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The Tongass National Forest, Southeast Alaska, USA: A Natural Climate Solution of Global Significance

Dominick A. DellaSala [1,*], Seth R. Gorelik [2] and Wayne S. Walker [2]

[1] Wild Heritage, a Project of Earth Island Institute, 222 Joseph Drive, Talent, OR 97540, USA
[2] Woodwell Climate Research Center, 149 Woods Hole Road, Falmouth, MA 02540, USA; sgorelik@woodwellclimate.org (S.R.G.); wwalker@woodwellclimate.org (W.S.W.)
* Correspondence: dominick@wild-heritage.org

Abstract: The 6.7 M ha Tongass National Forest in southeast Alaska, USA, supports a world-class salmon fishery, is one of the world's most intact temperate rainforests, and is recognized for exceptional levels of carbon stored in woody biomass. We quantified biomass and soil organic carbon (C) by land use designation, Inventoried Roadless Areas (IRAs), young and productive old-growth forests (POGs), and 77 priority watersheds. We used published timber harvest volumes (roundwood) to estimate C stock change across five time periods from early historical (1909–1951) through future (2022–2100). Total soil organic and woody biomass C in the Tongass was 2.7 Pg, representing ~20% of the total forest C stock in the entire national forest system, the equivalent of 1.5 times the 2019 US greenhouse gas emissions. IRAs account for just over half the C, with 48% stored in POGs. Nearly 15% of all C is within T77 watersheds, >80% of which overlaps with IRAs, with half of that overlapping with POGs. Young growth accounted for only ~5% of the total C stock. Nearly two centuries of historical and projected logging would release an estimated 69.5 Mt CO_2e, equivalent to the cumulative emissions of ~15 million vehicles. Previously logged forests within IRAs should be allowed to recover carbon stock via proforestation. Tongass old growth, IRAs, and priority watersheds deserve stepped-up protection as natural climate solutions.

Keywords: carbon emissions; carbon stores; inventoried roadless areas; old-growth forest; southeast Alaska; temperate rainforest; Tongass National Forest; natural climate solutions

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1. Introduction

The 6.7 M ha Tongass National Forest (TNF) in southeast Alaska, USA, is the largest national forest managed by the USDA Forest Service in the 77.2 M ha national forest system. The region's productive old-growth forests (POGs; wood standing volume >46.6 m^3/ha; forests ≥150 years old) [1,2] contain far more old growth than any other national forest, providing opportune settings for large-landscape conservation in one of the world's most relatively intact temperate rainforests [2,3]. The TNF also has been the focus of logging debates for decades with pro-conservation presidential administrations enacting forest protections and pro-development ones allowing increased timber removals. Under President Bill Clinton, the National Roadless Conservation Rule of 2001 [4] protected from development 23.4 M ha of federally Inventoried Roadless Areas (IRAs ≥ 2000 ha) across the entire national forest system, 3.7 M ha of which was in the TNF, the largest such expanse. Roadless areas tend to have higher levels of biodiversity and intact ecosystem services than logged and roaded areas [5–7].

To date, there have been 14 legal attempts to overturn roadless protections as they apply to the Tongass; none have invalidated the conservation rule in appellate courts (e.g., https://earthjustice.org/features/timeline-of-the-roadless-rule; accessed on 15 April 2022). However, both the George W. Bush and Donald Trump administrations used executive powers to roll back roadless protections on the Tongass in favor of old growth logging and development. The Joe Biden administration is set to "repeal or replace" the Trump reversal [8], and thus it is imperative that roadless values are well documented, particularly as conservation outcomes are ostensibly tied to political parties changing hands.

Industrial-scale POG logging began ramping up on the Tongass with passage of the Tongass Timber Act of 1947 that authorized two federally subsidized fifty-year pulp contracts [9]. The contracts expired in 2000 and, in 2016, the Barack Obama administration amended the Tongass Land Management Plan (TLMP) of 2008 with the intent to transition logging out of POGs and into suitable young-growth forests (previously logged, naturally reforested, and now commercially viable) [10]. Professional fish and wildlife societies and many scientists have repeatedly called for stepped-up protections for all POGs and IRAs on the TNF (e.g., https://conbio.org/policy/scb-and-other-science-societies-call-on-president-obama-to-save-tongass-rai; accessed on 12 February 2022). Conservation groups also have proposed 77 priority watersheds for salmon and wildlife known as the "Salmon Forest Proposal" or the "Tongass 77" (herein T77) [11]. Notably, POG logging was prohibited within the T77 under the 2016 TLMP transition amendment; however, that too was reversed by the Trump administration shortly thereafter. On 15 July 2021, the Biden administration announced plans to end all "large-scale old-growth logging" on the TNF, thereby providing de facto protections once again for most POGs, IRAs, and T77 priority areas while restarting the transition to timber harvests focused on young growth (https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/; accessed on 12 April 2022). Some small-scale POG logging would be permitted in transition.

Carbon (C) stocks have been quantified previously on the TNF [12] and recognized as nationally significant by USDA Forest Service researchers [13–15] and in congressional policy reviews [16]. However, the USDA Forest Service has undervalued the C stock importance of the TNF by routinely dismissing stock change from logging as inconsequential to total US greenhouse gases (GHGs) [10,17]. Further, the agency believes that logging emissions are simply offset by the storage of C in harvested wood product (HWP) pools and natural reforestation [10,17,18]. The significance of the region to the development of US forest policy around natural climate solutions demands that spatially explicit data on Tongass carbon stocks be updated and an assessment of stock change be attributable to historical, contemporary, and anticipated logging levels.

It follows that our objectives are to: (1) quantify current biomass and soil carbon stocks within land cover (POG, young growth) and land use categories (IRAs, T77 watersheds); and (2) estimate C emissions spanning ~2 centuries of logging on the TNF. Our analysis is key to shedding light on the importance of IRA protections and policy options for both old growth and young-growth forests. Given the national significance of C stocks on the TNF [12], managing forests to maximize C stock potential would demonstrate the US has made a forest-based nationally determined contribution (NDC) to the Paris Climate Agreement. Article 5.1 of the agreement recognizes the need for countries to take specific actions that conserve and enhance nature-based solutions as C sinks and reservoirs [19].

2. Methods

2.1. Study Area

The TNF in southeast Alaska is within the North Pacific Coastal Forest bioregion, which includes several WWF Global 200 ecoregions. At a finer scale, the Tongass also spans the perhumid temperate rainforest climate subzone [20], recognized as globally unique [2,3] (Figure 1). Temperate rainforests are distributed on the Alaskan mainland juxtaposed against the windward edge of the Coast Mountains, separating Alaska from British Columbia. Rainforests are scattered across an archipelago of thousands of islands from the Dixon Entrance (54° N) northward to Yakutat Bay (just north of Glacier Bay, 59° N), a distance of 835 km that includes 30,000 km of shoreline [3]. Interspersed are tree-stunted muskegs, tidewater glaciers, and deeply dissected fjords. Approximately 20% of the TNF is non-forested [10]. Importantly, about 90% of temperate rainforest on the TNF was considered POG in the early 1990s [21], among the largest such concentrations of temperate rainforests [3]. However, only 3% of forested areas include the largest old-growth trees (highest timber volumes) due to high-grade logging prior to the 1990s [1]. "Unproductive" old growth also occurs mostly in muskegs having no commercial timber value [10].

Figure 1. Study area (dark gray), defined as land managed by the United States Department of Agriculture Forest Service within the administrative boundary of the Tongass National Forest, southeast Alaska, and the spatial distribution of young-growth forest (light green) and productive old-growth forest (dark green).

The Koppen Climate Classification subtype for the southeast Alaska region of our study area is "Dfc" (Continental Subarctic Climate). Mean precipitation during the winter is 642 mm (125 mm to 1473 mm range) and mean temperature in the summer is 12.5 °C (9.9° to 17.9 °C range), which is on the wetter, cooler side of temperate rainforests globally [3].

Due to the northern latitude and short growing seasons, treeline on the TNF is generally 300 m, declining northward. Old-growth forests are characterized by multi-layered forest canopies mainly of western hemlock (*Tsuga heterophylla*), yellow-cedar (*Calliptropsis nootkatensis*), mountain hemlock (*T. mertensiana*), Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), and low growing shore pine (*Pinus contorta*) on wetter sites such as muskegs. Rainforest understories are rich in forbs and shrubs [20,21] with dense mats of oceanic lichens and bryophytes that carpet the ground and extend into the overstory canopy.

Prolific salmonid runs include chum (*O. keta*), coho (*O. kisutch*), king (*O. tshawytscha*), pink (*O. gorbuscha*), sockeye (*O. nerka*), and steelhead trout (*O. mykiss*) that support some of the largest concentrations of brown bears (*Ursus arctos*) and bald eagles (*Haliaeetus* *leucocephalus*) in the world [2,3]. Notably, old-growth forests and IRAs provide important refugia for salmonids and Sitka-black tailed deer (*Odocolieus hemionus sitkensis*), considered staple food sources for Alaskan tribes [2,3]

The T77 portion of the study area was based on a spatially explicit ranked-analysis performed by Trout Unlimited, the Nature Conservancy, and Audubon Alaska [11] (https://databasin.org/datasets/72977f90d25a4fcf9f455b9017f2a5e2/; accessed on 5 May 2022).

This dataset includes the highest ranked watersheds in 14 biogeograpical provinces on the TNF based on a suite of attributes, including: top-ranked habitat for the six salmonid species; habitat of the marbled murrelet (*Brachyramphus marmoratus*), a federally threatened seabird species that nests in old-growth forests from California to Washington; black bear (*Ursus americanus*) and brown bear summer habitat; Sitka black-tailed deer wintering habitat; and estuaries and riparian areas that have large-tree, old-growth forests [11]. Excluded were watersheds already protected, in non-federal ownership, managed for other values (such as urban recreation, experimental forest, or timber), and lacking public support [11]. T77 watersheds total 764,855 ha (~11% of the TNF land base); however, they have never been analyzed for C stocks.

2.2. Timber Sale Datasets

We accessed USDA Forest Service datasets on timber volume sold on the TNF and allocated them into five time periods (bins): (1) early historical (ca 1909–1951) [9]; (2) pulp (1952–2000) [22,23]; (3) post pulp (2001–2015) [9]; (4) transition (2016–2021) [10,24]; and (5) future (2022 projected to the end of century) [10].

Tongass management priorities are based on a zoning process known as Land Use Designations (LUDs). In general, there are 18 LUDs nested within three major groupings (summarized herein). LUD 1 includes strictly protected Wilderness and National Monuments; LUD 2 includes Natural Settings managed for non-motorized recreation, old-growth and watershed protections, and Research Natural Areas; and LUD 3 (Development) is managed mainly for timber and mineral extraction. This is in addition to IRAs that are a separate administrative category that precludes most development.

2.3. Carbon Datasets

Our spatially explicit gridded estimates of C density (ca. 2019) in woody plant biomass are derived from a combination of published datasets spanning the study area (Table S1). Researchers [25] combined FIA ground measurements (n > 1000 plots) with environmental covariates (e.g., topography, climate, and disturbance) to calibrate a machine learning algorithm producing lower and upper bound 30 m gridded estimates of C density (metric tons of carbon per hectare, t C ha^{-1}). These were grouped by woody biomass pools including live trees, roots, woody debris, seedlings/saplings, snags, and understory vegetation. C density estimates represent potential C storage, which should closely approximate current storage in old-growth ecosystems, but do not account for active or historical removals of C from logging. Thus, we applied pixel-level adjustments to estimate current (ca. 2019) C density in woody plant biomass. This was accomplished using tree cover data [26] to establish a baseline of ca. 2000 forest cover (>25% tree canopy within a 30 m grid cell), which we then used to remove (i.e., set to zero) all non-forested pixels from the ca. 2000 C density layers. Grid cells were also set to zero if they were identified in the tree cover data [26] as having lost forest cover during the 2001–2019 period. The remaining grid cells reflect the lower and upper bound estimates of current C density in all woody biomass pools. As a result of logging activities prior to 2000, these data are expected to overestimate C stock in young-growth forest.

For a small portion of the study region not included in prior work [25], we estimated C density using a multi-step approach. First, we combined the forest cover loss information for the 2001–2019 period [26] with the 30 m map of aboveground live dry woody biomass (AGB) density (ca. 2000) [27] to estimate current (ca. 2019) AGB density. Next, for grid cells in which we had estimates (ca. 2019) of both AGB ([27], modified data) and all woody biomass pools combined [25] (modified data), we computed the ratio of C in AGB to all biomass pools by forest group (using USFS data). Finally, we applied these ratios as a scaling factor—again by forest group—to the grid cells in which we had only estimates of AGB density, thus producing lower and upper bound estimates, as well as pixel-level mean estimates, of C density in all woody biomass pools Tongass-wide.

Soil C stocks were included using recently published data for the region. We used a 90 m gridded estimate of soil organic C for the top 1 m of mineral soil, including surface organic horizons [28]. We extracted the study region, resampled the grid cells to 30 m using a nearest neighbor approach and re-projected the data to the same coordinate reference system as the biomass density layers.

C stock herein refers to the total amount of C within a defined area and is generally displayed in units of millions (M) of metric tons (t) or petagrams (1 Pg = 1 billion t). Additional information on the errors and uncertainties associated with the biomass and soil C data sets incorporated here can be found in [25,26,28].

2.4. GIS Overlays

Several geospatial datasets were used to further characterize C stocks within the study area. First, the administrative boundary of the study area, land ownership information, and IRAs designated by the 2001 Roadless Area Conservation Rule were retrieved from the USFS Geodata Clearinghouse (https://data.fs.usda.gov/geodata/; accessed on 12 April 2022). Forest growth information, including spatially explicit delineations of young growth and POG—also produced by the USFS—were obtained via databasin.org. All GIS layers were acquired as Esri (polygon) shapefiles. Additional geospatial data used to identify scenarios of IRAs at risk from potential forest management plan changes were acquired from The Nature Conservancy and Audubon Alaska (18 September 2019, personal communication, D. Albert). We rasterized, re-projected, and resampled all layers to match the spatial resolution (30 m) and coordinate reference system of the C density estimates. Next, across all layers, areas outside of the study region were masked as No-Data grid cells. Areas of overlap between the young growth and POG layers were allocated to the young growth category. We then used raster-based zonal statistics to quantify the magnitude of C stored in woody biomass and soil organic matter (to a depth of 1 m) inside and outside of the areas defined by the various GIS overlays described above. All geoprocessing, analysis, and visualization were performed using R statistical software (version 3.4, https://www.r-project.org; accessed on 5 May 2020), Python (version 3.6, https://www.python.org; accessed on 5 May 2020), GDAL (version 3.2, https://gdal.org; accessed on 5 May 2020), and Esri ArcGIS Pro (version 2.9, https://www.esri.com; accessed on 5 May 2020).

2.5. Evaluating At-Risk IRA and POG Scenarios

Administrative policy changes on the TNF have mainly centered on IRAs. Therefore, using the GIS methods and spatial data sets described above, we analyzed existing C stocks and thus, the potential loss of these C stocks, as part of three policy scenarios: (1) all IRAs within the 2016 TLMP Development LUDs are vulnerable; (2) only IRAs with POGs within 2016 TLMP Development LUDs are vulnerable; and (3) all IRA POGs within the 2016 TLMP Development LUDs considered suitable for logging are vulnerable based on reversion to the 2008 TLMP plan (which could happen under a pro-development future administration).

2.6. Estimating Emissions from Harvested Wood Products

We estimated CO_2 emissions associated with past (1909–2021) and projected (2022–2100) logging for wood product pools (HWP) on the TNF following published methods [29]. Logging for wood products removes C from the forest, transferring it to a series of production phases and end uses. Some fraction of the extracted C (i.e., roundwood) is temporarily stored in wood products (e.g., lumber, plywood, paper, etc.) while they remain in use, followed by eventual disposal and emission to the atmosphere [30]. Determining the climate impacts of HWP typically involves estimating C that is temporarily stored in wood products and in solid waste disposal (SWD) sites. The difference between the amount of C in roundwood removed from the forest and that stored in products and SWD sites at any given time constitutes realized emissions [29,30].

The most common method used to estimate CO_2 emissions from HWP is the Production Approach, which tracks C in wood that was harvested in a specified area regardless of where the wood is ultimately consumed. There are several accounting options that guide this calculation [29]. Here, we estimated the amount of C from a given year's logging (annually 1909–2100) that remains stored in end uses and landfills over a subsequent 100-year period [30]. This approach approximates the annual climate impact of withholding C from the atmosphere (i.e., C temporarily stored in HWPs) by a certain amount each year for 100 years as described by a series of decay curves [29]. The 100-year disposition approach facilitates tracking the full temporal impact of harvesting and attribution from the year in which the logging occurs to the year when emissions are ultimately realized (i.e., "seen" by the atmosphere).

Figure S1 illustrates the basic set of calculations used to track C in HWP from forest removal to timber products to primary wood products to end uses and finally to disposal, applying regional estimates for product ratios and half-lives at each stage. Harvest records are used to distribute annual cut volumes among specific timber product classes (e.g., softwood, sawtimber). Timber products are further distributed to specific primary wood products (e.g., softwood lumber, softwood plywood, softwood mill residue used for non-structural panels, etc.) using default average primary product ratios from national level accounting that describe primary products output according to regional forest industry structure [31,32].

We implemented the following multi-step procedure [29] in the R software package: (1) enter roundwood harvest data for the reporting period; (2) allocate harvest to product classes (e.g., sawtimber softwood, pulpwood softwood); (3) estimate the weight of harvested wood using average specific gravities by species group; (4) calculate the weight of harvested C for each harvest year; (5) estimate the 100-year annual disposition of C as fractions of roundwood by product class; (6) calculate C stock changes in the HWP pool and emissions for the inventory period; and (7) calculate annual additions to the HWP pool and associated emissions for the inventory period.

As inputs to this procedure, we used TNF timber harvest records for the period 1909–2021 obtained from USDA Forest Service cut history reports [9]. Harvest projections (2022–2100) were based on the Tongass Forest Plan [10]. We applied the average annual proportions of Alaska region harvests distributed to timber product classes ([33]: Table 3). We established decay rates following disposition patterns contained in the literature ([29]: Table 6-A-5) for the Pacific Northwest-West (PNW-W) region. Other researchers [29] did not include comprehensive (i.e., 100-year) decay functions, but rather included disposition patterns based on a subset of points along the trajectory of each function (i.e., years 1–10 and five-year intervals thereafter beginning in year 15). We estimated decay functions for PNW-W softwood sawlog and pulpwood emissions by fitting asymptotic regression functions to these data (SSasymp) in R.

We note that our results do not reflect total gross emissions from logging; rather, they are limited to the fate of harvested roundwood removed from the forest. Other logging-related emissions, including decay of logging residue, decomposition of litter, and loss of soil organic C were not included. Similarly, the results do not reflect net emissions as they do not consider, for example, C sequestration associated with forest regrowth nor do they account for emissions reductions that might be realized through material substitution, i.e., when wood is substituted for other building materials such as concrete or steel, although wood substitution benefits have been grossly overstated [34].

3. Results

3.1. Young vs. Productive Old Growth Forests

POGs represent about 30% of the Tongass land base and 92% of the productive forests overall. The balance includes unproductive old growth mainly on muskegs as well as non-forest types (see Figure 1). About 8% of the productive forest on the TNF or 3% of the total land base is in young growth condition, almost exclusively the result of old-growth clearcut logging. POG logging and associated road building has resulted in high levels of localized fragmentation, particularly on Prince of Wales Island (*Taan* in Tlingit), the largest and most productive island in terms of POG in the archipelago (Figure 1).

3.2. Timber Volume Sold by Time Period

Annual logging levels throughout the first half of the 20th century (i.e., early historical era) were 243,000 m^3 yr^{-1}, with the lowest levels recorded in 1909 at 37,000 m^3 (Table 1, Table S2). Logging ramped up substantially in the second half of the 20th century (pulp era), averaging ~2 million m^3 yr^{-1} and peaking in 1973 at nearly 3.6 million m^3, followed by a sharp decline in the late 1990s to <900,000 m^3 yr^{-1} (Table 1, Table S2). Between 2001 and 2015 (post pulp era), average logging volume was 230,000 m^3 yr^{-1}. From 2016 to 2021 (transition), average logging fell to 132,000 m^3 yr^{-1}, with the lowest level recorded at 71,000 m^3 in 2019 (Table 1, Table S2). Projecting forward, annual logging levels are expected to rise to 279,000 m^3 yr^{-1} from 2022 to 2031, and then to 595,000 m^3 yr^{-1} from 2032 to the end of the century (Table 1, Table S2). Nearly all of the projected harvest volume would come from young-growth forests should the transition to young-growth logging hold.

Table 1. Past (1909–2021) and projected (2022–2100) timber harvest levels on the Tongass National Forest by era, including average (thousand cubic meters per year) and total (thousand cubic meters) harvest levels. Projections are based on [10]. See Table S2 for annual harvest data.

