwest Forest Plan—the first 25 years (1994–2018): status and trends of late-successional and old-growth forests.

Davis RJ, Ohmann JL, Kennedy RE, Cohen WB, Gregory MJ, Yang Z, Roberts HM, Gray AN, Spies TA. 2015. Status and trends of late-successional and old-growth forests. https://www.fs.usda.gov/research/treesearch/download/50060.pdf.

DellaSala DA, Gorelik SR, Walker WS. 2022. The Tongass National Forest, Southeast Alaska, USA: A Natural Climate Solution of Global Significance. Land 11:717.

Dhari J. 2023. Old growth protections in British Columbia: A comparative analysis. https://summit.sfu.ca/item/36163.

Dietz MS, Barnett K, Belote RT, Aplet GH. 2021. The importance of US national forest roadless areas for vulnerable wildlife species. Global Ecology and Conservation.

Forest Analysis and Inventory Branch. 2023. B.C. Timber Harvest Boundaries.

Franklin JF. 1981. Ecological characteristics of old-growth Douglas-fir forests. USDA PNW Research Station

Gergely KJ, McKerrow A. 2013. PAD-US—National inventory of protected areas. US Geological Survey https://pubs.er.usgs.gov/publication/fs20133086.

Gilhen-Baker M, Roviello V, Beresford-Kroeger D, Roviello GN. 2022. Old growth forests and large old trees as critical organisms connecting ecosystems and human health. A Review. Environ Chem Lett 20:1529–1538.

Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R. 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2017.06.031.

Gorley A, Merkel G. 2020. A New Future for Old Forests: A Strategic Review of How British Columbia Manages for Old Forests Within its Ancient Ecosystems. Old Growth Review Panel

Government of Canada 2021. Canadian protected and conserved areas database.

Gray AN, Brandeis TJ, Shaw JD, McWilliams WH, Miles PD. 2012. Forest inventory and analysis database of the United States of America (FIA). Biodiversity, Evolution and Ecology of Plants

Gray AN, Pelz K, Hayward GD, Schuler T, Salverson W, Palmer M, Schumacher C, Woodall CW. 2023. Perspectives: The wicked problem of defining and inventorying mature and old-growth forests. Forest Ecology and Management 546:121350.

Harmon ME, Ferrell WK, Franklin JF. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science 247:699–702.

Harris A, Farr W. 1974. The forest ecosystem of southeast Alaska. USDA Forest Service, Pacific Northwest Research Station https://www.fs.usda.gov/pnw/pubs/pnw_gtr025.pdf.

Hegyi F. 1981. Site Index Equations and Curves for the Major Tree Species in British Columbia. Ministry of Forests, Victoria, B.C. https://www.for.gov.bc.ca/hfd/library/documents/bib24877.pdf.

Hermann RK, Lavender DP. 1990. Pseudotsuga menziesii (Mirb.) franco Douglas-fir. Silvics of North America 1. http://dendro.cnre.vt.edu/DENDROLOGY/USDAFSSilvics/105.pdf.

Hilbert J, Wiensczyk A. 2007. Old-growth definitions and management: A literature review. Journal of Ecosystems and

Management. http://jem-online.org/index.php/jem/article/view/360.

Hurni K, Heinimann A, Würsch L. 2017. Google earth engine image pre-processing tool: background and methods. https://www.cde.unibe.ch/e65013/e542846/e707304/e707386/e707388/CDE_Pre-processingTool-BackgroundAndMethods_eng.pdf.

JAXA EORC. 2024. ALOS Global Digital Surface Model 'ALOS World 3D - 30m (AW3D30)'. https://www.eorc.jaxa.jp/ALOS/en/dataset/aw3d30/aw3d30_e.htm

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP, Kessler M. 2017. Climatologies at high resolution for the earth's land surface areas. Sci Data 4:170122.

Keith H, Mackey BG, Lindenmayer DB. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proc Natl Acad Sci USA 106:11635–11640.

Kennedy RE, Yang Z, Cohen WB. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms. Remote Sensing of Environment 114:2897–2910.

Kennedy RE, Yang Z, Gorelick N, Braaten J, Cavalcante L, Cohen WB, Healey S. 2018. Implementation of the LandTrendr Algorithm on Google Earth Engine. Remote Sensing 2018(10):691.

Lamping J, Lucash M, Bell DM, Irvine DR, Gregory M. 2025. Moderate-resolution mapping of aboveground biomass stocks, forest structure, and composition in coastal Alaska and British Columbia. Forest Ecology and Management 583:122576.