Years	Era	Average Harvest (1×10^3 m^3 yr^{-1})	Total Harvest (1×10^3 m^3)
1909–1951	Early Historical	243	10,450
1952–2000	Pulp	2041	100,018
2001–2015	Post Pulp	230	3452
2016–2021	Transition	132	789
2022–2031	Projections	279	2793
2032–2100	Projections	595	41,059

3.3. Carbon Stocks

Total C stocks on the TNF are approximately 2679 Mt C (or ~2.7 Pg C, Table 2) with C density varying spatially across the region (Figure 2). Nearly half (48%; 1283.3 Mt) of the C is stored in POGs, split nearly evenly between soil (52.7%; 676.5 Mt C) and woody biomass (47.3%; 607.3 Mt C) (Table 2, Figures 3 and S2). Young growth accounts for just 4.8% (128.8 Mt C) of the total C, with nearly all of it (96%; 124.0 Mt C) outside IRAs (Table 2, Figure 3). IRAs account for just over half (51.3%; 1373.7 Mt) of the C, with soil and woody biomass accounting for 61.5% (845.4 Mt C) and 38.5% (528.3 Mt C) of that C, respectively (Table 2, Figures 3 and S3). Nearly 15% (392.9 Mt C) of all C in the study area is within T77 watersheds, with >80% (328.1 Mt C) of that C overlapping with IRAs and half of that (163.7 Mt C) overlapping with POG (Table 2, Figure 3). As anticipated, the C density of woody biomass in POG (293.5 (259–327) t C ha^{-1}) is greater than the C density of woody biomass in young-growth forest (281.6 (249–314) t C ha^{-1}) (Table 2); however, given the source data used in our analysis [25], C density in young-growth forest is likely overestimated.

Table 2. Carbon stocks (million metric tons) in woody plant biomass and soil organic matter by forest age class (productive old growth vs. young growth) inside and outside of Inventoried Roadless Areas (IRAs) and within the T77 watersheds in the Tongass National Forest, southeast Alaska. POG = Productive Old Growth; YG = Young Growth. Values in parentheses indicate ranges (lower and upper bounds). Biomass was scaled [25] to determine lower and upper bounds using the range of ratios between the live trees measured by Forest Inventory Analysis (FIA) plot data and the other C pools (excluding soils) [12]. Soil was not scaled (see [28]), hence the lack of ranges.

	Area	**Soil**	**Woody Biomass**	**Total**
	(ha)	**(Mt C)**	**(Mt C)**	**(Mt C)**
Inside T77 Watersheds				
Inside IRAs				
POG	256,897	92.2	71.6 (63.2–79.8)	163.7 (155.4–171.9)
YG	1112	0.4	0.2 (0.2–0.3)	0.6 (0.6–0.7)
Other	429,312	117.6	46.1 (40.7–51.3)	163.7 (158.3–168.9)
Subtotal	687,321	210.2	117.9 (104.1–131.3)	328.1 (314.4–341.5)
Outside IRAs				
POG	52,143	18.8	16.1 (14.3–18.0)	35.0 (33.1–36.8)
YG	20,904	8.4	6.1 (5.4–6.8)	14.5 (13.8–15.2)
Other	35,251	10.6	4.7 (4.2–5.3)	15.4 (14.8–15.9)
Subtotal	108,298	37.8	27.0 (23.8–30.1)	64.8 (61.7–67.9)
Total				
POG	309,040	111.0	87.7 (77.5–97.8)	198.7 (188.5–208.8)
YG	22,015	8.8	6.3 (5.6–7.0)	15.1 (14.4–15.9)
Other	464,563	128.2	50.8 (44.9–56.6)	179.0 (173.1–184.8)
Total	795,619	248.1	144.8 (128.0–161.4)	392.9 (376.0–409.4)
All Tongass				
Inside IRAs				
POG	1,060,035	349.5	311.7 (275.5–347.4)	661.2 (625.0–696.9)
YG	7978	2.9	1.8 (1.6–2.0)	4.7 (4.5–5.0)
Other	2,657,417	493.0	214.8 (189.8–239.3)	707.8 (682.7–732.3)
Subtotal	3,725,431	845.4	528.3 (466.9–588.7)	1373.7 (1312.3–1434.1)
Outside IRAs				
POG	1,009,308	327.0	295.6 (261.3–329.5)	622.6 (588.3–656.5)
YG	178,473	73.3	50.7 (44.8–56.5)	124.0 (118.1–129.8)
Other	1,860,951	376.8	181.6 (160.5–202.3)	558.4 (537.3–579.2)
Subtotal	3,048,732	777.1	527.9 (466.6–588.3)	1305.1 (1243.7–1365.4)
Total				
POG	2,069,344	676.5	607.3 (536.8–676.9)	1283.8 (1213.3–1353.3)
YG	186,451	76.3	52.5 (46.4–58.5)	128.8 (122.7–134.8)
Other	4,518,369	869.8	396.5 (350.2–441.6)	1266.3 (1220.0–1311.4)
Total	6774,163	1622.6	1056.3 (933.4–1177.0)	2678.8 (2556.0–2799.5)

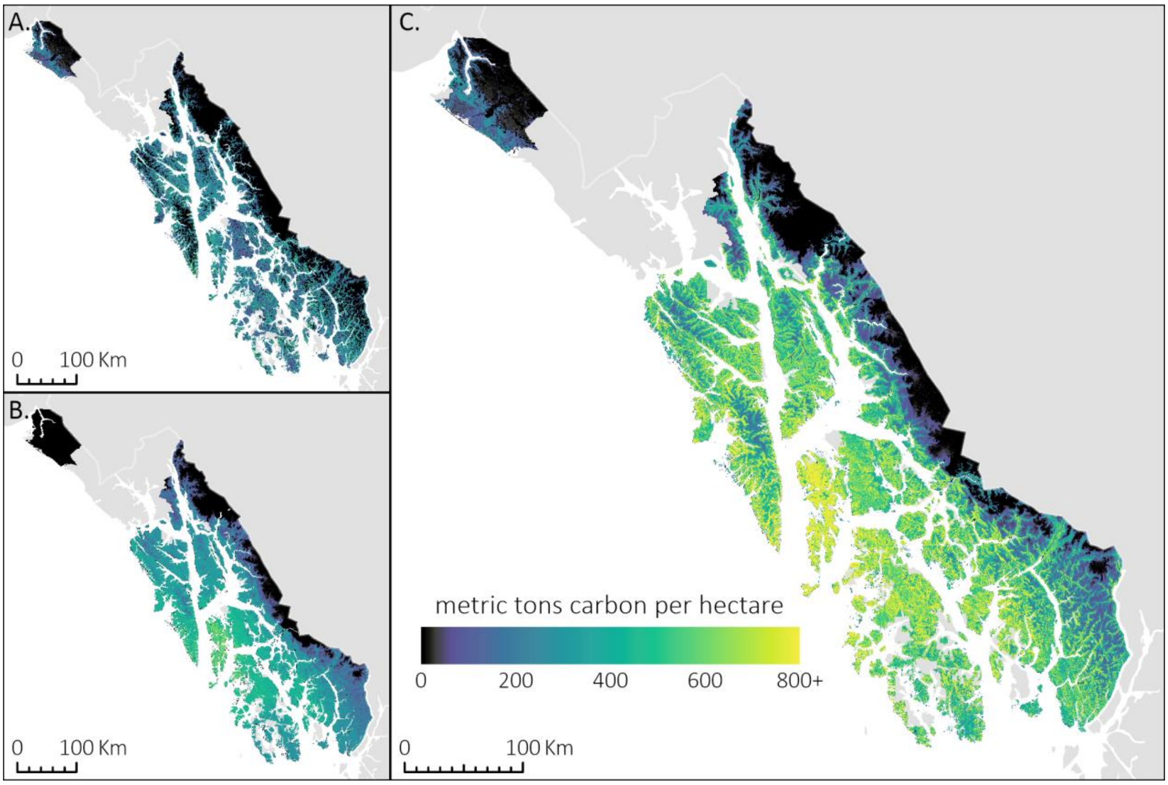

Figure 2. Spatial distribution of carbon (metric tons ha^{-1}) stored in (**A**) woody plant biomass (carbon pools include trees, roots, woody debris, seedlings/saplings, snags, and understory vegetation), (**B**) soil organic matter (top 1 m of mineral soil plus surface organic horizons), and (**C**) the sum of biomass and soil in the Tongass National Forest.

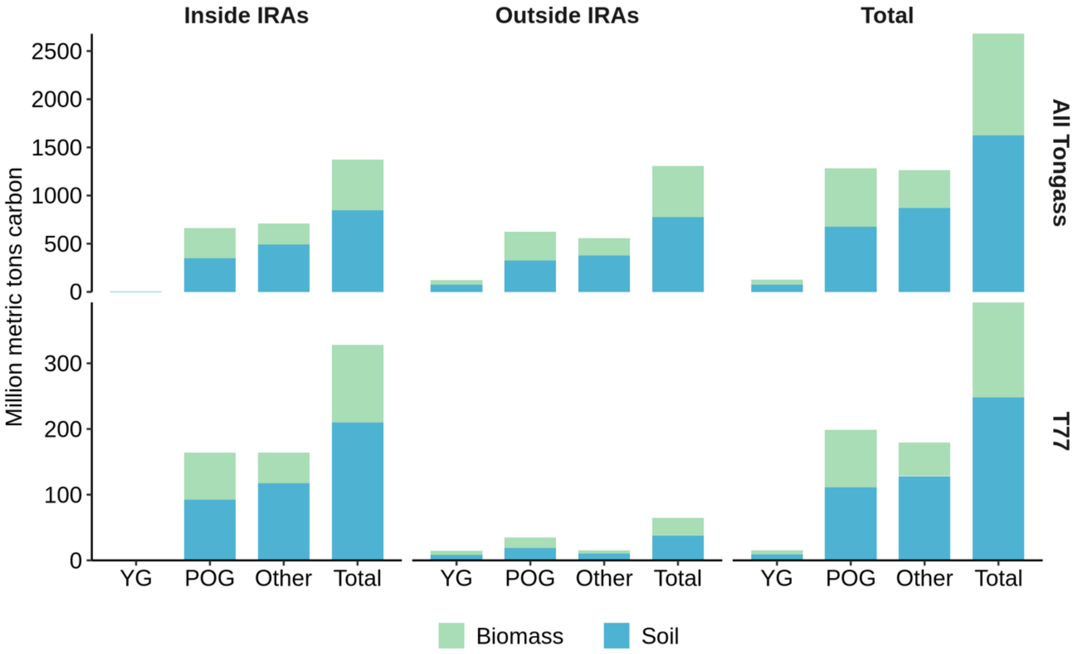

Figure 3. Carbon (million metric tons) stored in woody plant biomass and soil by forest age class (YG = young growth; POG = productive old growth) both inside and outside of Inventoried Roadless Areas (IRAs) and inside Tongass 77 watersheds (T77; bottom row) on the Tongass National Forest (top).

3.4. At-Risk Scenarios

About 11% of the total IRAs on the TNF are within LUDs that could be developed (Scenario 1, Table 3). Some 40% of the vulnerable IRAs and their C stock contain POG (Scenario 2, Table 3). About half those in at-risk IRAs would be exposed to development under the Trump administration's rollback of roadless protections (Scenario 3, Table 3). Notably, West Chichagof-Yakobi and Prince of Wales Island, along with several smaller islands close to the mainland, show the highest concentration of IRA vulnerabilities to development (Figure 4). Overall, our analysis illustrates the importance of retaining the protective measures of IRAs on the TNF.

Table 3. Area (hectares, ha) and carbon stocks (million metric tons) affected by three policy scenarios centered on at-risk inventoried roadless areas. See Section 2.5. for description of scenarios. Note, the areas of these regions are not mutually exclusive and are depicted visually in Figure 4. Values within parentheses are ranges (lower and upper bound). Biomass was scaled [25] to determine lower and upper bounds using the range of ratios between the live trees measured by Forest Inventory Analysis (FIA) plot data and the other C pools (excluding soils) [12]. Soil was not scaled (see [28]), hence the lack of ranges.

Scenario	Area (ha)	Soil (Mt C)	Woody Biomass (Mt C)	Total (Mt C)
1.	1,015,701	342.6	196.8 (173.9–219.3)	539.4 (516.5–561.9)
2.	408,808	148.1	117.5 (103.9–131.0)	265.6 (252.0–279.1)
3.	201,483	75.3	60.6 (53.6–67.6)	135.9 (128.8–142.8)

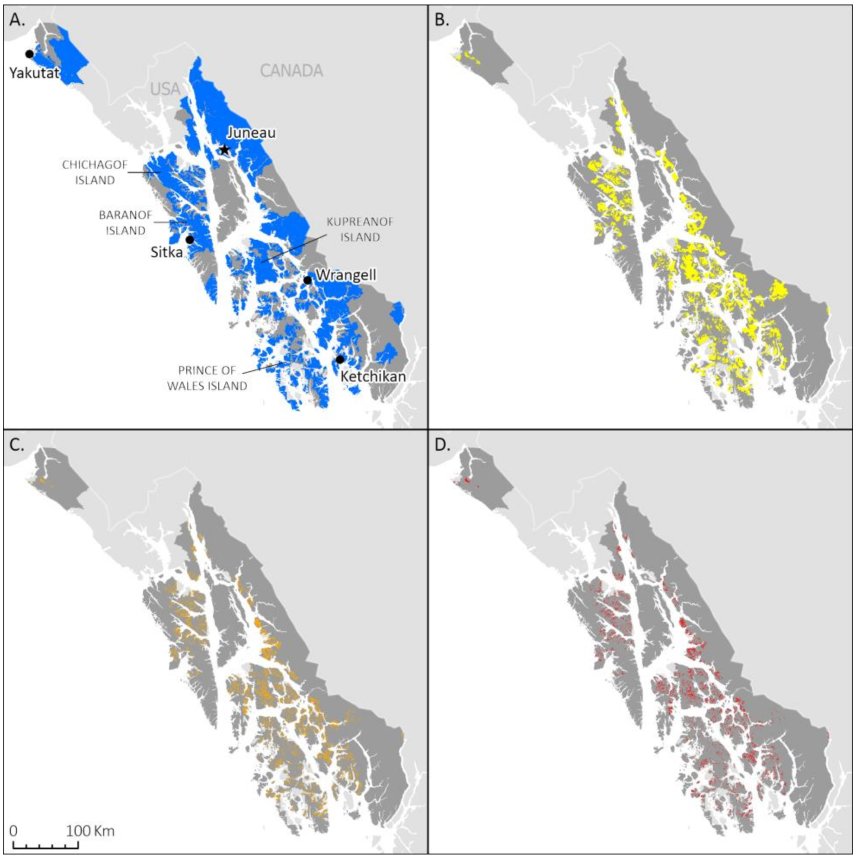

Figure 4. Spatial distribution of inventoried roadless areas based on: (**A**) all roadless areas (blue), (**B**) scenario 1 (yellow), (**C**) scenario 2 (orange), and (**D**) scenario 3 (red). Study area shown in gray. See Section 2.5. for description of scenarios.

3.5. Estimated Carbon Emissions

Our estimates of committed 100-year carbon dioxide emissions attributable to HWP (1910–2013) exhibit strong agreement with previous estimates [33] for the USFS Alaska Region (Tongass and Chugach National Forests combined; Figure S4). On the TNF, over the period 1909–2100, committed 100-year emissions track annual logging levels, rising sharply from the 1950s and peaking in the 1970s, followed by a decreasing trend into the 21st century (Figure 5). During this period (pulp era, 1952–2000), committed 100-year emissions average >900,000 t CO_2 yr^{-1}, the most of any period (Table 4). By the transition era (2016–2021), average committed emissions dropped more than 90% to 60,449 t CO_2 yr^{-1} (Table 4). With logging levels projected to rise into the future, committed emissions are anticipated to more than double to approximately 128,374 t CO_2 yr^{-1} between 2022 and 2031 and then more than double again to 273,492 t CO_2 yr^{-1} from 2032 onward (Table 4). Despite the expected increases, projected emissions should remain far below the peak emissions of the 1970s (Figure 5B, Table 4). Following a similar trend, annual realized emissions peaked during the pulp era (1952–2000), averaging >750,000 t CO_2 yr^{-1} followed by a drop to <250,000 t CO_2 yr^{-1} by the present day (Figure 5B, Table 4). Cumulative realized emissions show the fastest increase during the second half of the 20th century (Figure 5B), and over the full period of the analysis (1909–2100), we estimated 69.5 Mt CO_2 of cumulative emissions from HWP (Table S2).

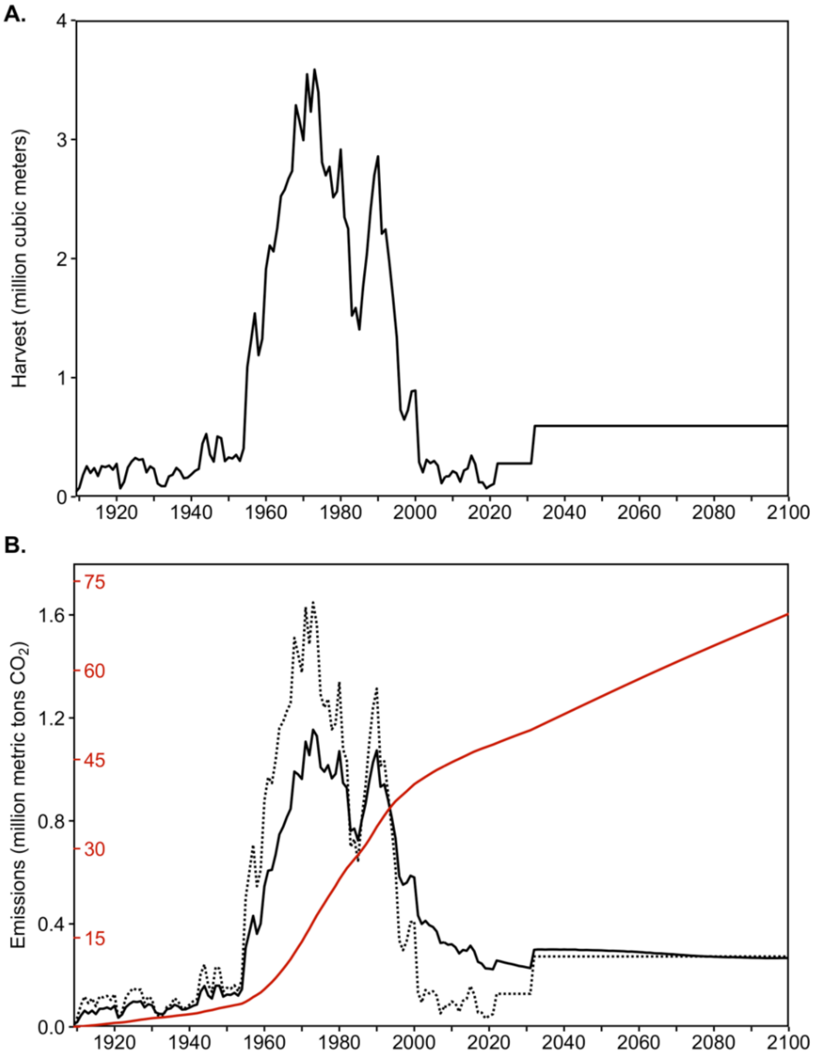

Figure 5. (**A**) Historic (1909–2021) and projected (2022–2100) annual harvest volumes (million cubic meters) for the Tongass National Forest. (**B**) Estimated 100-yr emissions from harvested wood products

(i.e., based on (**A**)), including annual committed (black dotted line), annual realized (black solid line), and cumulative realized (red line) emissions (million metric tons CO_2). Committed emissions reflect the CO_2 emissions that are annually committed to reach the atmosphere given the total harvested volume in a given year. Realized emissions model a more temporally realistic disposition of CO_2 emissions to the atmosphere following published wood product decay curves (see methods). Cumulative realized emissions track the cumulative sum of annual realized emissions through time.

Table 4. Historic (1909–2021) and projected (2022–2100) carbon dioxide emissions from harvested wood products (HWP) on the Tongass National Forest by era. Average (metric tons CO_2 per year) and total (million metric tons CO_2) annual committed and realized emissions are based on a 100-year HWP disposition period. See Table S2 for all annual-level estimates as well as cumulative realized emissions for the 1909–2100 timeframe.

Years	**Era**	**Committed 100-Year Emissions**		**Realized 100-Year Emissions**	
		Average ($t\ CO_2\ yr^{-1}$)	**Total ($Mt\ CO_2$)**	**Average ($t\ CO_2\ yr^{-1}$)**	**Total ($Mt\ CO_2$)**
1909–1951	Early Historical	111,692	4.8	81,673	3.5
1952–2000	Pulp	938,147	46.0	761,687	37.3
2001–2015	Post Pulp	105,763	1.6	346,387	5.2
2016–2021	Transition	60,449	0.4	244,912	1.5
2022–2031	Projections	128,374	1.3	242,374	2.4
2032–2100	Projections	273,492	18.9	284,168	19.6

4. Discussion

4.1. Timber Volume and Associated Impacts

Logging on the TNF can be traced back to at least 1909 with timber volume at 37,000 m^3; logging remained at relatively low levels of $\leq$243,000 $m^3\ yr^{-1}$ for decades prior to World War II. The relatively low early historical levels were mainly because Alaska was the last old growth timber frontier in the USA and the high cost of access (roads) and shipping logs overseas. However, the onset of the pulp era, and signing of two 50-year contracts in the 1950s, ushered in nearly a 15-fold increase over the early historical period, with a peak in logging volume in 1973 followed by a precipitous decline when the pulp contracts expired in 2000. During peak years, the largest tree POG forests were disproportionately targeted due to high levels of timber volume at the stand level [1]. Timber volumes hit their lowest contemporary levels in 2019, a 50-fold decrease from the 1973 peak. Logging levels are projected to increase ~8-fold from the 2019 low through the end of the century, with most of the volume anticipated from young forests (if the transition to young-growth logging holds). In general, future fluctuations in timber volumes are anticipated under the TLMP transition plan due to a range of factors, including timber demand (e.g., exports vs. domestic), political pressure (presidential administrations), forest plan amendments, and institutional factors related to the time required by the agency to fully transition.

Historical logging on the TNF has come at the expense of primary, old-growth rainforest and intact forest landscapes (roadless areas), which have been replaced by >186,451 ha of production, high road density (>2.6 km/km^2), and naturally regenerated monocultures lacking the structural complexity, C storage capacity, and biodiversity of old growth [2,3]. Much of the logging has been concentrated on Prince of Wales Island, the largest island with the most POG in the Alexander Archipelago [35]. Notably, over 8000 km of roads crisscross the TNF, 2400 km (30%) of which are on Prince of Wales Island alone (https://dot.alaska.gov/stwdplng/scenic/byways-pow.shtml, accessed on 11 February 2022). The impacts of road building can extend 1 km on either side of the road, potentially affecting sensitive taxa, water quality, C storage and sequestration among other impacts [6]. Additionally, since 1980, the timber volume sold from the TNF has generated a deficit, with administrative expenses exceeding revenues and sales proceeding regardless due to congressionally subsidized below-cost timber sales at a cost of approximately $1.7 billion (https:

//www.taxpayer.net/energy-natural-resources/cutting-our-losses-tongass-timber-2/, accessed on 11 February 2022). The TNF represents the most expensive timber program in the national forest system mainly because of road construction and maintenance costs in a remote, island-dominated region.

Despite peak logging periods and high-grade logging practices [1], 92% of productive forests on the TNF remain in old growth condition, compared to 8% in young growth (following previous clearcut logging). Earlier studies reported 90% of productive forests were POG based on USDA reports in 1991 [21]. Others [1,35] reported 88% of the entire region of southeast Alaska (state and native Alaskan corporation lands included) was POG at the time. Slight differences in POG estimates are likely due to differences in spatial extent and methods among studies. Nevertheless, the TNF is unique in that most of its forests remain POG, unlike those in the conterminous USA where nearly all old growth was logged long ago and replaced by intensively managed timber lands.

4.2. Carbon Stock (Carbon Reservoir)

Our findings underscore the significance of the C stock on the TNF. Using FIA plot data, researchers [12] reported the total Tongass C stock of 2.8 ± 0.5 Pg as compared to 2.7 Pg (upper bound 2.8) in our study. The earlier study [12] also noted that the TNF represented 8% of the total C stock in all forests in the conterminous USA. Our figure of 20% compares the Tongass C stock to that of the national forest system [36] rather than all conterminous USA forests [12], showcasing the significance of the TNF among federally managed national forests. The high C stock value of the TNF is particularly noteworthy given that the TNF represents just under 9% of the total area of the national forest system but has a relatively large share (20%) of the national forest C stock. This relative comparison speaks not only to the significance of the TNF as a C reservoir, but also as a region of conservation focus, allowing decision makers to prioritize strategically important natural climate solutions [37,38]. Notably, the 2.7 Pg C stock estimate for the TNF represents a CO_2e of 1.5 times US aggregate GHG emissions in 2019 (https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf?VersionId=uuA7i8WoMDBOc0M4ln8WVXMgn1GkujvD; accessed on 15 April 2022).

In this study and a prior one [12], a substantial amount of the stored C was in the soils. We reported ~53% and 47% of C in soils and woody biomass, respectively, compared to the earlier [12] estimate of 66% and 36% of C in the soil and woody biomass pools. Our findings for IRAs are closer to earlier figures [12], with 62% and 39% of C in soils and biomass, respectively. Differences in C stock estimates likely reflect the datasets used (FIA plots vs. pooled datasets in our study) and perhaps differences in site productivity among sampled areas. Importantly, our study provides a spatially explicit and updated dataset that can be publicly accessed (databasin.org).

It should be noted that we assessed only the C stock value of the TNF. Prior researchers [12] provided an estimate of the annual C sequestration rate of unlogged forests at 0.04–0.33 Tg C yr^{-1}, which would build on the C sink potential of the TNF as logging transitions out of the most C rich and biodiverse areas.

4.3. Importance of IRAs and Tongass 77 Watersheds

Inventoried roadless areas have a long history of conservation in the USA, beginning in the 1970s with the RARE I and RARE II (Roadless Area Review and Evaluation) mapping processes used for making wilderness nominations to Congress [39]. Subsequently, a lot of attention has focused on IRAs, with some areas being designated wilderness, and most others protected administratively (National Roadless Conservation Rule) because of their superior biodiversity values compared to logged areas [5–7].

The TNF is a “hot spot” of IRA values and challenges, representing 16% of the nation’s total IRAs and the subject of numerous court cases. While IRA fish and wildlife habitat values have been documented on the TNF [40], our study is the first to quantify the C stock value of IRAs, which contain over half the entire C stock on the TNF. Importantly, the C stock within IRA POGs (and POGs generally) are likely to remain relatively stable compared to the interior of Alaska and the southern extent of the North Pacific coastal temperate rainforest biome subject to more extreme climate change [41–43].

The protection of IRAs also has enjoyed broad public support (>95% of thousands of comments received by the USDA Forest Service have been supportive; https://www.usda.gov/media/press-releases/2021/11/19/usda-announces-steps-restore-roadless-protections-tongass-national; accessed on 14 February 2022) from Alaskan tribes, scientists, conservation groups, and fishing and recreational interests that may benefit economically and culturally (traditional tribal values) from these intact ecosystems if they are fully protected.

The T77 watersheds also contain important POG habitat, but the T77 conservation strategy alone represents far less C savings than IRAs, with only about 15% of the total C stock in T77s, mostly within the T77 POGs. The lower C stock value is likely an artifact of the selection process for the T77, which was weighted toward salmon conservation regardless of the presence of POGs, so long as watersheds were intact (no roads) and productive in terms of salmon. Nevertheless, the T77 watersheds have biodiversity and other values that extend well beyond the C-centric focus of our study [11].

4.4. Stock Change Due to Logging

The USDA Forest Service has repeatedly stated that emissions from logging on the TNF are insignificant compared to total US GHGs and thus logging emissions can be summarily dismissed since they are offset by both natural forest regeneration and storage in HWP pools [10,24]. However, offsetting emissions by forest regrowth involves a time lag of at least a century for an equivalent stock of C to be re-sequestered [30]. While forest regeneration on productive Tongass sites proceeds quickly (within a decade), and is from natural seed sources (nearby standing trees), young forests are expected to remain on short logging rotations with harvests planned every 55–70 years on productive sites under the TLMP transition plan. On average, after 100 years, storage in wood products from the PNW, for example, accounts for ~13% of the original C stock with an additional ~29% in landfills [29]. Thus, wood products represent little more than delayed emissions [30]. Additionally, the extensive road network, including log-landings and haul-out sites, means an unknown amount of the C stock may never be replaced so long as those areas remain treeless.

Our estimates of logging emissions from the TNF are conservative given that they involve the conversion of roundwood in cubic meters to CO_2 emissions. Accounting for out-of- boundary emissions in wood processing and log transport is beyond the scope of our study; however, these additional emissions can be substantial given that up to 50% of roundwood logs can be exported over large distances (e.g., to China and Japan) [10].

5. Conclusions

As one of the world's last relatively intact temperate rainforests, the TNF provides ecosystem services that are of global significance and warrant expanded conservation. The TNF represents ~12% of the entire Pacific Northwest Coastal Forest bioregion, an expansive rainforest region spanning several globally distinctive ecoregions and climatic subzones from the Coast Redwoods to the northern Kodiak archipelago in Alaska, which collectively make up 34% of all the world's temperate rainforests, the largest such concentration [3]. Some 2.1 M ha of the TNF remains as POG, also among the largest such amounts for temperate rainforests [2,3]. The TNF, contains 16% of the nation's IRAs, which, along with the Chugach National Forest to the north, represent the most relatively intact national forest in the national forest system. Its abundant salmon runs (all six *Oncorhynchus* species) and wildlife populations, some of which are imperiled in the lower 48 states, achieve their highest densities in intact watersheds such as the Tongass 77 [11].

Our study builds on the knowledge base of the Tongass' disproportionate values by documenting that some 20% of the entire national forest C stock is remarkably held by this single national forest alone, providing if nothing else a C reservoir of national significance.

Most of the C stock is in POGs, roughly distributed between roaded areas and IRAs. By contrast, only ~5% of the C stock is within young growth and mostly roaded areas.

The maritime climate and intact forests of the TNF have climate refugia properties compared to more extreme climatic zones in the interior of Alaska and temperate rainforests further south [41–43], thereby offering a relatively stable C reservoir. However, due to declining late-season snow cover that prevents late-winter root freezing, yellow-cedar is experiencing a range contraction, and is a climate-sensitive focal species [44]. Importantly, many fish and wildlife species that benefit from IRAs and POGs are the staple foods of Native Alaskans, representing an important bio-cultural connection made possible by the relative intactness of the Tongass rainforest system.

Despite its global recognition, including its near incomparable position among old-growth temperate rainforests, the TNF is a dynamic system where island biogeographic effects have contributed to isolation factors with potentially high species turnover rates [45]. Notably, the cumulative addition of novel anthropogenic fragmentation from expansive roads and clearcuts may result in more consequential isolation of vulnerable species over time, especially on Prince of Wales Island where logging and roads are greatest. For instance, the Alexander Archipelago wolf (*Canis lupus ligoni*) has been repeatedly proposed for listing under the USA Endangered Species Act with the US Fish and Wildlife Service recently determining that listing may be warranted (https://www.fws.gov/alaska/stories/service-completes-initial-review-petition-list-alexander-archipelago-wolf-species-status#:~:text=The%20U.S.%20Fish%20and%20Wildlife,you%20can%20access%20the%20document; accessed on 14 February 2022). Concerns over the status of wolf populations on Prince of Wales Island are mainly due to declining deer populations and hunting pressures [46]. However, the relative intactness of IRAs, POGs, and the T77 offer the best prospects for maintaining viable wildlife populations that are otherwise under combined pressures of climate change and anthropogenic habitat fragmentation.

Our results, coupled with broad scientific and public interest in the TNF as "America's rainforest," provide a foundation for a multi-pronged conservation strategy that includes: (1) protecting all remaining old growth, IRAs, and T77 priority areas from logging as strategic carbon reserves [38]; (2) supporting the transition to logging young-growth forests that by some accounts can already accommodate a full transition without further POG logging [47]; and (3) increasing ecological-based restoration of high road density areas (e.g., road decommissioning). A small portion (7978 ha) of young-growth forest is within IRAs where logging was likely conducted by helicopter. Those areas should be candidates for proforestation [37] to restore carbon stocks over time. Thus, a climate-smart strategy centered on sequestration and accumulation of C is generally essential to addressing the climate crisis [37] and would offer co-benefits, including a host of ecosystem services derived from C dense forests [48] as well as potential climate refugia [41–43].

The TNF is uniquely positioned for large-landscape conservation that protects remaining primary rainforest given that the transition out of old growth logging is taking place before most, if not all, of the primary forests are gone, unlike most nations that only transition when primary forests are liquidated and replaced by industrial forest lands [49]. As the national champion of forest C stocks, federally mandated protection of TNF POGs, IRAs, and T77 areas would offer global leadership on the establishment of land-based targets under the Paris Climate Agreement, while following through on the Glasgow leaders' declaration to end global forest losses by 2030 (which included President Biden) [50].

Notably, Article 5.1 of the Paris Agreement states [19], "Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases." Additionally, the Summary for Policy Makers (SPM) of the Working Group II contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [51] noted that "safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation (very high confidence)." Our results support the inclusion of the Tongass National Forest in a forest carbon reserve system centered on IRAs, POGs, the T77, and a portion of young growth to conserve and enhance the substantial carbon values and resilience potential of this forest.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11050717/s1, http://www.databasin.org, Figure S1: Approach to quantifying harvested wood product pools (HWP) storage and emissions; Figure S2: Spatial distribution of total carbon (metric tons ha^{-1}) in woody plant biomass and soil in at-risk scenarios for IRAs (inventoried roadless areas): (A) all IRAs, (B) Scenario 1, (C) Scenario 2, and (D) Scenario 3. Figure S3: Spatial distribution of T77 watersheds and total carbon (metric tons ha^{-1}) in woody plant biomass and soil pools combined. Figure S4: Committed 100-year emissions from both Tongass and Chugach National Forest timber harvests (1910–2013). Comparison of our study with prior research. Table S1: Carbon datasets used in this study. Table S2: Historic (1909–2021) and projected (2022–2100) harvest levels (thousand cubic meters per year, 1×10^3 m^3 yr^{-1}), committed 100-year emissions (thousand metric tons carbon dioxide equivalents per year, 1×10^3 tCO_2 yr^{-1}), annual realized emissions (1×10^3 tCO_2 yr^{-1}), and cumulative realized emissions (1×10^3 tCO_2 yr^{-1}) on the Tongass National Forest. All emissions estimates are based on a 100-year HWP disposition period. Supplemental references provided [52].

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Presidential Documents

Executive Order 14072 of April 22, 2022

Strengthening the Nation's Forests, Communities, and Local Economies

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. *Policy.* Strengthening America's forests, which are home to cherished expanses of mature and old-growth forests on Federal lands, is critical to the health, prosperity, and resilience of our communities—particularly in light of the threat of catastrophic wildfires. Forests provide clean air and water, sustain the plant and animal life fundamental to combating the global climate and biodiversity crises, and hold special importance to Tribal Nations. We go to these special places to hike, camp, hunt, fish, and engage in recreation that revitalizes our souls and connects us to history and nature. Many local economies thrive because of these outdoor and forest management activities, including in the sustainable forest product sector.

Globally, forests represent some of the most biodiverse parts of our planet and play an irreplaceable role in reaching net-zero greenhouse gas emissions. Terrestrial carbon sinks absorb around 30 percent of the carbon dioxide emitted by human activities each year. Here at home, America's forests absorb more than 10 percent of annual United States economy-wide greenhouse gas emissions. Conserving old-growth and mature forests on Federal lands while supporting and advancing climate-smart forestry and sustainable forest products is critical to protecting these and other ecosystem services provided by those forests.

Despite their importance, the world's forests are quickly disappearing; only a small fraction of the world's mature and old-growth forests remains. Here at home, the primary threats to forests, including mature and old-growth forests, include climate impacts, catastrophic wildfires, insect infestation, and disease. We can and must take action to conserve, restore, reforest, and manage our magnificent forests here at home and, working closely with international partners, throughout the world.

It is the policy of my Administration, in consultation with State, local, Tribal, and territorial governments, as well as the private sector, nonprofit organizations, labor unions, and the scientific community, to pursue science-based, sustainable forest and land management; conserve America's mature and old-growth forests on Federal lands; invest in forest health and restoration; support indigenous traditional ecological knowledge and cultural and subsistence practices; honor Tribal treaty rights; and deploy climate-smart forestry practices and other nature-based solutions to improve the resilience of our lands, waters, wildlife, and communities in the face of increasing disturbances and chronic stress arising from climate impacts. It is also the policy of my Administration, as outlined in *Conserving and Restoring America the Beautiful*, to support collaborative, locally led conservation solutions.

The Infrastructure Investment and Jobs Act (IIJA) I signed into law provides generational investments in ecosystem restoration and wildfire risk reduction. As we use this funding, we will seek opportunities, consistent with the IIJA, to conserve our mature and old-growth forests on Federal lands and restore the health and vibrancy of our Nation's forests by reducing the threat of catastrophic wildfires through ecological treatments that create resilient forest conditions using active, science-based forest management and prescribed fires; by incorporating indigenous traditional ecological knowledge; and by scaling up and optimizing climate-smart reforestation. My Administration also is committed to doing its part to combat deforestation around the world and to working with our international partners toward sustainable management of the world's lands, waters, and ocean.

Sec. 2. *Restoring and Conserving the Nation's Forests, Including Mature and Old-Growth Forests*. My Administration will manage forests on Federal lands, which include many mature and old-growth forests, to promote their continued health and resilience; retain and enhance carbon storage; conserve biodiversity; mitigate the risk of wildfires; enhance climate resilience; enable subsistence and cultural uses; provide outdoor recreational opportunities; and promote sustainable local economic development. Science-based reforestation is one of the greatest opportunities both globally and in the United States for the land sector to contribute to climate and biodiversity goals. To further conserve mature and old-growth forests and foster long-term United States forest health through climate-smart reforestation for the benefit of Americans today and for generations to come, the following actions shall be taken, in consultation with State, local, Tribal, and territorial governments and the public, and to the extent consistent with applicable law:

(a) The Secretary of the Interior and the Secretary of Agriculture (Secretaries)—the Federal Government's primary land managers—shall continue to jointly pursue wildfire mitigation strategies, which are already driving important actions to confront a pressing threat to mature and old-growth forests on Federal lands: catastrophic wildfires driven by decades of fire exclusion and climate change.

(b) The Secretary of the Interior, with respect to public lands managed by the Bureau of Land Management, and the Secretary of Agriculture, with respect to National Forest System lands, shall, within 1 year of the date of this order, define, identify, and complete an inventory of old-growth and mature forests on Federal lands, accounting for regional and ecological variations, as appropriate, and shall make such inventory publicly available.

(c) Following completion of the inventory, the Secretaries shall:

(i) coordinate conservation and wildfire risk reduction activities, including consideration of climate-smart stewardship of mature and old-growth forests, with other executive departments and agencies (agencies), States, Tribal Nations, and any private landowners who volunteer to participate;

(ii) analyze the threats to mature and old-growth forests on Federal lands, including from wildfires and climate change; and

(iii) develop policies, with robust opportunity for public comment, to institutionalize climate-smart management and conservation strategies that address threats to mature and old-growth forests on Federal lands.

(d) The Secretaries, in coordination with the heads of other agencies as appropriate, shall within 1 year of the date of this order:

(i) develop a Federal goal that charges agencies to meet agency-specific reforestation targets by 2030, including an assessment of reforestation opportunities on Federal lands and through existing Federal programs and partnerships;

(ii) develop, in collaboration with Federal, State, Tribal, and private-sector partners, a climate-informed plan (building on existing efforts) to increase Federal cone and seed collection and to ensure seed and seedling nursery capacity is sufficient to meet anticipated reforestation demand; and

(iii) develop, in coordination with the Secretary of Commerce, with State, local, Tribal, and territorial governments, and with the private sector, nonprofit organizations, labor unions, and the scientific community, recommendations for community-led local and regional economic development opportunities to create and sustain jobs in the sustainable forest product sector, including innovative materials, and in outdoor recreation, while supporting healthy, sustainably managed forests in timber communities.

Sec. 3. *Stopping International Deforestation*. As described in the *Plan to Conserve Global Forests: Critical Carbon Sinks*, my Administration has committed to deliver, by 2030, on collective global goals to end natural forest loss and to restore at least an additional 200 million hectares of forests and other ecosystems, while showcasing new economic models that reflect the services provided by critical ecosystems around the world. The plan recognizes that conserving and restoring global forest and peatland ecosystems, particularly in the Amazon, Congo Basin, and Southeast Asia, can provide significant global greenhouse gas emissions mitigation, both by preventing the emissions caused by deforestation and by increasing the amount of carbon dioxide captured from the atmosphere and stored in soils and forest biomass. My Administration is also committed to combating illegal logging and stopping trade in illegally sourced wood products pursuant to the Lacey Act, as amended, 16 U.S.C. 3371 *et seq*., and to addressing the related importation of commodities sourced from recently deforested land. To further advance these commitments, conserve these critical ecosystems, and address drivers of global deforestation—including illegal forest clearing to produce agricultural commodities—the following actions shall be taken:

(a) within 1 year of the date of this order, the Secretary of State, in consultation with the Secretary of the Treasury, the Secretary of Agriculture, the Secretary of Commerce, the Secretary of Homeland Security (through the Commissioner of U.S. Customs and Border Protection), the Administrator of the Small Business Administration, the Administrator of the United States Agency for International Development, the United States Trade Representative, and the Special Presidential Envoy for Climate, shall submit a report to the President evaluating options, including recommendations for proposed legislation, for a whole-of-government approach to combating international deforestation that includes:

(i) an analysis of the feasibility of limiting or removing specific commodities grown on lands deforested either illegally or after December 31, 2020, from agricultural supply chains; and

(ii) an analysis of the potential for public-private partnerships with major agricultural commodity buyers, traders, financial institutions, and other actors to voluntarily reduce or eliminate the purchase of such commodities and incentivize sourcing of sustainably produced agricultural commodities.