Luyssaert S, Schulze E-D, Börner A, Knohl A, Hessenmöller D, Law BE, Ciais P, Grace J. 2008. Old-growth forests as global carbon sinks. Nature 455:213–215.

MacKinnon A. 2003. West coast, temperate, old-growth forests. The Forestry Chronicle 79:475–484.

McCune B, Grace JB, Urban DL. 2002. Analysis of ecological communities.

McNicol G, Bulmer C, D'Amore D, Sanborn P, Saunders S, Giesbrecht I, Arriola SG, Bidlack A, Butman D, Buma B. 2019. Large, climate-sensitive soil carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest. Environmental Research Letters 14:014004.

Moyer JM, Owen RJ, Duinker PN. 2008. Forest values: A framework for old-growth forest with implications for other forest conditions. The Open Forest Science Journal 1:27–36.

Nowacki GJ, Spencer P, Fleming M, Brock T, Jorgenson T. 2003. Unified ecoregions of Alaska: 2001. US Geological Survey https://pubs.er.usgs.gov/publication/ofr2002297.

Ohmann J, Gregory MJ. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research 32:725–741.

Ohmann JL, Gregory MJ, Henderson EB, Roberts HM. 2011. Mapping gradients of community composition with nearest-neighbour imputation: extending plot data for landscape analysis. J Vegetation Science 22:660–676.

Orians GH, Schoen JW, editors. 2013. North Pacific temperate rainforests: ecology & conservation. Seattle: Audubon Alaska and the Nature Conservancy of Alaska in association with University of Washington Press

Owen RJ, Duinker PN, Beckley TM. 2009. Capturing Old-Growth Values for Use in Forest Decision-Making. Environmental Management 43:237–248.

Parai BJ, Esakin TC. 2003. Beyond conflict in Clayoquot Sound: the future of sustainable forestry. Natural resource conflict management case studies: an analysis of power, participation and protected areas:163–82.

Pelz KA, Hayward G, Gray AN, Berryman EM, Woodall CW, Nathanson A, Morgan NA. 2023. Quantifying old-growth forest of United States Forest Service public lands. Forest Ecology and Management 549:121437.

Price K, Daust D, Daust K, Holt R. 2023. Estimating the amount of British Columbia's ''big-treed'' old growth: Navigating messy indicators. Front For Glob Change 5.

Price K, Holt RF, Daust D. 2021. Conflicting portrayals of remaining old growth: the British Columbia case. Can J for Res 51:742–752.

Spies TA. 2004. Ecological Concepts and Diversity of Old-Growth Forests. Journal of Forestry 102:14–20.

Spies TA, Franklin JF. 1996. The diversity and maintenance of old-growth forests. Biodiversity in managed landscapes: theory and practice Oxford University Press, New York, New York, USA:296–314.

Spies TA, Stine PA, Gravenmier RA, Long JW, Reilly MJ. 2018. Synthesis of science to inform land management within the Northwest Forest Plan area. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station https://www.fs.usda.gov/treesearch/pubs/56278.

Ter Braak CJF. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67:1167–1179.

Turner NJ, Hebda RJ. 1990. Contemporary use of bark for medicine by two salishan native elders of Southeast Vancouver Island, Canada. Journal of Ethnopharmacology 29:59–72.

United States of America. 1980. Alaska National Interest Lands Conservation.

United States of America. 1990. Tongass Timber Reform Act.

United States of America. 2022. Executive Order 14072: Strengthening the Nation's Forests, Communities, and Local Economies.

USDA. 2022. U.S. Timber Harvest Boundaries, Alaska.

USDA Forest Service. 2010. Alaska National Interest Lands Conservation Act (ANILCA) and Tongass Inventoried Roadless Areas.

USDA Forest Service. 2023. Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management. USDA Forest Service https://www.fs.usda.gov/sites/default/files/mature-and-old-growth-forests-tech.pdf

Veblen TT, Alaback PB. 1996. A Comparative Review of Forest Dynamics and Disturbance in the Temperate Rainforests of North and South America. In: Springer, New York, NY. pp 173–213. http://link.springer.com/https://doi.org/10.1007/978-1-4612-3970-3_9.

Williams NG, Powers MD. 2019. Carbon storage implications of active management in mature Pseudotsuga menziesii forests of western Oregon. Forest Ecology and Management 432:761–775.