(b) within 1 year of the date of this order, the Secretary of State, in coordination with other appropriate agencies, shall submit a report to the President on how agencies that engage in international programming, assistance, finance, investment, trade, and trade promotion, can, consistent with applicable law, accomplish the following:

(i) incorporate the assessment of risk of deforestation and other land conversion into guidance on foreign assistance and investment programming related to infrastructure development, agriculture, settlements, land use planning or zoning, and energy siting and generation;

(ii) address deforestation and land conversion risk in new relevant trade agreements and seek to address such risks, where possible, in the implementation of existing trade agreements;

(iii) identify and engage in international processes and fora, as appropriate, to pursue approaches to combat deforestation and enhance sustainable land use opportunities in preparing climate, development, and finance strategies;

(iv) engage other major commodity-importing and commodity-producing countries to advance common interests in addressing commodity-driven deforestation; and

(v) assess options to direct foreign assistance and other agency programs and tools, as appropriate, to help threatened forest communities transition to an economically sustainable future, with special attention to the participation of and the critical role played by indigenous peoples and local communities and landholders in protecting and restoring forests and in reducing deforestation and forest degradation.

Sec. 4. *Deploying Nature-Based Solutions to Tackle Climate Change and Enhance Resilience*. Just as forest conservation, restoration, and adaptation generate broad benefits related to climate change and other areas, other nature-based solutions can advance multiple benefits. These solutions include actions that protect coasts and critical marine ecosystems, reduce flooding, moderate extreme heat, replenish groundwater sources, capture and store carbon dioxide, conserve biodiversity, and improve the productivity of agricultural and forest lands to produce food and fiber. To ensure that agencies pursue nature-based solutions, to the extent consistent with applicable law and supported by science, the following actions shall be taken:

(a) The Chair of the Council on Environmental Quality, the Director of the Office of Science and Technology Policy, and the Assistant to the President and National Climate Advisor shall, in consultation with the Secretary of Defense (through the Assistant Secretary of the Army for Civil Works), the Secretary of the Interior, the Secretary of Agriculture, the Secretary of Commerce (through the Administrator of the National Oceanic and Atmospheric Administration), the Secretary of Housing and Urban Development, the Secretary of Transportation, the Secretary of Energy, the Secretary of Homeland Security (through the Administrator of the Federal Emergency Management Agency), the Administrator of the Environmental Protection Agency, the Administrator of the Small Business Administration, and the heads of other agencies as appropriate, submit a report to the National Climate Task Force to identify key opportunities for greater deployment of nature-based solutions across the Federal Government, including through potential policy, guidance, and program changes.

(b) The Director of the Office of Management and Budget shall issue guidance related to the valuation of ecosystem and environmental services and natural assets in Federal regulatory decision-making, consistent with the efforts to modernize regulatory review required by my Presidential Memorandum of January 20, 2021 (Modernizing Regulatory Review).

(c) Implementation of the United States Global Change Research Program shall include an assessment of the condition of nature within the United States in a report carrying out section 102 of the Global Change Research Act of 1990, 15 U.S.C. 2932.

Sec. 5. *General Provisions*. (a) Nothing in this order shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(b) This order shall be implemented consistent with applicable law and subject to the availability of appropriations.

(c) This order is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

J.R. Biden Jr.

THE WHITE HOUSE,
April 22, 2022.

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AGU Advances

RESEARCH ARTICLE
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Key Points:

- The Tongass and Chugach are the largest and most intact of all US National Forests, with key bald eagle, brown bear, and gray wolf habitat
- The Tongass and Chugach are cool and wet with forest carbon stocks minimally impacted by wildfire and likely to increase with climate change
- The Tongass, Chugach and Pacific Northwest's National Forests are high priority for protection to meet climate and biodiversity goals

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

B. E. Law and L. T. Berner,
lawb@oregonstate.edu;
berner.logan@gmail.com

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Author Contributions:

Conceptualization: B. E. Law, L. T. Berner, W. J. Ripple
Data curation: L. T. Berner
Formal analysis: B. E. Law, L. T. Berner, R. A. Birdsey
Investigation: B. E. Law, C. Wolf, E. J. Trammell, R. A. Birdsey

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Southern Alaska's Forest Landscape Integrity, Habitat, and Carbon Are Critical for Meeting Climate and Conservation Goals

B. E. Law[1,2], L. T. Berner[3], C. Wolf[1], W. J. Ripple[1,2], E. J. Trammell[4], and R. A. Birdsey[5]

[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR, USA, [2]Conservation Biology Institute, Corvallis, OR, USA, [3]EcoSpatial Services L.L.C., Juneau, AK, USA, [4]Southern Oregon University, Ashland, OR, USA, [5]Woodwell Climate Research Center, Falmouth, MA, USA

Abstract The interdependent crises of climate change and biodiversity losses require strategic policies to protect, manage, and restore essential ecosystems. Here, we evaluate the relative importance of US national forests (NFs) for protection and conservation as natural climate and biodiversity solutions. We compared landscape integrity (degree of modification by humans), habitat for three keystone species, forest carbon density, accumulation, and total biomass carbon stocks across 154 NFs in the United States. Southern Alaska's Tongass and Chugach NFs hold disproportionally large amounts of high landscape integrity area among all NFs with 25.3% and 5.6% (total 30.9%) of all high (≥9.6) landscape integrity found on NF lands. The Tongass and Chugach store approximately 33% and 3% of all biomass carbon stocks that occur in NFs with high landscape integrity. These two NFs together account for about 49%, 37%, and 18% of all bald eagle, brown bear, and gray wolf habitat found on NF lands. Gray wolf habitat extent was 4% of the total or less on remaining NFs. The Tongass and Chugach were historically wetter and cooler among NFs, and are projected to experience much larger increases in precipitation and much lower increases in maximum temperatures over the coming century. Combined with relatively low recent occurrence of wildfire, this makes permanence more likely. The Tongass and Chugach forests, along with the Pacific Northwest's high carbon density forests should be a high priority for protection and conservation to meet climate and biodiversity goals given their landscape-scale scarcity and high value.

Plain Language Summary Permanent protection of forests with relatively high carbon stocks, landscape integrity, and habitat extent would contribute substantially to climate mitigation and species adaptation. The Tongass and Chugach National Forests in southern Alaska rank highest among U.S. National Forests in all three areas. These forests also have relatively low near-term vulnerability to wildfire and climate, higher connectivity for animal movement, and lower human impacts, making permanence more likely.

1. Introduction

Forests play crucial roles for mitigating climate change and supporting biodiversity, thus making it important to identify and protect the most vital forests (IPCC, 2022; Law et al., 2021). Terrestrial ecosystems have been removing about 30% of global anthropogenic CO_2 emissions from the atmosphere each year for the past 60 years and most of the removal is by forests (Friedlingstein et al., 2022). Climate impacts would be even more severe without this ecosystem service. Yet intact forests with high carbon density and biodiversity are disappearing at an alarming rate (Potapov et al., 2017), such as in the Brazilian Amazon and Canadian British Columbia, which have become net carbon sources (Gatti et al., 2021; Government of British Columbia, 2022; Harris et al., 2021; Qin et al., 2021). Concerningly, current national climate pledges will increase greenhouse gas emissions by 16% from 2010 to 2030, indicating that the planned emissions reductions and increased removals from the atmosphere by the biosphere need to be much more aggressive (UNFCCC, 2021).

Nature-based Climate Solutions (NbCSs) are essential for protecting interdependent forest carbon and biodiversity (Dinerstein et al., 2020), leading to calls for conservation of 30%–50% of Earth's surface in the coming decades (IPCC, 2022). NbCSs allow ecosystems to continue to store and accumulate carbon from the atmosphere, provide habitat for plant and animal species, and protect watersheds. Intact forests are crucial for supporting wildlife, fish, clean water, carbon sequestration, and other ecosystem services (Grantham et al., 2020; Watson et al., 2018). Protected public lands (e.g., Wilderness Areas, National Parks) provide important NbCSs (Law

Methodology: B. E. Law, L. T. Berner, R. A. Birdsey
Supervision: B. E. Law
Validation: L. T. Berner
Visualization: L. T. Berner
Writing – original draft: B. E. Law, L. T. Berner
Writing – review & editing: B. E. Law, L. T. Berner, C. Wolf, W. J. Ripple, E. J. Trammell, R. A. Birdsey

et al., 2021, 2022), in part because they likely afford greater permanence of carbon storage than private lands (Anderegg, 2021). In the United States (US), there are 154 National Forests (NFs) that account for 76% of all federal forest land (590,240 km^2 of 773,620 km^2) (Smith et al., 2019). Logging and other extractive activities are allowed throughout most NF forest lands, with only about 19% classified as "reserved" from timber production (Smith et al., 2019), albeit with varying levels of biodiversity and logging protection. Consequently, there is a substantial gap between current conservation of NF forest lands and conservation targets focused on protecting biodiversity and carbon stocks.

Federal lands managed by the U.S. Forest Service (FS), the National Forest System (NFS), and the Bureau of Land Management are managed under a multiple use—sustained yield model (US Congress, 1960, 1976). The statute directs the agencies to "balance multiple uses of their lands and ensure a sustained yield of those uses in perpetuity" (Riddle, 2022). The balance of multiple uses on federal lands has been an ongoing point of contention (Riddle, 2022), with many concerned that conservation isn't a higher priority given the critical need for meeting conservation targets for climate mitigation and adaptation. Forest management activities, particularly harvest, appear to be in conflict with the intertwined goals of protecting forest carbon and biodiversity for climate mitigation and adaptation. NFs in the conterminous US particularly in the West have experienced increasing incidence of wildfire, insects, and drought, yet still represent the majority of late mature and old-growth forest area remaining, which imparts a unique role in protecting these areas for biodiversity and climate change. Research studies have shown that older forests containing large trees are more resilient and have greater ecosystem integrity than younger forests (Rogers et al., 2022).

The coastal rainforests of southern Alaska are unique ecosystems that could help fill the conservation gap on NF forest lands (DellaSala et al., 2022; Vynne et al., 2021). Two NFs in the region are the Tongass and Chugach NFs (Figure 1). In addition to storing a large amount of carbon (Barrett, 2014; DellaSala et al., 2022), these coastal rainforests have extensive intact forests, complete wildlife assemblages, and are strongholds for wild salmon and other fish (Vynne et al., 2021). Unlike much of the conterminous US, this region still has substantial populations of large carnivores including bald eagle (*Haliaeetus leucocephalus*), brown bear (*Ursus arctos*), and gray wolf (*Canis lupus*). Therefore, to guide conservation planning it is important to understand current forest integrity and protection status in these coastal rainforests, as well as how they compare with other US NFs.

Recently developed spatial data sets can provide valuable insights into current forest integrity and other forest bioclimatic characteristics that are important to consider in conservation planning. For instance, the new forest landscape integrity index (FLII) characterizes the level of forest landscape degradation from human activities in a consistent manner worldwide (Grantham et al., 2020). Other large-scale spatial data sets provide detailed information on forest biomass carbon stocks (Spawn et al., 2020), wildlife habitat (USGS GAP, 2022), and fire activity (Giglio et al., 2018), as well as current and potential future climate (Brun et al., 2022a, 2022b). Forest carbon stocks and wildlife habitat can be eroded by high fire activity and climatic changes that lead to hotter and drier conditions (Buotte et al., 2019). Together, these data sets provide new opportunities to characterize forest bioclimatic conditions across coastal rainforests in southern Alaska and to understand how these rainforests compare with forest lands in other US NFs.

To better understand potential conservation benefits of preserving forest lands in the Tongass and Chugach NFs (Figure 1), we compared forest bioclimatic attributes of these NFs with all other NFs in the conterminous US. We focus on the need to retain large tracts of intact forest landscapes that help mitigate climate change and protect biodiversity as part of a "Strategic Forest Reserve" system emphasizing NbCSs on federal lands in the US. Our objectives are:

1. Compare forest area, landscape integrity, and biomass carbon among NFs;
2. Determine and compare the areal extent of habitat for bald eagle (*Haliaeetus leucocephalus*), brown bear (*Ursus arctos*), and gray wolf (*Canis lupus*) among NFs;
3. Compare recent and projected climate conditions and wildfire occurrence among NFs to determine risk.

Our analysis was based on spatial data sets primarily derived from satellite remote sensing and geospatial modeling (Giglio et al., 2018; Grantham et al., 2020; Hansen et al., 2013; Spawn et al., 2020), though also included future climate projections from CMIP6 (Brun et al., 2022a, 2022b) and current preservation status from the Protected Areas Database of the United States (PAD-US version 3) produced by the US Geological Survey (USGS) Gap Analysis Project (GAP; USGS GAP, 2018). These spatial data sets enable consistent analysis of

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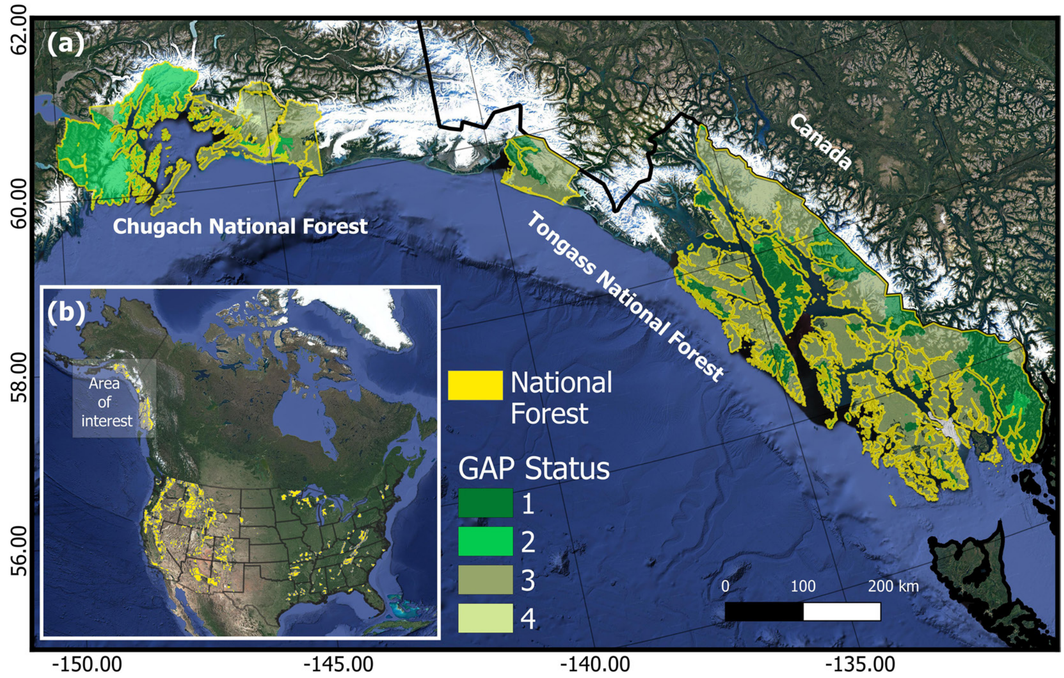

Figure 1. Administrative boundaries of the (a) Tongass and Chugach National Forests in southern Alaska and (b) National Forests throughout the USA. Also shown (a) are the current GAP Status of lands in the Tongass and Chugach National Forests. GAP 1 and GAP 2 lands are managed for biodiversity, GAP 3 lands are managed for multiple uses including mining, logging, and off highway vehicle use, and GAP 4 lands are those with no known mandate for protection. GAP Status data were from the Protected Area Database of the US (PAD-US version 3; USGS GAP, 2022). Basemap from Google Satellite © 2021 Google.

forest attributes across all US NFs. Our analysis highlights unique bioclimatic characteristics of coastal rainforests in southern Alaska that prioritize increased protection for forests in the region.

2. Materials and Methods

2.1. General Approach

We analyzed and ranked forest attributes among NFs using existing spatial data sets related to forest extent, landscape integrity, carbon, biodiversity, wildfires, and climate. Specifically, we focused on federally managed lands within the administrative boundary of each NF, with management type determined based on a spatial overlay with the PAD-US (USGS, 2022). Therefore, our analysis does not include inholdings within NF administrative boundaries, such as lands managed by local or state governments or Alaska Native Corporations. Our analysis also does not include the El Yunque National Forest in Puerto Rico due to data limitations. Most of the spatial data sets had a spatial resolution of ~300 m, therefore we chose to conduct the analysis using a common 300 m resolution grid in an Albers Equal Area projection. We reprojected categorical data sets using nearest neighbor resampling and continuous numeric data sets using bilinear interpolation. We analyzed and visualized data using the R software (version 4.2) (R Core Team, 2021) with the libraries *terra* (Hijmans, 2022), *raster* (Hijmans, 2019), *sf* (Pebesma, 2018), *data.table* (Dowle & Srinivasan, 2021), and *ggplot2* (Wickham, 2016). We created the maps using open-source software QGIS (v3.20; QGIS.org, 2021).

2.1.1. Forest Extent

We quantified the areal extent of forest within each NF using a global tree canopy cover data set (Hansen et al., 2013). This spatial data set provides per pixel estimates of tree canopy cover (0%–100%) at 30 m resolution for peak growing season circa 2010 based on Landsat 7 satellite imagery and regression tree modeling. We mean resampled these data from 30 to 300 m spatial resolution and then identified forestlands as areas with tree canopy cover ≥10%. We determined the total area of forestlands within each NF and used this layer to mask other spatial

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data sets to forestlands. Supplemental analysis showed a strong linear relationship between estimates of total forest area at 30 versus 300 m spatial resolution across NFs ($r^2 = 0.996$, $y = -219 + 0.946\,x$).

2.1.2. Forest Landscape Integrity

We assessed forest ecological integrity across each NF using the forest landscape integrity index (FLII; Grantham et al., 2020). This spatial data set describes the degree of modification of forests by humans and is derived from observed human pressures (infrastructure, agriculture, tree cover loss), inferred human pressure based on proximity to the observed pressures, and loss of forest connectivity (ratio of current to potential connectivity) (Grantham et al., 2020). The anthropogenically disturbed nature of many areas with temporary tree cover loss and recovery is reflected in scoring within the index, because temporary tree cover loss in the categories of shifting cultivation or rotational forestry is treated as an observed pressure. It does not treat tree cover loss associated with wildfire as an observed pressure because fires are often the result of natural processes. The FLII ranges from 0 to 10, with higher scores describing more intact forest landscapes that have ecosystem functions (e.g., carbon storage, biodiversity, watershed protection) closer to natural levels barring potential impacts of climate change. Scores are divided into three levels of integrity, low (≤ 6.0), medium (>6.0 and <9.6), and high (≥ 9.6) and were identified by the data creators (Grantham et al., 2020). Forests with scores ≥ 9.6 are considered to have high integrity based on inspection of benchmark locations (Grantham et al., 2020). The FLII was mapped globally at 300 m resolution using spatial data from 2000 to 2019 and can be applied at subnational to global scales. We computed the average and standard deviation of the FLII across each NF, as well as the total areal extent of high integrity forest (FLII $\geq$ 9.6) within each NF.

2.1.3. Forest Carbon

We quantified tree carbon stocks using harmonized global maps of above and belowground biomass carbon density in the year 2010 at 300 m spatial resolution (Spawn et al., 2020). The data set provides estimates of carbon storage in live tree aboveground (i.e., stems, branches, twigs, and bark) and belowground (i.e., roots) biomass for stems greater than 10 cm diameter at breast height. The data set was derived from remotely sensed measurements of tree aboveground biomass density combined with measurements of biomass carbon content and root to shoot ratios (Spawn et al., 2020). An accuracy assessment showed that estimates of total state-wide tree carbon stocks for states in the conterminous USA were very similar whether derived from the harmonized maps or independent USFS forest inventory data ($r^2 = 0.96$, slope $= 1.17$, $n = 48$; Spawn et al., 2020). We masked this data set to forestlands and then computed average and standard deviation of tree carbon density (Mg C ha^{-1}) for each NF, as well as total tree carbon stock (Tg C) in each NF.

2.1.4. Forest Wildlife Habitat for Keystone Species

We assessed the current areal extent of habitat for bald eagle (*Haliaeetus leucocephalus*), brown bear (*Ursus arctos*), and gray wolf (*Canis lupus*) across each NF using species distribution data sets produced by the USGS Gap Analysis Project (GAP) (Gotthardt et al., 2014; USGS, 2018). These species are important apex predators that can trigger trophic cascades (Ripple et al., 2014) and were historically ubiquitous in much of North America. Moreover, these top predators may function as umbrella species, hence conserving them could offer broader biodiversity benefits (Sergio et al., 2006). The GAP project produced separate species distribution models for Alaska (Gotthardt et al., 2014) and the continental US (USGS, 2018) at 60 and 30 m spatial resolution, respectively. Each species' distribution was predicted using models that linked occurrence records with geospatial data sets related to soil, hydrologic, topographic, land cover, development, disturbance climate, and ecological conditions. For each species, we reprojected data sets onto the common 60 m resolution grid and then quantified the areal extent of contemporary habitat that occurred within the boundaries of each NF.

2.1.5. Climate Data

We characterized historical climate conditions and potential future climate change across forestlands in each NF using two bioclimatic variables from the CHELSA-BIOCLIM + data set (Brun et al., 2022a, 2022b). This data set included climatologies for historical (1981–2010) and future (2071–2100) periods that were mechanistically downscaled to 1 km spatial resolution. For future conditions, we examined climatic changes predicted by an ensemble of five earth system models (ESMs) that were run as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6) following a high-carbon emission shared socioeconomic pathway scenario (SSPS585). We focused on mean daily maximum temperature of the warmest month (hereafter *maximum temperature*, °C)

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and annual precipitation (mm), which are derived bioclimate variables that provide insight into ecosystem energy and moisture limitations. We reprojected these data onto the common 300 m resolution grid and masked out non-forest areas (e.g., icefields in the Tongass NF). For each grid cell, we computed the projected climatic changes from historical to future periods (i.e., 2071–2100 minus 1981–2010) using each climatology from the five ESMs. Next, we calculated the spatial average and standard deviation of historical and future climate and climatic changes for forestlands in each NF. For each NF, we focused on the ensemble median change predicted in spatially-averaged climate across the five ESMs, and also computed the minimum and maximum changes across the ensemble.

2.1.6. Wildfire Data

We quantified forest area burned in recent decades across each NF using the MODIS satellite burned area data set (MCD64A1 version 6; Giglio et al., 2018). This data set provides burned area extent every month across the world at 500 m spatial resolution. We accessed these data using Google Earth Engine (GEE; Gorelick et al., 2017) and for each grid cell determined whether it had burned from 2001 through 2020. We exported these data from GEE, resampled them to 300 m resolution to match the forest cover data set, and then computed total forest area burned for each NF, as well as the percentage of forest area that burned during these two decades.

2.1.7. Protected Area Data

We identified federally managed lands and evaluated the current extent of forest protection in the Tongass and Chugach NFs using the Protected Area Database of the United States (PAD-US version 3.0) produced by the United States Geological Survey Gap Analysis Project (USGS GAP, 2022). This spatial data set is the official inventory of protected areas across the nation (USGS GAP, 2022). Protected status is characterized by GAP status codes that describe management intent to preserve biodiversity following guidelines from the International Union for the Conservation of Nature (IUCN). GAP 1 and GAP 2 lands are managed for biodiversity, GAP 3 lands are managed for multiple uses including mining, logging, and off highway vehicle use, and GAP 4 lands are those with no known mandate for protection. GAP 1 typically aligns with IUCN Categories Ia, Ib, and II and is the only designation that protects all ecological functions and limits firefighting yet does allow hunting in Alaska. GAP 2 typically aligns with IUCN Categories III through VI and aims to maintain a "primarily" natural state but may receive uses or management that degrades the quality of existing natural communities, including suppression of natural disturbance. We rasterized land ownership and GAP status codes at 300 m spatial resolution, selecting the lowest GAP status if a land had multiple designations. We then masked all analyses to federally managed lands (i.e., excluded inholdings) and calculated total area and carbon stocks of forestlands falling under each GAP status code.

3. Results

3.1. Forest Area and Landscape Integrity

The Tongass and Chugach are among the few national forests (NFs) with high landscape integrity, and the Tongass has by far the largest forest area of all 154 NFs in the country (Figure 2). The Tongass and Chugach comprise 9.4% and 2.0% (total 11.4%) of all federally managed forest area on NF lands (~539,850 km^2 total) and are ranked first and second out of all NFs in terms of their forest area. Moreover, the Tongass and Chugach have mean (±1SD) FLII values of 9.8 ± 0.5 out of 10, respectively comprising 25.3% and 5.6% (total 30.9%) of all high (≥9.6) integrity forest landscapes found in the NFS, where FLII averages 8.0 ± 2.3. Other NFs with high mean forest landscape integrity (≥9.6) but less area include Challis NF in Idaho and Humboldt NF in California, which comprise 0.8% and 0.5% of all forest area on NF lands (Table S1 in Supporting Information S1). Compared to other NFs, the Tongass and Chugach are thus unique not only because of their extensive forest area but also their high forest landscape integrity.

3.2. Forest Carbon

Mean tree carbon densities are higher-than-average on the Tongass NF, but quite low on the Chugach NF (Figure 3a). The mean (±1SD) tree carbon density on the Tongass (88 ± 45 Mg C ha^{-1}) and Chugach (35 ± 25 Mg C ha^{-1}) are about ~10% higher and ~56% lower, respectively, than that of all forestlands in the National Forest System (61 ± 46 Mg C ha^{-1}; Figure 3a). The top 5 NFs with the highest mean tree carbon density (141–170 Mg C ha^{-1})

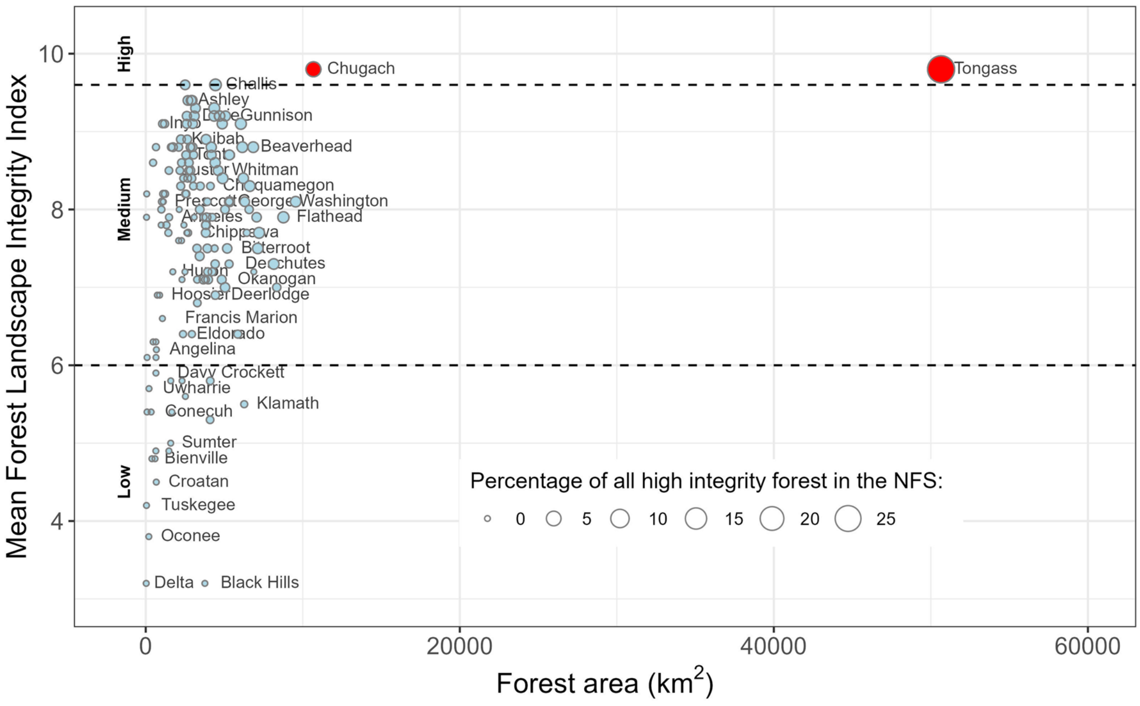

Figure 2. Forest area (km^2) and mean forest landscape integrity (unitless) for each national forest in the US National Forest System. The forest landscape integrity index ranges from 0 (lowest integrity) to 10 (highest integrity). Low (≤6.0), medium (>6.0 and <9.6), and high (≥9.6) forest integrity are identified using thresholds from the data creators (Grantham et al., 2020). The plotting character for each national forest is scaled by its relative holding of all high integrity forest in the National Forest System. Note the exceptional forest area and integrity of the Tongass and Chugach National Forests (red points).

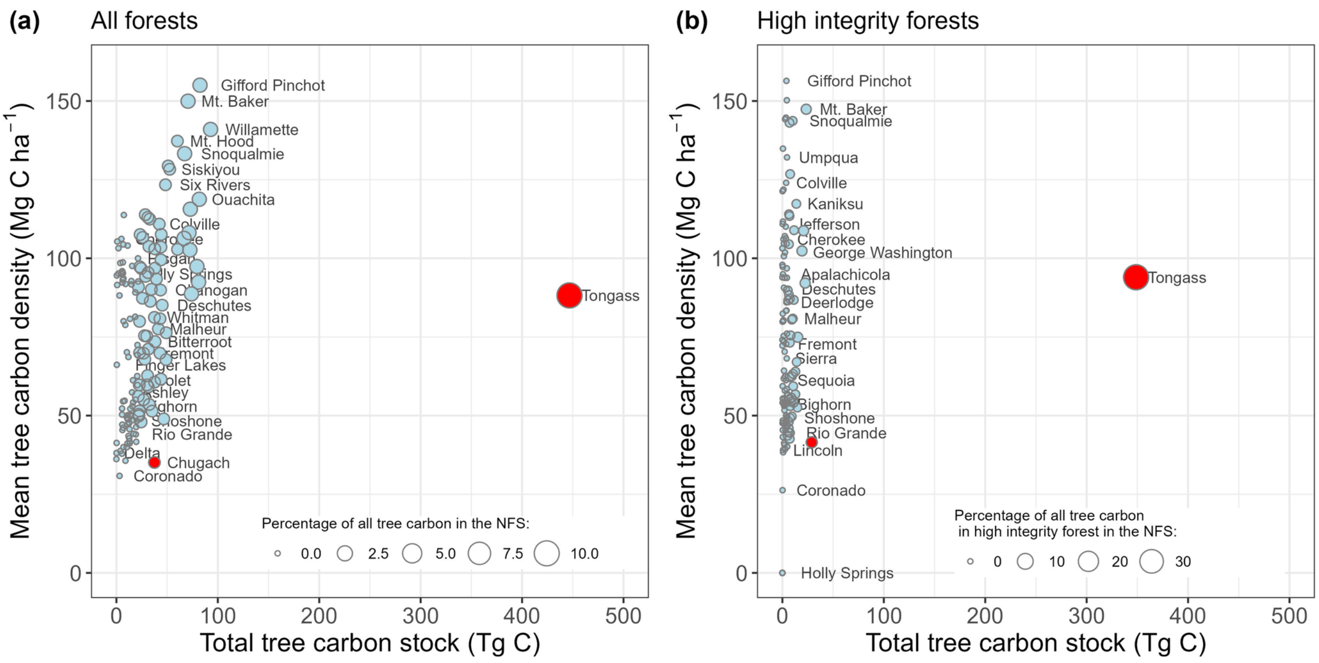

Figure 3. Mean tree carbon density (Mg C ha^{-1}) and total tree carbon stock (Tg C) for each national forest in the National Forest System (NFS). Summaries are provided for (a) all forests and (b) high integrity forests within each national forest. Tree carbon includes live aboveground and belowground biomass. The plotting character for each national forest is scaled by its overall contribution to total tree carbon stocks across (a) all forests and (b) high integrity forests in the NFS. Forests were considered high integrity if the forest landscape integrity index was ≥9.6 out of 10 (Grantham et al., 2020). There were 25 national forests without any high integrity forest, so in (b) these are plotted at the origin (0,0). The Tongass and Chugach National Forests are plotted as red points. Note the exceptionally large tree carbon stock of the Tongass and the much smaller carbon stock on the Chugach (red points).

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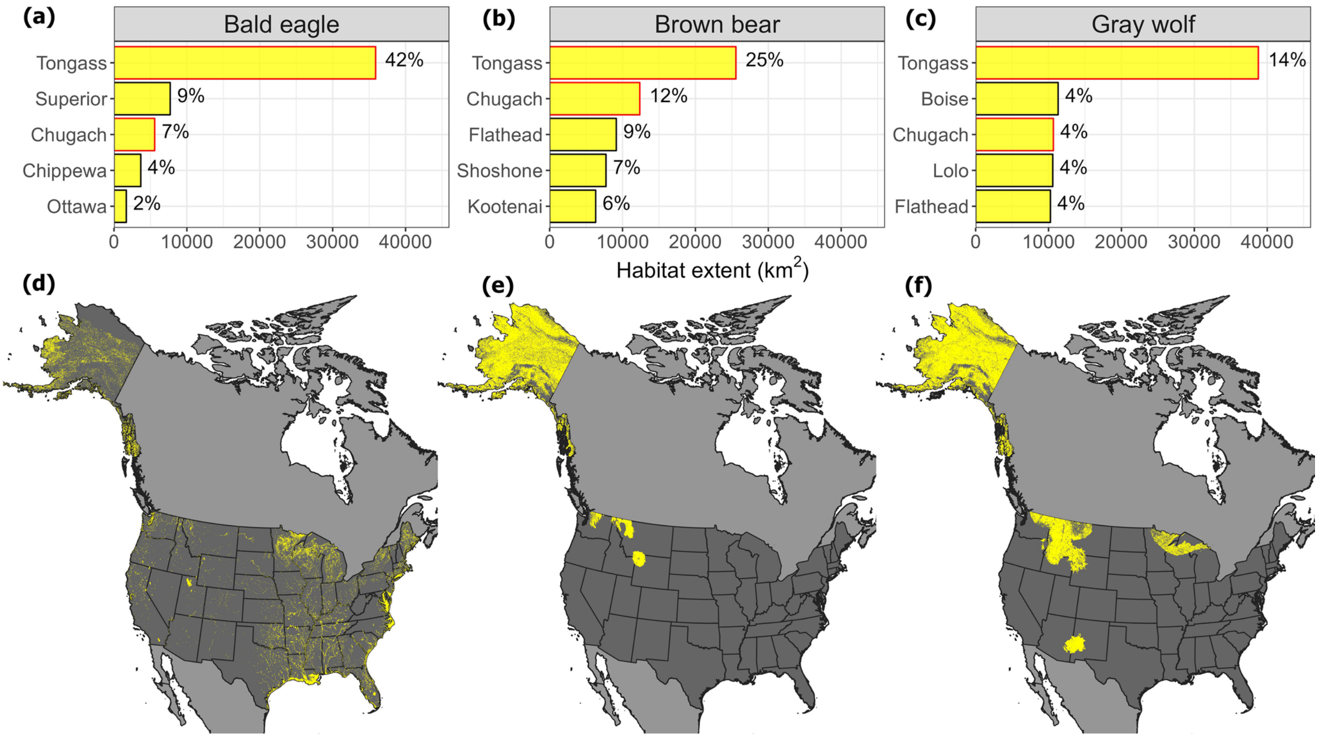

Figure 4. Current areal extent of bald eagle, brown bear, and gray wolf habitat in the (a–c) five national forests with the most habitat for each species and (d–f) the overall USA. In panels (a–c), the percentages denote the extent of species habitat within each national forest relative to the total extent of species habitat on all national forest lands. Species habitat distribution data sets generated as part of the USGS GAP (Gotthardt et al., 2014; USGS, 2018).

are the Siuslaw, Olympic, Gifford Pinchot, Mt. Baker, and Willamette, which all occur in either the Coast Range or Cascade Range of western Oregon and Washington (Table S2 in Supporting Information S1).

The Tongass and Chugach store approximately 10.4% and 0.9% (total 11.3%) of all tree carbon stocks that occur on NF lands (~4,305 Tg C total) and are ranked 1st and 40th out of all NFs in terms of their total tree carbon stocks (Figure 3a). Furthermore, the Tongass and Chugach store approximately 33% and 3% of all tree carbon stocks that occur in forests with high landscape integrity (FLII ≥9.6), placing them first and second among all NFs in this regard (Figure 3b; Table S2 in Supporting Information S1). Notably, the Tongass tree carbon stock (~447 Tg C) is nearly five time larger than that of the second ranked NF (Willamette). The top 5 NFs with the highest tree carbon stocks also include Ouachita, Flathead, and Gifford Pinchot, which is the only NF that also makes the top 5 for highest tree carbon densities.

3.3. Forest Wildlife Habitat

The Tongass provides substantially more habitat for bald eagles, brown bears, and gray wolves than any other NF, while the Chugach provides the second or third most habitat depending on species (Figure 4a). These two NFs together account for about 49%, 37%, and 18% of all bald eagle, brown bear, and gray wolf habitat found on NF lands, respectively. Other NFs important for bald eagles include Superior, Chippewa, and Ottawa in the upper Midwest (Figure 5), though the Tongass provides nearly three times as much habitat as all of these combined. While brown bears and gray wolves are found throughout much of Alaska, their current distributions in the continental US are restricted to the Northwest and, in case of gray wolves, to small areas in the Southwest and upper Midwest (Figure 4b).

3.4. Climate and Wildfire Risk

The Tongass and Chugach historically (i.e., 1981–2010) had the highest annual precipitation and lowest maximum temperature of all NFs (Figure 5a), as well as the largest projected increases in annual precipitation and among

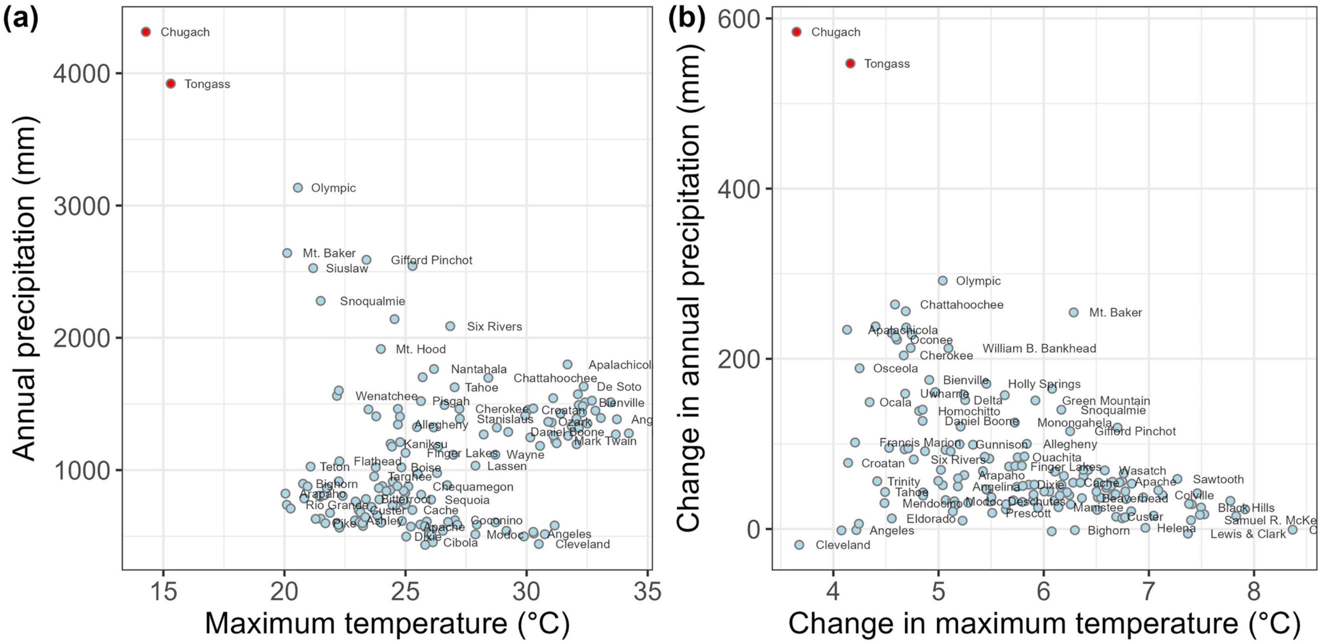

Figure 5. Historical climate (1981–2010) and future climate changes (2071–2100 minus 1981–2010) for each National Forest. (a) Climate variables include annual precipitation and mean daily maximum temperature of the warmest month (i.e., maximum temperature, °C). Climate data were spatially averaged across forestlands in each NF. (b) Climatic changes were derived from the ensemble median of predictions from five CMIP6 Earth system models driven by a high-carbon emission shared socioeconomic pathway scenario (SSPS585). Climate data were from the CHELSA-BIOCLIM + data set (Brun et al., 2022a, 2022b).

the lowest projected increases in maximum temperature over the coming century (i.e., 2071–2100; Figure 5b). Across forestlands in the Tongass and Chugach, annual precipitation historically averaged 3,920 ± 890 mm and 4,310 ± 1,390 mm, respectively, and is projected to increase 547 [195, 700] mm and 584 [413, 855] mm by the end of 21st century. Not only have the Tongass and Chugach historically been far wetter than any other NF, but future changes in annual precipitation are projected to be nearly two times larger than any other NF. Similarly, across forestlands in the Tongass and Chugach, maximum temperatures historically averaged 15.3 ± 2.1°C and 14.3 ± 1.6°C, respectively, and are projected to increase by 4.2 [3.5, 9.9] °C and 3.6 [2.5, 11.5] °C by the end of the century. The Tongass and Chugach historically had maximum temperatures that were about 5°C lower than any other NF, with rates of future warming that are the lowest to sixth lowest of any NF. Overall, the Tongass and Chugach were historically much colder and wetter than any other NF and are projected to experience much larger increases in precipitation and much lower increases in maximum temperatures over the coming century.

Satellite data showed fires burned a minuscule amount of forest area in the Tongass and Chugach from 2001 through 2020 (Figure 6). In total, forest fires burned about 70,251 km^2 (13.0%) of NF lands during the last two decades. The Tongass and Chugach together accounted for merely 0.1% of total forest burn area on NF lands but comprised about 11.4% of total forest area. During this period, forest fires burned a total of 61 km^2 (0.1%) and 27 km^2 (0.2%) in the Tongass and Chugach, respectively. These two NFs ranked near the bottom (144th and 140th) of all NFs in terms of their percent of forest area that burned in recent decades, in contrast with Mendocino and Angeles NFs where 66%–90% of forest area burned. Forests that burned multiple times (i.e., reburns) during this period are only counted once. Overall, forest fires were very uncommon during recent decades in Alaska's coastal rainforests.

3.5. Protected Areas

The forest area currently protected at GAP 1 or 2 levels sums to 17,983 km^2 on the Tongass (35.5% of the NF area) and 6,150 km^2 on the Chugach (57.6% of the NF area) (Figure 1, Table 1). The Tongass protected area is primarily GAP 1 status, mostly due to the six wilderness areas. The Chugach has no GAP 1 protected areas, with most protected areas designated as GAP 2 because of wilderness study and national heritage areas designated within its boundaries. GAP 3 areas are managed for multiple uses but also contain roadless areas which would be good candidates for higher levels of protection.

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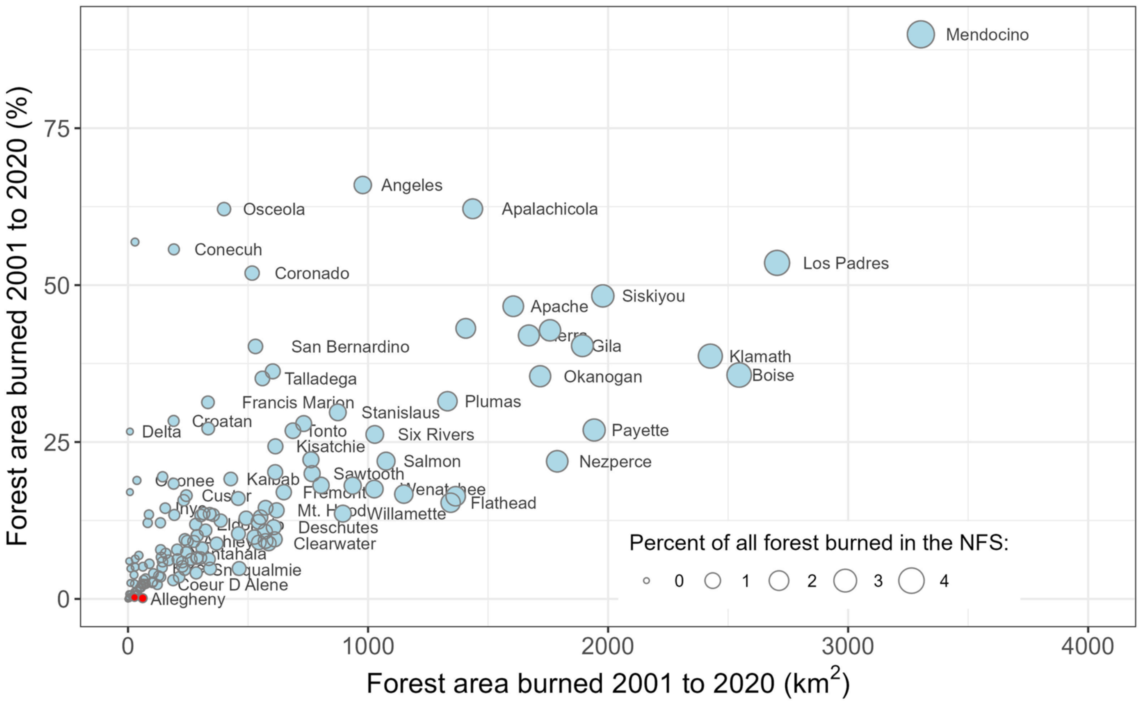

Figure 6. Absolute and relative forest area burned from 2001 to 2020 for each national forest in the US National Forest System. The plotting character for each national forest is scaled by its overall contribution to total forest burned area across all national forests. Note the exceptionally low absolute and relative forest burned areas of the Tongass and Chugach (small red points in bottom left). Burn area was derived from MODIS satellite data (Giglio et al., 2018).

4. Discussion

Severe ecological disruption is expected to occur over the next 10–30 years as the climate rapidly warms, hence immediate actions are needed to mitigate climate change and protect biodiversity (IPCC, 2018, 2021). These actions include effective conservation of 30%–50% of Earth's land, freshwater and ocean areas, including current near-natural ecosystems (IPCC, 2022). To better understand potential conservation benefits of preserving forestlands in the Tongass and Chugach NFs, we compared forest bioclimatic attributes of these NFs with all other NFs in the conterminous US. We focus on forests because of their significant carbon storage and accumulation of carbon over decades to centuries. Actions that support biodiversity also support ecosystem resilience in the long term (Oliver et al., 2015). Thus, our analysis compares landscape integrity among national forests, as well as tree biomass carbon stocks and habitat extent for keystone species while accounting for projected climate conditions that may impact some forests more than others. Current protected areas at GAP 1 and 2 levels can help to identify NFs where additional areas could be moved into these levels of protection with some changes in management, although there are some preexisting stipulations and allowances for other uses in Alaska. Our analysis highlights the Tongass and Chugach are exceptionally large and intact forests that provide important habitat and carbon sequestration that are buffered against fires and future climate disturbance.

Table 1
Current Extent of Land and Forest Protection Under Federal Management in the Chugach and Tongass National Forests in Southern Alaska

National Forest	GAP status	All lands		Forest lands		Forest carbon	
		km^2	%	km^2	%	Tg C	%
Chugach	1	0	0	0	0	0	0
	2	13,733	60.9	6,150	57.6	353	58.4
	3	8,821	39.1	4,520	42.3	251	41.6
	4	12	0.1	11	0.1	0	0
Tongass	1	23,421	34.3	17,267	34.1	1,005	33.3
	2	836	1.2	716	1.4	42	1.4
	3	43,986	64.5	32,667	64.5	1,974	65.3
	4	1	0	1	0	0	0

4.1. Forest Landscape Integrity

We found the Tongass and Chugach NFs have the highest forest landscape integrity of all NFs, and are ranked first and second in their forest area, making them high priority areas for protecting forest landscape integrity. Large contiguous tracks of intact forest landscape are important for biodiversity, carbon sequestration, water regulation, indigenous culture, and human health (Grantham et al., 2020; Potapov et al., 2017; Watson et al., 2018). However, globally, the extent of intact forest landscapes declined ~7% from

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Table 2
Estimated Accumulation Rate of CO_2 by National Forest Region

National Forest region	Net change in stock ($Mg CO_2/yr$)	Area (ha)	Accumulation ($MgCO_2/ha/yr$)
Alaska	4.0	3,057,631	1.3
Eastern	11.5	4,767,960	2.4
Intermountain	−11.5	9,051,830	−1.3
Northern	−0.9	8,889,956	−0.1
Pacific Northwest	28.3	9,041,109	3.1
Pacific Southwest	5.7	5,994,752	1.0
Rocky Mountain	−12.2	6,118,661	−2.0
Southern	25.5	5,321,390	4.8
Southwestern	−6.9	6,164,438	−1.1
All Regions	43.5	58,407,728	0.7

Note. Net change in C stock from Domke et al. (2023). Area estimates are from the FIA database. Negative numbers mean CO_2 stocks are declining.

2000 to 2013 (Potapov et al., 2017), with overall forest landscape integrity also declining such that now only ~40% of forest area has high landscape integrity (Grantham et al., 2020). Moreover, just 27% of high-integrity forestland is designated as protected and, within the protected areas, slightly more than half of forestlands are considered high integrity (Grantham et al., 2020). Therefore, there is a pressing need to conserve the remaining large tracts of forest with high landscape integrity. There was extensive industrial logging in parts of southeastern Alaska during the second half of the twentieth century (DellaSala et al., 2022), yet our analysis underscores that the Tongass and Chugach NFs still have exceptionally large and intact forests compared to other NFs. Nevertheless, most NFs (83%) have at least some high integrity forests. Future analyses could identify conservation priorities within individual NFs by determining where contiguous tracts of intact forests occur using existing spatial data sets (e.g., Grantham et al., 2020).

4.2. Forest Carbon

Alaska's coastal rainforests have accumulated vast amounts of carbon for hundreds to thousands of years, keeping it out of the atmosphere (Smith et al., 2019). Drawing on a satellite-derived data set (Spawn et al., 2020), our results showed that the Tongass had higher and the Chugach had lower than average biomass density over all NFs. But because of the large area of these two forests, we estimated that the total live tree biomass in the Tongass and Chugach amounted to ~484 Tg C of the ~4,305 Tg C (i.e., 11.3%) found in the National Forest System, with tree biomass carbon stocks on the Tongass ~12 times greater than the Chugach. This is generally consistent with estimates derived from forest inventory data that indicate tree biomass in the broader Alaskan coastal rainforest region stores 464–557 Tg C (Barrett, 2014; Smith et al., 2019; Yatskov et al., 2019; Zhu & McGuire, 2016) and that regional tree biomass carbon stocks account for ~10.7% of the ~4,330 Tg C found in forests in the National Forest System that are managed by the Forest Service (Smith et al., 2019). In these coastal rainforests, live tree biomass comprises ~31% of forest ecosystem carbon stocks, which also includes understory vegetation, snags, woody debris, litter, and especially soil organic matter (Yatskov et al., 2019). Regional forest ecosystem carbon stocks have been estimated at 1,385 based on inventory data across nine NFs in Alaska (Smith et al., 2019), while a recent query of the FIA data shows 783 Tg C for Tongass and 154 Tg C for Chugach, 937 Tg C total, which is closer to Smith et al. (2019). However, the forest ecosystem carbon stocks in the Tongass alone have been estimated at 2,679–2,800 Tg C (DellaSala et al., 2022; Leighty et al., 2006). Our analysis further underscores that Alaska's coastal rainforests, particularly the Tongass, are a carbon reservoir of national importance that should be protected to help mitigate climate change. Nevertheless, discrepancies in regional carbon stock estimates emphasize that additional efforts are needed to improve understanding of current forest ecosystem carbon stocks across the region.

Estimates of annual net C accumulation for the Tongass and Chugach National Forests are becoming available as repeated forest inventories expand in these areas. A recent report by Domke et al. (2023) estimates that the annual net change in C stocks for these two forests is about 4 $Mg CO_2/yr$. Converting to CO_2 density, this represents 1.3 $Mg CO_2/ha/yr$ or nearly twice the average for all FS national forests combined (Table 2). Several regions in the Western U.S. are losing C stocks because of increases in natural disturbances, but this is not the case for southern Alaska public forests which are protected from fire and drought by ample rainfall. The net annual accumulation of CO_2 in the two Alaska national forests is about half the average for private forest lands in the U.S. of 2.7 $Mg CO_2/ha/yr$, most of which occurs in Eastern regenerating forests (Domke et al., 2023). Thus, besides the value of protecting the vast accumulated C stocks in southern Alaska, these forests are also accumulating additional CO_2 each year and do not appear to be affected by increasing threats to the long-term sustainability of this accumulation rate. Some proposed policies advocate conversion of older forests with large C stocks to younger and faster growing forests rather than letting them grow, but this argument ignores the huge C debt that must be covered before there would be any net additional C accumulation because it would take many decades to centuries to re-stock the C emissions from harvesting mature and old-growth forests (Birdsey et al., 2023; Harmon et al., 1990; Law et al., 2021).

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4.3. Forest Wildlife Habitat

Our analysis showed the Tongass and Chugach NFs provide important habitat for bald eagles, brown bears, and wolves. These keystone species used to occur widely in northern North America but have been extirpated from much of their historical ranges. Historically, bald eagles occurred throughout the contiguous United States and Alaska (Buehler, 2000). Brown bears were native to the western half of North America, and those in California and Mexico are extinct (Haroldson et al., 2022). The historical range of gray wolves was coast to coast and north of 20° latitude over North America—they are second only to humans in adapting to climate extremes (Laliberte & Ripple, 2004).

The Tongass and Chugach forests have relatively abundant populations of animals that have become uncommon in other parts of the U.S. Alaska has over 98% of the US brown bear population, and the largest North American breeding populations of bald eagles are in Alaska and Canada. Gray wolf distribution covers about 85% of Alaska (total 7,000–11,000 wolves), with the highest densities in the Southeast. However, brown bears, and gray wolf have been impacted by hunting and predator control programs that reduced their numbers, leading to local declines and extirpations (Crupi et al., 2017; Ripple et al., 2019).

There are three species of special concern in the coastal forests of southern Alaska: The Alexander Archipelago wolf (*Canis lupus ligoni*), the marbled murrelet (*Brachyramphus marmoratus*), and the yellow cedar (*Callitropsis nootkatensis*). The Alexander Archipelago wolf is a subspecies of the gray wolf that is found in the coastal rainforests of Alaska and British Columbia (Schoen et al., 2014). These wolves have been impacted by logging as they rely heavily on old-growth forests for their habitat, cover, den sites, and prey (Gilbert et al., 2022). The marbled murrelet is a small seabird that nests in old-growth forests along the coast of Alaska and the Pacific Northwest. These birds are particularly vulnerable to habitat loss because they rely on mature trees for nesting sites (Carter et al., 2009; Piatt & Naslund, 1995). The logging of old-growth forest in coastal Alaska has led to a decline in the marbled murrelet population. Yellow cedar in the coastal rainforests of southeast Alaska has been listed as a species of concern under the Endangered Species Act, with population declines due to logging and climate change (Hennon et al., 2018).

In the Tongass, five species of salmon with a diversity of spawning periods provide food for a high concentration of bears, eagles, and other animals over a prolonged period each year. Brown bears are the dominant predator of salmon (Levi et al., 2015). Wolves in the region obtain about 20% of their diet from actively fishing salmon, which appears to contribute to the high survival rate of pups (90% compared with 50% in Minnesota). Where other prey is low, wolves are extremely reliant on a marine diet compared to coastal bears (Szepanski et al., 1999). After spawning, the salmon carcasses provide nutrients for forests.

Extinction risk is most acute for the largest and smallest vertebrates, and the largest vertebrates, for example, bears, are most vulnerable to direct killing by humans (Ripple et al., 2019). Thus, stronger protections and reduction of harvest of both trees and animals will give them a better chance of survival and resilience to the dual crises of climate change and biodiversity loss.

4.4. Climate and Wildfire Risk

We found the Tongass and Chugach historically had the highest annual precipitation and lowest maximum temperature of all NFs, as well as the largest projected increases in annual precipitation and among the lowest projected increases in maximum temperature over the coming century. The cool, wet conditions contribute to there being little wildfire activity in the region, with future increases in wildfires likely mitigated by increases in annual precipitation.

While much attention has been paid to climate change in northern Alaska, southern Alaska is expected to experience changes that are moderate by comparison. For example, temperature extremes in southeast Alaska are expected to be small compared to the rest of Alaska (Gray et al., 2018; Lader et al., 2022), and the length of warm and dry spells is not expected to change much. Nevertheless, climate risks for forests in southern Alaska include increased frequency and severity of forest disturbances and changes in hydrology. Such risks can affect forest sustainability and resilience both inside and outside protected areas and lead to shifts in suitable habitat boundaries for vegetation and wildlife communities (Shanley et al., 2015). For example, heavy rains and flooding are expected over coastal areas, as well as warmer water temperatures and warmer springs that have impacted

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Alaska yellow cedar (Hennon et al., 2018). Yet projected warmer and wetter climate in southern Alaska probably will not destabilize forest carbon and biodiversity as much as in other NFs that are expected to become hotter and drier (Buotte et al., 2019; Law et al., 2021).

Ecosystem model simulations with climate projections indicated that this cool region with low forest fire risk is expected to remain a stable carbon sink or even increase in the future due to climate change (McGuire et al., 2018; Zhu & McGuire, 2016). Simulations under scenarios of climate change for southeast and south-central regions show that if these forests are allowed to grow without harvest, forest carbon could increase by 27% by 2100 (Zhu & McGuire, 2016). Furthermore, climate change could increase the importance of protection in this region since species may disproportionately favor protected areas as their ranges shift poleward and appropriate management could slow climate-related declines (Thomas & Gillingham, 2015).

4.5. Forest Protection in Southern Alaska

We found that about 35.5% of the Tongass and 57.6% of the Chugach are preserved at GAP 1 or 2 levels of protection that meet IUCN standards for conservation. Much of the Chugach has been inventoried as roadless, but is still classified as GAP 3 status, meaning that multiple use management that may involve logging is still the priority in this forest. An initial step has been taken to limit timber harvest on a portion of the Tongass through reinstating the roadless rule. The Biden administration finalized the Alaska roadless rule in 2023 that restores roadless protection to more than 36,422 km^2 of the Tongass, keeping it free from road-building and extraction. However, other uses may still be allowed. Our results demonstrate that the priority areas for conservation of landscape-integrity over large areas include the Tongass and Chugach NFs.

4.6. Limitations

Forest inventory plot density is lower in southern Alaska than in the other NFs. Forest Service wilderness areas and interior Alaska have not been inventoried by FIA, but are in progress for inclusion in future inventories (USDA Forest Service, 2023). Observation-based forest carbon mapping combining satellite and field data could be improved and spatially derived using methods such as those of the Landscape Ecology Modeling Mapping and Analysis program (https://lemma.forestry.oregonstate.edu/data). Due to limitations with available spatial data sets, we did not assess carbon stocks in dead standing trees (i.e., snags), woody debris, trees smaller than 10 cm diameter, understory vegetation, or soil.

The analysis of habitat extent that can support apex species under future climate is limited by data availability (Gotthardt et al., 2014). Habitat and species distribution modeling based on the reference data needs improvement. Yet, these are the only consistent spatial data available. Although habitat extent in southern Alaska is likely underestimated, it is by far the largest among NFs. The results provide estimates of areas with the potential for protection of forest carbon and key species, and closer landscape analysis will refine estimates of candidate areas to protect for carbon, plant and animal species and ecological resilience under climate change.

Similarly, the ability to map human modification in Alaska is limited by data and accuracy issues, as well as pressures that are often unmapped because they differ from those experienced in lower latitudes (Reynolds et al., 2018). These unmapped pressures mean that forest integrity could be overestimated for some of these forests. Yet, these forests are experiencing tremendous pressures that demand additional protection (Trammell et al., 2022).

4.7. Policy and Management Implications

A recent United Nations proposal calls for national parks, marine sanctuaries and other protected areas to cover nearly one-third or more of the planet by 2030 as part of an effort to stop a sixth mass extinction and slow global warming (IUCN, 2021). Climate change and biodiversity loss are closely interconnected by human actions such that policies should simultaneously address synergies between mitigating climate change and biodiversity loss to maximize co-benefits (Pandit et al., 2021). NbCSs can be most effective when planning for longevity of carbon storage rather than rapid carbon sequestration. Avoiding and reversing the loss and degradation of carbon- and species-rich ecosystems of land and waters is of highest importance for combined biodiversity protection and climate change mitigation actions with large adaptation co-benefits.

Key strategies emerging for mitigating climate change and preventing biodiversity losses include:

1. Establish national strategic reserves that protect existing mature and old forests from resource extraction, and expand wilderness areas. Forests with medium to high carbon density also tend to have high critical habitat and genetic diversity (Buotte et al., 2020; Dinerstein et al., 2020; Law et al., 2021).
2. Resilience-building strategies that address elements of biodiversity (preventing extinctions, ecoregion diversity) and facilitate animal movement by connectivity of protected areas, and new and expanded protected areas.
3. Implement measurement, reporting and verification from local to national levels that are consistent and meet international standards for tracking progress in protecting forest carbon and biodiversity.

Governments must establish and achieve NbCS targets in the Nationally Determined Contributions to meet Paris Agreement goals (Dinerstein et al., 2020; Griscom et al., 2017). Currently, there is a large gap between pledges and desired outcomes (UNEP, 2022). In the U.S., more public lands have been opened up for resource extraction since 2020 compared to the previous years while at the same time pledges were made to protect 30% of lands and waters by 2030. President Biden's Executive Order 14008 is a call to action to work together with stakeholders to conserve, connect and restore 30% of U.S. lands and waters by 2030 (White House, 2021). The Tongass is the ancestral homeland of the Tlingit and Haida Peoples, who developed a climate adaptation plan with stakeholders that identifies potential impacts on tree and vertebrate species and actions to increase resilience. Collaboration and consistency with national and international climate and conservation goals will be essential.

Area-based preservation must contribute more effectively to meeting international goals that aim to protect elements of biodiversity, including preventing the accelerating extinctions and protecting the remaining intact forests as well as mature and old forests from extractions.

An integrated climate-biodiversity agenda is gaining momentum at multiple levels. We propose Strategic Forest Reserves for permanent protection of forest carbon and biodiversity at the highest levels (GAP 1 and 2, IUCN categories I–VI) to support targets that protect 30% of the area by 2030 and 50% by 2050. We found that southern Alaska's forests have high landscape integrity, carbon stocks and habitat availability for key species, and should be protected on federal lands before irreversible losses of these forests continue (Goldstein et al., 2020). The Tongass and Chugach have 30% of the forest area protected at GAP 1 or 2. Although the Chugach has no area protected at the GAP 1 level, this could be improved by transitioning current areas with less protection to GAP 1. It is possible to elevate the preservation status of GAP 3 areas on federal lands by phasing out grazing, mining, and logging and strengthening protection by administrative rule. Inventoried Roadless Areas are key GAP 3 areas that have already been identified and are available for permanent protection. Making good on our national and international pledges will determine whether resilience and climate stability can provide life support for future generations on Earth.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

All custom scripts written for the analysis are publicly available through GitHub (https://github.com/ecospatial-services/seak_preservation). Furthermore, all datasets used in this study are publicly available through online repositories. The National Forest Systems Land Unit dataset is available from https://data.fs.usda.gov/geodata/edw/datasets.php. The tree canopy cover dataset is available from https://glad.umd.edu/dataset/global-2010-tree-cover-30-m. The forest landscape integrity dataset is available from https://www.forestintegrity.com/. The forest carbon stock dataset is available from https://daac.ornl.gov/VEGETATION/guides/Global_Maps_C_Density_2010.html. The MODIS burned area data are available through Google Earth Engine https://code.earthengine.google.com/. The Protected Area Database of the US (version 3.0) is available from https://www.usgs.gov/programs/gap-analysis-project/science/pad-us-data-download. The species habitat datasets are available for the Continental US from https://gapanalysis.usgs.gov/apps/species-data-download and for Alaska http://akgap.uaa.alaska.edu/species-data. The CHELSA-BIOCLIM + climate dataset is available from https://www.envidat.ch/#/metadata/bioclim_plus.

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UNITED STATES DEPARTMENT OF AGRICULTURE
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20250

July 2, 2013

SECRETARY'S MEMORANDUM 1044-009
Addressing Sustainable Forestry in Southeast Alaska

1. PURPOSE AND BACKGROUND

Alaska's Tongass National Forest is a national treasure. At 17 million acres, the Tongass includes vast old growth temperate rainforests that are increasingly rare globally. The Tongass is also a place that has sustained the people and communities of Southeast Alaska for generations. Whether through providing food and other subsistence uses to the rural communities in the region, supporting cultural practices and identity, drawing people to the region for world-class recreation and fishing, or supporting wood products and other forest-based industries, the Tongass is vital to the economic and cultural well-being of the region. The Forest is also important to the climate; while the Tongass comprises about 2 percent of the Nation's forests, according to one scientific study it contains the equivalent of 8 percent of the carbon sequestered in the forests of the conterminous United States. The Department of Agriculture is committed to maintaining Southeast Alaska's exceptional natural resources in perpetuity. USDA is equally committed to doing its part to ensure that the communities within and adjacent to the Tongass National Forest are economically vibrant. These two goals must go hand in hand.

To conserve the Tongass National Forest under the principles of the Multiple-Use Sustained-Yield Act of 1960, Tongass Timber Reform Act and other relevant statutes, we must speed the transition away from old-growth timber harvesting and towards a forest industry that utilizes second growth – or young growth – forests. Moreover, we must do this in a way that preserves a viable timber industry that provides jobs and opportunities for residents of Southeast Alaska.

This Memorandum affirms that this transition to a more ecologically, socially, and economically sustainable forest management is a high priority for USDA, the Forest Service, and the Tongass National Forest. USDA's goal is to effectuate this transition over the next 10 to 15 years, so that at the end of this period the vast majority of timber sold by the Tongass will be young growth. This timeframe will conserve old growth forests while allowing the forest industry time to adapt. To achieve this goal, several steps must be taken as described in the Actions section of this Memorandum.

Over the past three years, USDA has increased investments in alternative economic development opportunities for communities across the region in the recreation, tourism, fishing and renewable energy sectors, while initiating a transition away from a historical reliance on old growth timber harvests. To accomplish the transition to a timber program based primarily on young growth, it is important to retain the expertise and infrastructure of the existing industry so businesses can quickly re-tool. These businesses are fundamental to both the young growth and restoration components of the future timber program, and to the economic vitality of the region. Such an approach requires a reliable supply of economically viable timber, with the old growth component decreasing over time while the young growth component increases.

Updated forest inventories have improved our understanding of the age, location, and amount of young growth across the Tongass, and helped clarify the challenges in establishing an economically viable young growth program due to the relatively young age of the available stands, market conditions, and other factors. Additional research will be necessary to develop effective ways to meet these challenges. Achieving the transition in 10 to 15 years also calls for enactment of a statutory provision, to exempt a limited amount of young growth on the Tongass from current requirements that generally restrict harvesting young growth timber until it reaches maximum growth rates. Administrative mechanisms to accomplish such an adjustment are time consuming and would divert scarce resources from achieving the goals of the transition. Compared to private lands, the Culmination of Mean Annual Increment (CMAI) requirements could delay development of an economically viable young growth program for decades. USDA will continue to work with Congress on such a provision.

To ensure a smooth transition, the Forest Service will continue to offer a supply of old growth timber while increasing the supply of young growth to provide industry in Alaska the opportunity to develop new markets, learn new skills, and acquire new equipment. The continuation of limited sales of old growth timber is essential to maintain the existing industry until young growth can efficiently be processed. The Forest Service will also continue the Tongass National Forest's micro-sale program and the old growth small sale program that targets niche markets, while developing a new integrated program of work focused on young growth, ecological restoration, and forest stewardship that protects and restores the Forest's extraordinary fish and wildlife habitat. This strategy will maintain and restore the Forest's clean water, abundant fish, healthy populations of wildlife, and scenic beauty while sustaining deep-rooted community and cultural ties to the land and providing jobs in the woods.

Through an all lands, all hands approach USDA will utilize all of its expertise, tools and resources such as economic assistance, workforce training, capacity building, and improved delivery of services to help strengthen and diversify local economies. Working with Rural Development and the Farm Service Agency; other Federal agencies as appropriate; State, local, and Tribal entities; non-governmental organizations; and local communities will be essential to success. Collaborative development of a transition strategy increases collective ownership of the approach; collaborative implementation with our many partners offers opportunities to leverage funding available from the Forest Service.

2. ACTIONS

The objective of this Secretarial Memorandum is to ensure that USDA, the Chief of the Forest Service, the Alaska Region of the Forest Service, and the Tongass National Forest work together to catalyze a transition from a timber sale program based on old growth to one based on young growth. Pursuant to this Memorandum, the Secretary asks the Forest Service to:

a. Seek opportunities to supply sufficient old growth “bridge timber” while the industry re-tools for processing young growth. The first step is the Big Thorne timber sale. This project along with other planned timber sales would supply timber to existing mills for several years and allow the Forest Service to reallocate staff to young growth projects.

b. As soon as possible, allocate staff and financial resources to planning young growth projects, ramping down old growth sales and increasing investments in young growth.

c. Continue to work with Congress to exempt a limited amount of young growth on the Tongass from current requirements that generally restrict harvesting young growth timber until it has reached maximum growth rates, or CMAI. Providing flexibility with regard to CMAI is essential to permit the development of economically viable young growth projects within the timeframe set as a goal for the transition.

d. Develop by July 30, 2013, scenarios that effectuate a more rapid transition by prioritizing and developing additional young growth and restoration projects that could be completed over the next 5 years. Examine scenarios that assume adoption of the statutory provision noted above that provides Forest Service greater flexibility in harvesting young growth timber.

e. Strongly consider whether to pursue an amendment to the Tongass Forest Plan. Such an amendment would evaluate which lands will be available for timber harvest, especially young growth timber stands, which lands should be excluded, and additional opportunities to promote and speed transition to young growth management. A determination of whether to initiate an amendment should be completed by September 30, 2013. If an amendment in pursued, identify an efficient timeline for completion that supports the timeframe for transition outlined in this Memorandum.

f. Continue support for research on how best to manage young growth, develop markets for it, and help industry re-tool to process it. As results become available, apply them as needed to improve young growth management.

g. Intensify work with Rural Development to pursue opportunities to facilitate investments in re-tooling. Develop by December 31, 2013, in collaboration with Rural Development and other stakeholders, a plan for providing financial assistance to re-tool timber processing equipment in Southeast Alaska to assist the industry to efficiently handle young growth timber.

h. Pursue partnerships with foundations, non-profits, corporations, and others to advance a second growth industry, undertake restoration projects, and otherwise speed the transition.

I will remain engaged in this effort to ensure the Tongass National Forest transitions effectively to a timber program based primarily on young growth. It is vital that the Forest Service continue to seek input from and work with stakeholders in the region towards this transition. In this regard, I will approve establishment of an advisory committee under the Federal Advisory Committee Act to provide advice to the Forest Service on how to expedite the transition to young growth management.

3. MISCELLANEOUS

a. Effective Date. July 1, 2013

b. This Memorandum does not create any right or benefit, substantive or procedural enforceable by law or equity. This Memorandum creates no private right of action.

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REVIEW

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Wildlife studies on the Tongass National Forest challenge essential assumptions of its wildlife conservation strategy

Winston P. Smith[1] | **Elizabeth A. Flaherty**[2]

[1]Institute of Arctic Biology, University of Alaska-Fairbanks, 10915 Glacier Highway, Juneau, AK 99801, USA

[2]Department of Forestry and Natural Resources, Purdue University, 195 Marsteller Street, West Lafayette, IN 47907, USA

Correspondence
Elizabeth A. Flaherty, Department of Forestry and Natural Resources, Purdue University, 195 Marsteller Street, West Lafayette, IN 47907, USA.
Email: eflaher@purdue.edu

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Abstract

The Tongass National Forest in southeast Alaska, USA, includes the Alexander Archipelago and narrow North American mainland, comprising one of the largest remaining, largely pristine, coastal temperate rainforest in the world. Management of the Tongass has become increasingly challenging because of expectations of a conservation framework designed to maintain viable populations of native wildlife species while decades of extensive clearcut logging of old-growth forests has continued. We used the findings of multiple published studies conducted on the Tongass from 1998 to 2017 to examine 4 assumptions of its wildlife conservation strategy (WCS): forest planning assessments of wildlife viability were realistic, forest management and conservation policies are implemented at appropriate ecological scales, old-growth reserves are effective habitat conservation areas and ensure functional connectivity, and forest-wide standards and guidelines ensure sufficient habitat for sensitive species in managed landscapes. Several ecological field studies, population and spatial analyses and modeling, and statistical analyses revealed that wildlife viability assessments to evaluate forest plan alternatives underestimated the risk of extinction by only examining individual vulnerable species rather than considering joint probabilities across multiple species; the ecological scale of management

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and conservation policies do not adequately consider area-sensitive vulnerabilities of island communities as evidenced by the increasing risk of extirpation of island endemics whose populations have become isolated and reduced; old-growth reserves are unlikely to maintain viable populations of endemic small mammals in isolation or as functionally connected metapopulations; and a spatially explicit analysis of individual home ranges demonstrated that forest-wide standards and guidelines provide about half the breeding habitat needed by a federally listed endemic raptor, the Queen Charlotte goshawk *(Accipiter gentilis laingi)*, of which only half of that is secure. Thus, assertions that the WCS is properly functioning as designed are dubious because a comprehensive monitoring plan has not been implemented and vital underlying assumptions are not supported by available science. We recommend 3 forest management and conservation policy adjustments: limit size and location old-growth forest harvests, restore forests through intermediate stand management of second growth, and conduct a formal review of WCS elements and assumptions.

KEYWORDS

biodiversity, clearcut logging, ecological scale, island endemics, old-growth forests, reserve network, temperate rainforest, wildlife viability

The Tongass National Forest (Figure 1) is one of the largest, relatively pristine, temperate rainforests in the world (DellaSala et al. 2011, 2022) with 6.7 million ha distributed across ≥20,000 islands and a narrow mainland in southeast Alaska, USA (Everest et al. 1997). It extends from the southern tip of Prince of Wales Island 800 km north to the Hubbard Glacier.

Southeast Alaska is globally recognized for its expansive tracts of intact rainforest that contribute to climate stabilization (DellaSala et al. 2022). Wind disturbance plays a fundamental role in shaping forest dynamics, at large and small scales, and over a continuum dependent on landscape features including exposure, landscape position, and topography. These forests support complete wildlife communities, most notably all-inclusive trophic assemblages that include primary producers to top carnivores (Vynne et al. 2021). The Alexander Archipelago has a terrestrial mammalian fauna with a nested structure that resulted primarily from differential colonization following glacial retreat (Conroy et al. 1999, Sawyer et al. 2019). Regardless of the primary mechanism, habitat loss and fragmentation are expected to reduce diversity of mammalian taxa in southeast Alaska through increasing extinction probabilities (Burkey 1995, Frankham 1998, Crooks et al. 2017, Püttker et al. 2020, Vynne et al. 2021). Furthermore, vital interspecific interactions across ecological communities are altered if a predator, prey, or symbiote is extirpated (Smith 2012*a*, Brodie et al. 2018, Kelt et al. 2019).

In 1997, Tongass planners were commissioned to manage wildlife habitats to maintain viable, widely distributed populations of existing native and desired non-native vertebrate species as directed by the 1982 viability rule of the 1976 National Forest Management Act (NFMA; U.S. Forest Service [USFS] 1982). Procedures

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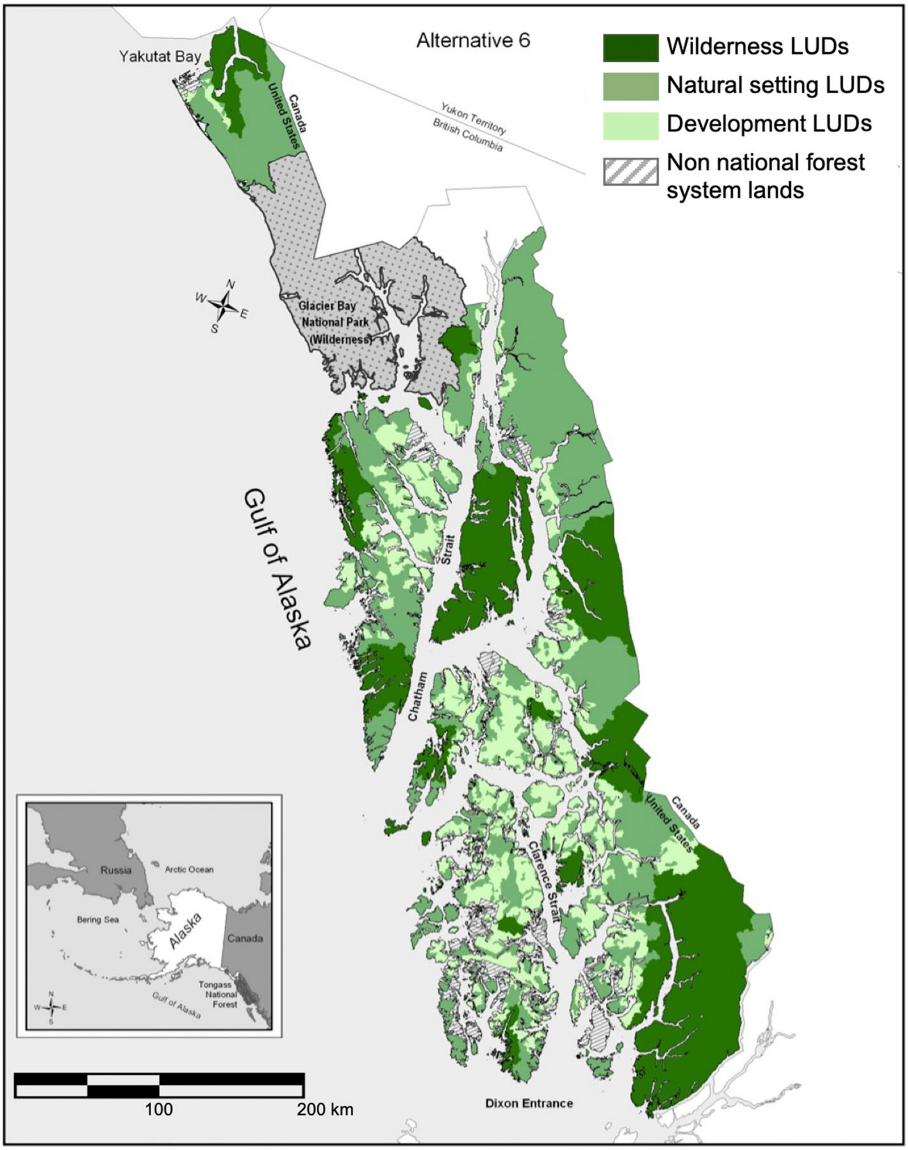

FIGURE 1 The Tongass National Forest in southeast Alaska, USA, extends from the southern tip of Prince of Wales Island 800 km north to the Hubbard Glacier and includes the Alexander Archipelago and a narrow strip of North American mainland encompassing 6.7 million ha. Single ranger districts exceed the size of many national forests in the continental United States. The Wildlife Conservation Strategy old-growth reserve network is depicted as wilderness and natural setting land use designations (LUDs) within Alternative 6 of the 2008 Forest Plan Amendment (USFS 2008). Wilderness LUDs include wilderness areas and National Monuments. Natural setting LUDs includes lands that maintain old-growth forest: congressionally designated unroaded areas; old-growth forest LUDs; remote and semi-remote recreation; municipal watersheds; special interest areas; wild, scenic, and recreational rivers; and research natural areas. Development LUDs include timber production, modified landscapes, scenic viewsheds, and experimental forests; <25% of these lands are suitable for timber harvest. Non national forest system lands represent state, Native, and private lands (USFS 2008).

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for implementing NFMA viability provisions are expected to occur through the following processes: 1) describing the ecological context, 2) identifying species of viability concern, 3) collecting information on species of viability concern, 4) identifying species groups, 5) describing conservation approaches, 6) developing land and resource management plan (LRMP) alternatives, 7) evaluating the effects of LRMP alternatives on viability, and 8) conducting monitoring activities.

Historical timber management of the Tongass limited old-growth rainforest available to planners in framing a conservation strategy. A large majority of timber harvests occurred before the 1997 forest plan revision (USFS 2008), with cumulative disturbance and ecological consequences from 5 decades of high grading (i.e., exclusive harvest of the most valuable forests) across the region, including large-tree stands and expansive landscapes with contiguous productive old-growth (timber volume >46.6 m^3/ha) forests (Albert and Schoen 2012). While approximately 79% of the Tongass remains largely undisturbed and undeveloped (stream and shoreline buffers, reserves, wilderness areas), the majority of the unmanaged portion is highly fragmented, composed of ≥20,000 small (<400 ha), uninhabited islands with little opportunity for timber harvest (USFS 1997). The managed portion (~21%) has been subjected to intensive broad-scale disturbance from extensive clearcut logging that produced sharply contrasting land cover types within single landscapes (Figure 2). The highest rates of change occurred among biogeographic provinces and landform associations that originally contained the largest concentrations of highest volume, productive old growth (POG). Although only 12% of POG forests have been logged, large-tree stands were reduced by ≥28%, karst forests by 37%, and landscapes with the highest volume of contiguous old growth by 66.5% (Albert and Schoen 2012).

The USFS responded to this management challenge with a comprehensive, science-based revision of the forest plan (Swanston et al. 1996). The 1997 Tongass Land and Resource Management Plan (TLMP; USFS 1997) combined familiar, previously used elements and processes gleaned from the scientific literature with regional ecological information from journal publications, workshops, expert panels, and agency reports to design a unique, strategic conservation framework (Swanston et al. 1996, Everest et al. 1997, Smith and Person 2007, Smith et al. 2011, Smith 2013). Emulating natural disturbances offered an approach to designing management plans that maintain prevailing ecological conditions (Nowacki and Kramer 1998). Tongass planners chose a management plan alternative that departed substantially from the natural disturbance regime in which ≥95% of canopy openings produced by windstorms average <0.03 ha (Nowacki and Kramer 1998). The 1997 TLMP continued to emphasize

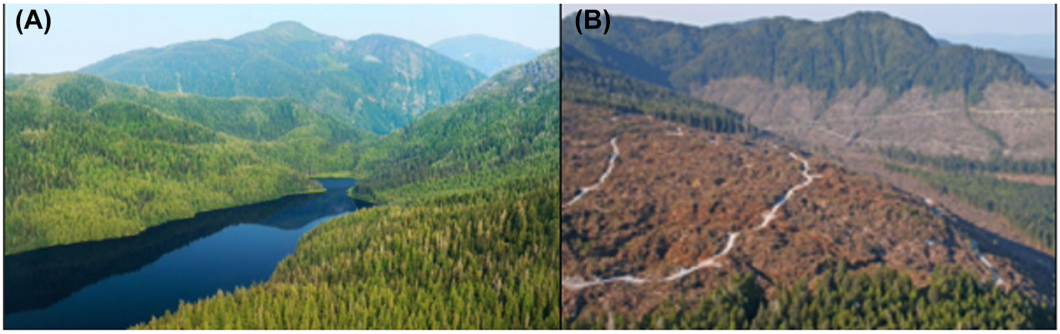

FIGURE 2 Timber management of the Tongass National Forest in southeast Alaska, USA, was dichotomous, producing sharply contrasting unmanaged and managed landscapes of A) intact old-growth temperate rainforests (photo by Alan Wu/Flickr Creative Commons) and B) extensive clearcuts (photo by John Schoen). A small proportion (12%) of the entire Tongass National Forest was logged; still, 67% of the highest volume forests were harvested (Albert and Schoen 2012). Some smaller islands experienced broad-scale disturbance across a significant proportion of the entire distribution of resident endemic mammals (Smith et al. 2011, Smith and Fox 2017).

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clearcut logging, adding broad-scale disturbance to expansive landscapes of young, unmanaged, even-aged second growth (USFS 1997).

Despite its size and southeast Alaska's highly fragmented island biogeography, an important and far-reaching central hallmark of the 1997 TLMP is that the Tongass National Forest is largely managed as a single contiguous forest ecosystem. This has been evident from expectations that the Tongass would continue to persist as interconnected late-successional ecosystems across southeast Alaska (Shaw 1999), assessments and summary data would be presented as forest-wide statistics (USFS 1997, 2008, 2016), and management would disregard the variety and significance of unique biota and ecological communities (Smith 2012*a*), including the consequences of disproportionate loss and fragmentation of available habitat from cumulative effects of logging to island endemics (Smith and Person 2007, Smith et al. 2011, Albert and Schoen 2012, Smith 2013, Smith and Fox 2017).

Although amendments to TLMP have occurred since 1997 (USFS 2008, 2016), today the Tongass Wildlife Conservation Strategy (WCS) remains largely intact (USFS 2016). Unfortunately, a continuous decline in funding since 1997 has limited resources and capability to implement a proposed comprehensive long-term monitoring plan for sensitive or other vulnerable species (Smith et al. 2011, Smith 2013, Smith and Fox 2017). Consequently, there is little documentation regarding the implementation of management or conservation actions or corresponding responses and outcomes for intended forest resources.

Until recently, the most apparent alterations or amendments to the WCS have been the removal, movement, or change in composition of designated old-growth reserves (Smith et al. 2011). Small old-growth reserves have remained spatially inexplicit (USFS 2008), obscuring assessments of landscape structure and functional connectivity. In the 2016 forest plan amendment, an immeasurable number of small (many isolated) conservation areas totaling 1.3 million ha of old-growth forest were established across the Tongass, and 8,350 ha of old-growth forest was preserved among 73 watersheds to protect anadromous streams (USFS 2016: appendix D). It remains unclear if the watershed allocation was in addition to the old-growth reserve network expectation that ≥16% of the area be retained as old-growth forest (USFS 1997: appendix K). Regardless, without additional research, including spatially explicit analyses of watersheds and surrounding landscapes, contributions to functional connectivity or essential habitat of sensitive or old-growth obligate wildlife remain uncertain.

The Tongass WCS embodies a complex land and resource management framework intended to maintain biological diversity that comprises numerous elements, some of which are integrated within a hierarchical structure that is susceptible to systemic failure because each component is essential for overall functioning (Smith et al. 2011, Smith 2013). Although some elements have been successfully implemented for select species under specific circumstances elsewhere (USFS and Bureau of Land Management 1994), the Tongass WCS was implemented as an experiment with several essential underlying assumptions (Smith and Person 2007, Smith et al. 2011, Smith 2013). Yet statements asserting or accepting the 1997 Tongass WCS as a scientifically sound foundation from which to base management decisions continued to occur in forest and project planning documents (USFS 2008: D26, USFS 2016: K1–3), meetings, internal communications (W. P. Smith, USFS, personal communications), received emails, internal and cooperator meetings, oral comments during public workshops and meetings, and external communications (e.g., newspaper articles). Such assertions lack sufficient monitoring data or supporting evidence from scientific studies, potentially enabling further threats to essential old-growth ecosystems and native wildlife.

Our objective was to illustrate apparent disparities between designed expectations and documented outcomes of implementing the WCS through an investigation of published wildlife research conducted on the Tongass, including studies explicitly designed to examine inherent assumptions. Specific objectives were to use published results to examine 4 assumptions of the Tongass WCS: forest planning assessments of wildlife viability were realistic, forest management and conservation policies are implemented at appropriate ecological scales, old-growth reserves are effective habitat conservation areas and ensure functional connectivity, and standards and guidelines ensure sufficient habitat for sensitive species in managed landscapes.

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STUDY AREA

Southeast Alaska is composed of mainland extending south along the western coast of Canada and >1,000 islands. The area includes fjords and glaciated mountain ranges and a cool, wet (200–600 cm annual precipitation) maritime climate, with mean monthly temperatures ranging from 13°C in July to 1°C in January (Smith and Nichols 2003, 2004). Elevation ranges from sea level to 1,643 m. The region is highly fragmented, with islands ranging in size from <1 ha to 6,670 km^2. The narrow mainland is largely isolated from other large, contiguous landmasses because of mountains, glaciers, and ice fields immediately to the east (Everest et al. 1997). Southeast Alaska is further stratified by 21 biogeographic provinces according to various configurations of physical, climatic, and biotic features. About 4 million ha (60%) is rainforest, of which 2.2 million ha is productive forests (USFS 1997). Coniferous rainforest dominates the landscape from shoreline to about 600-m elevation. The forest canopy is dominated by western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) in uplands but includes shore pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), western redcedar (*Thuja plicata*), and Alaska-cedar (*Chamaecyparis nootkatensis*) in wetlands (Nowacki and Kramer 1998); remaining areas are riparian, alpine, muskeg, or sparsely vegetated mountain peaks and other rock formations (Smith and Nichols 2003, 2004). About 90% of commercial forests are upland Sitka spruce–western hemlock forests (USFS 1997).

Large trees (>75-cm diameter), downed and decaying wood, snags, and heterogeneous substrates are key components of old-growth rainforest ecosystems (Alaback 1982, Nowacki and Kramer 1998). The understory is dominated by blueberry (*Vaccinium* spp.), especially in canopy gaps (Smith and Nichols 2003, 2004; Smith 2012*a*). Unmanaged forests have a multilayered overstory of uneven-aged trees, dominant trees that generally are ≥300 years old, and structurally diverse understories (Alaback 1982; Smith and Nichols 2003, 2004). These forests vary in structure from scrub, or low-volume, communities of short (<10 m), small (<0.5-m diameter) trees with open canopies and dense, shrubby understories on poorly drained sites (peatland) to high-volume stands with a closed canopy, tall (>60 m), large (>3-m diameter) trees, and a predominantly herbaceous understory on highly productive sites (Harris and Farr 1974, Alaback 1982). The western hemlock-Sitka spruce forest type constitutes most of the closed-canopy forests in the region (Alaback 1982). It is spatially heterogeneous at a fine scale (<1 ha) and typically occurs on low-elevation, well-drained sites, often as a mosaic with fens and muskegs (Smith and Nichols 2003, 2004).

Southeast Alaska has a unique mammalian fauna that is significantly correlated with island isolation and extinction events resulting from differential colonization and island area effects (Conroy et al. 1999). Consequently, southeast Alaska is a hot spot of endemism (Cook et al. 2001), with varying and unique mammal assemblages and ecological communities (Cook and MacDonald 2001; Cook et al. 2001, 2006; Smith 2012*a*). The life history of birds is also influenced by the fragmented nature of the region, most notably northern goshawks (*Accipiter gentilis*) and other species that require large breeding ranges (Smith 2013). Prominent indigenous vertebrates include the Queen Charlotte goshawk (*A. g. laingi*), marbled murrelet (*Brachyramphus marmoratus*), Alexander Archipelago wolf (*Canis lupus ligoni*), brown bear (*Ursus arctos*), American marten (*Martes americana*), Sitka black-tailed deer (*Odocoileus hemionus sitkensis*), and numerous endemic small mammals whose distributions are restricted (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006), including the following island endemics: Prince of Wales Island flying squirrel (*Glaucomys sabrinus griseifrons*), Wrangell Island vole (*Myodes gapperi wrangeli*), and Suemez Island ermine (*Mustela erminea seclusa*).

METHODS

Because the purpose of this review was not a meta-analysis or systemic literature review, we first conducted literature searches focused on our published research papers and the citations within and summarized the findings of numerous studies conducted in Southeast Alaska during 1998–2017. We then used a Web of Science^{TM} word

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search conducted 31 May 2021 using the keywords Tongass, management, wildlife, and conservation. This search produced 57 results. We expanded our search by reviewing the publications citing relevant sources from this search and by reviewing the sources cited within all of these. We extracted publications from the search output that focused on research or management of wildlife within the Tongass that related to ≥1 of the 4 objectives for this review. We excluded studies of wildlife species that were not identified as a focal or management species within TLMP (e.g., bears, bald eagle [*Haliaeetus leucocephalus*]).

Viability assessments (objective 1)

An initial, integral step in developing a forest plan that prioritizes maintaining biological diversity is establishing a procedure in which planners can objectively evaluate the effect of LMRP alternatives on the persistence of native wildlife (Shaw 1999). The USFS convened numerous risk assessment panels during the 1997 TLMP revision (USFS 1997). Each panel comprised subject matter experts with knowledge of the natural resource under consideration. Seven panels estimated the relative risk that implementation of a range of alternative approaches to management of the Tongass would impose upon continued persistence of select wildlife species across the landscape. Ostensibly, the chosen set of species represented a broad enough range of taxa and ecological lifestyles that the breadth of possible responses to each of the 10 forest plan alternatives under consideration was captured in responses of vulnerable species but with little or no correlation among species' responses to a particular alternative (Shaw 1999).

An eighth panel evaluated old-growth ecosystems, assigning likelihood scores to outcomes that characterized the persistence of interconnected and representative late-successional ecosystems across southeast Alaska according to 3 attributes: abundance and ecological diversity, which considered if "old growth would be equal to or greater than long-term (i.e., 100 years) average and is well distributed across environmental gradients, provinces, and community types;" processes and functions, which considered whether the full range of disturbance processes are represented, and if "stand structure-dynamics and landscape structure-dynamics-age attributes occur across all provinces;" and whether connectivity would be as "effective as it was prior to large-scale timber harvest" (Shaw 1999: 11–12). Assessments from each of the panels became an integral element of the effects analyses that ultimately determined the management policies and actions incorporated in the 1997 TLMP (USFS 1997).

Risk assessment panels evaluated the likelihood of persistence of the northern goshawk, Alexander Archipelago wolf, brown bear, marbled murrelet, American marten, Sitka black-tailed deer, and other terrestrial mammals (Shaw 1999). Other terrestrial mammals included a group of more widely distributed mammals and a group of endemic small mammals whose known distribution in southeast Alaska is restricted (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006). To assess the influence of varying management applications and intensities on wildlife viability, panels examined the marginal risk (individual extinction probability) of vulnerable species under each alternative and focused attention on the taxon with the highest projected risk of extinction with implementation of the alternative. This most sensitive species and its probability of extinction was used to reflect the risk to wildlife population viability for all vertebrates across the planning area for the alternative under consideration (Shaw 1999). This approach has been challenged because of untenable assumptions regarding the interpretation and application of select, individual vulnerable species from viability assessments to conservation planning (Soulé 1987, Smith and Zollner 2005, Jenkins et al. 2021).

Number of species influences the probability of any extinction

Smith and Zollner (2005) detailed an approach to assessing wildlife viability that explicitly considers the risk of any extinction among vulnerable vertebrate species in the planning area, calculated as the "likelihood of at least

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one success" (Snedecor and Cochran 1980: 115). Thus, the assessed probability of extinction following implementation of an alternative is the joint probability of marginal probabilities, each of which represents the risk to viability of individual species (Smith and Zollner 2005). They created a scenario with multiple hypothetical species at risk using each's corresponding independent marginal probabilities (acknowledging distinctive rather than correlated responses) for each of several management alternatives, similar to procedures used in planning TLMP (Shaw 1999). Smith and Zollner (2005) used this scenario to illustrate how the probability of any extinctions and the probability of the single most likely extinction differ as a function of the number of species examined. Recall, one panel assessed viability risks of a group of 26 terrestrial mammals (Shaw 1999) that included 14 endemic small mammal taxa and 12 additional terrestrial mammal taxa (USFS 2008: appendix D68). Moreover, endemic mammals were the most vulnerable of all wildlife species to future landscape disturbances assessed by the panel (Swanston et al. 1996: 11).

When marginal probabilities are used to calculate the joint probability of any extinction under each management alternative, the risk to wildlife viability is consistently and markedly higher than that obtained from selecting the most vulnerable species at risk (Figure 3). This occurs because the risk of local extirpation increases with the number of extinction-prone species in a region (Smith and Zollner 2005). Furthermore, the 1982 NFMA planning rule to ensure wildlife viability explicitly charges managers with the responsibility of protecting all vertebrates in a planning area, not just selecting species that appear to be the most vulnerable (Shaw 1999, Smith and Zollner 2005). Forest plan alternatives that pose the highest risk to more vulnerable species might not necessarily represent the greatest threat to wildlife communities, in part because of the variety of unique assemblages and their interspecific relationships and dependencies (Conroy et al. 1999, Smith 2012*a*, Smith and Fox 2017, Kelt et al. 2019, Jenkins et al. 2021) but also because of the varying number of sensitive species that occur among southeast Alaska's unique fragmented communities (Conroy et al. 1999, Smith 2012*a*, Colella et al. 2021).

Tongass planners in 2008 did acknowledge the influence of the number of species at risk on the probability of any extinction and compared 1997 assessment panel results among management alternatives with corresponding joint probability estimates and among proposed forest plan alternatives (USFS 2008: D85–86).

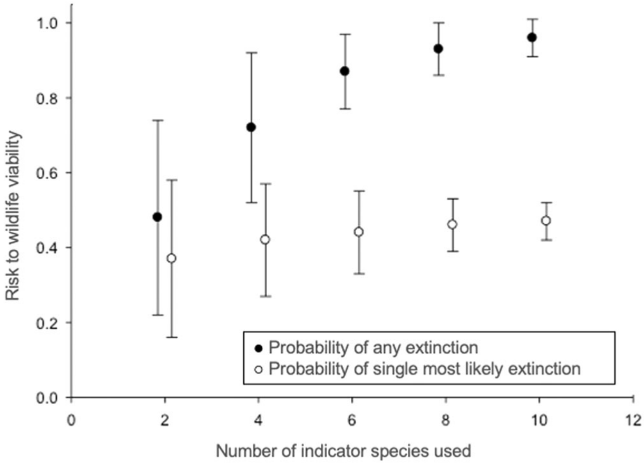

FIGURE 3 Disparity in risk to wildlife viability between estimating the probability of the most likely extinction (extinction of most sensitive species) and the probability of any extinction when assessing the relative risk that implementation of alternative approaches to management of national forest would impose upon continued persistence of indigenous wildlife across the landscape. Figure reprinted with permission from Smith and Zollner (2005).

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Still, it remains unclear whether the joint probability calculations used the mean marginal probability of each wildlife assessment panel (*n* = 7) or included the marginal probabilities of each of the 14 individual endemic small-mammal taxa and 12 other terrestrial mammals. The latter seems unlikely because marginal probabilities were not assessed for each of the 26 terrestrial mammals (Shaw 1999). More importantly, the acknowledged higher extinction risks did not appear to raise concerns sufficient to generate discussion about acceptable threshold values of viability risks relative to policy or implementing future management actions or conservation measures (USFS 2008).

Implicit in the Tongass approach is an assumption that similar species are perfectly correlated in how each responds to a management alternative (Shaw 1999). Such an assumption is not ecologically tenable (Szaro 1986, Soulé 1987, Todd and Burgman 1998, Jenkins et al. 2021). Vertebrate faunas comprise diverse ecological assemblages of organisms that include herbivores, granivores, insectivores, carnivores, and omnivores, which often use the environment at different scales and in different ways (Wiens et al. 1993, Lancaster 1996, Kelt et al. 2019). Species in wildlife communities, even those with seemingly similar habitat affinities and life histories, do not respond to disturbance uniformly within habitat patches (Szaro 1986, Laurance 1991, Niemi et al. 1997) or across broader spatial scales (McGarigal and McComb 1995). Consider also the nature of forces that influence wildlife populations; anthropogenic disturbances are additive and extraneous to ecosystems (Püttker et al. 2020). Because wildlife communities evolved under unique environmental circumstances, local populations respond differently to anthropogenic disturbances compared with natural regimes (Wilson et al. 2005). Individual species likely respond differently to the same anthropogenic disturbance (Szaro 1986, Wiens et al. 1993, McGarigal and McComb 1995, Niemi et al. 1997). Within the same community, species of management concern can require strikingly different disturbance regimes and consequently respond divergently to the same management prescription (Smith 2013). Thus, it is unrealistic to expect that a select set of vulnerable species can represent the risk to viability of the entire vertebrate fauna across numerous unique, diverse communities with varying life histories and sensitivities to anthropogenic disturbance and spatial context (Wiens 1989, 1996).

Managing a large-scale island archipelago (objective 2)

Issues of ecological scale are a major concern in wildlife conservation, and many ecological patterns and processes are scale-dependent (Wiens 1989). Perceptions of how populations are spatially subdivided and impressions of extinction and dispersal dynamics depend on the scale at which the population is viewed (Wiens 1996). Conservation of biological diversity also requires maintaining evolutionary diversity (genetic and life-history attributes) of organisms indigenous to a region (Cook and MacDonald 2001, Colella et al. 2021), including the composition, structure, and functions of local ecological communities (Smith 2005, Watson et al. 2018, Grantham et al. 2020). Land management planning for the Tongass National Forest, however, has occurred at the scale of millions of hectares (USFS 1997, 2008, 2016), which is a much broader scale than the contiguous landscapes available to fragmented wildlife populations and ecological communities across an island archipelago and isolated mainland (MacDonald and Cook 1996, Conroy et al. 1999, Cook et al. 2001). Cook et al. (2001) listed 24 endemic mammals, several of which occur only on one or a few islands (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006, Colella et al. 2021). The entire known distribution of the Suemez Island ermine, a small carnivore, is <160 km^2 (MacDonald and Cook 1996). Moreover, several species encompass multiple, genetically distinct lineages (some representing incipient or new species) attributable to independent colonization histories from divergent source populations (Cook et al. 2006). The insular landscapes of the Alexander Archipelago have produced highly endemic populations that should be prudently managed as hotspots of biological and evolutionary diversity. Thus, islands available for timber harvest should each initially be considered an independent biological unit (Cook et al. 2006).

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Consequences of management at inappropriate ecological scales among island communities

The Wrangell Island vole is a habitat specialist that achieves its highest densities in old-growth forests (Figure 4A) and is unable to sustain breeding populations in peatland scrub (mixed-conifer) forest (Figure 4B), clearcuts (Figure 4C), or second growth (Figure 4D,E; Smith and Nichols 2004, Smith et al. 2005*a*, Smith and Fox 2017). This red-backed vole is known only from Wrangell and Etolin islands (MacDonald and Cook 1996, Runck 2001). Wrangell Island is 544 km^2 (54,400 ha) and 85% of the island is in Tongass National Forest, of which 72% is available for timber harvest. Approximately 2,700 ha of old-growth forest has been clearcut logged, with a proposed timber project to harvest an additional 16,600 ha (USFS 2019). Moreover, there are no explicit conservation directions or actions to protect this vulnerable island endemic from local extirpations (USFS 1997: 4–87).

On Wrangell Island, voles are sympatric with the Keen's mouse (*Peromyscus keeni macrorhinus*), a habitat generalist that flourishes in old-growth, managed, and scrub forests (Smith and Fox 2017). Keen's mouse can be an intense competitor of voles, with interspecific competition between the 2 species explaining more variation in vole abundance (and vice versa) among habitats than the variance associated within habitats (Smith and Fox 2017). Thus, clearcut logging of old-growth forests on Wrangell Island favors populations of the Keen's mouse by creating habitats that breeding vole populations cannot exploit and further reducing vole abundance across managed landscapes because of increased interspecific competition from increasing mice populations (Smith and Fox 2017). Furthermore, opportunities for voles to reoccupy managed landscapes are limited because broad-scale disturbance can take ≥300 years for ecological succession to achieve old-growth forest conditions (Nowacki and Kramer 1998).

Thus, when forest management is applied indiscriminately across archipeleagos (*defacto* contiguous landscapes), it is implemented at inappropriate ecological scales and thus insensitive to the variation and uniqueness of species composition, phylogeography, life-history attributes, and interspecific relationships among island communities (Cook et al. 2006). The consequences of disproportional habitat loss and fragmentation typical of island endemics results in isolation, local extirpation, and overall reduction of endemic populations, increasing risk of extinction (Burkey 1995, Frankham 1998, Crooks et al. 2017, Püttker et al. 2020, Vynne et al. 2021).

Effectiveness of old-growth reserve system (objective 3)

The WCS has 2 components, each representing sharply contrasting management and landscape conditions. The first is a forest-wide, old-growth reserve network (Figure 1; USFS 1997) in which the reserves and other protected lands are expected to provide sufficient habitat to sustain viable, well-distributed populations of old-growth-obligate wildlife (Iverson and Renè 1997, Smith and Person 2007). This network was intended to serve as a coarse filter to maintain a functional and interconnected old-growth ecosystem (USFS 2008: D6). Coarse filters use the compositional integrity and functional proficiency of landscapes or ecosystems as surrogates to predict or ensure the wellbeing of particular taxa or ecological communities (Jenkins et al. 2021). A second function of the old-growth reserve system is to facilitate functional connectivity of protected lands, which also contributes old-growth structural elements in the development land-use designations of the Tongass planning area within which timber harvest and other anthropogenic disturbances occur over time.

The old-growth reserve network included all non-development lands and a system of large, medium, and small habitat conservation areas (reserves). Islands <400 ha were included and received protection from additional logging (USFS 1997, 2016). Each major watershed is required to have at least a small reserve encompassing ≥16% of its area. The preferred biological objective of a small reserve is to contain ≥50% POG; the minimum prescription is ≥25% POG. Medium reserves were delineated as contiguous landscapes of ≥4000 ha with ≥2000 ha of POG, of which ≥50% must be in the highest volume category. Large reserves must be ≥16,000 ha of contiguous landscape, with ≥50% POG and ≥25% in the highest volume category (USFS 1997: appendix K).

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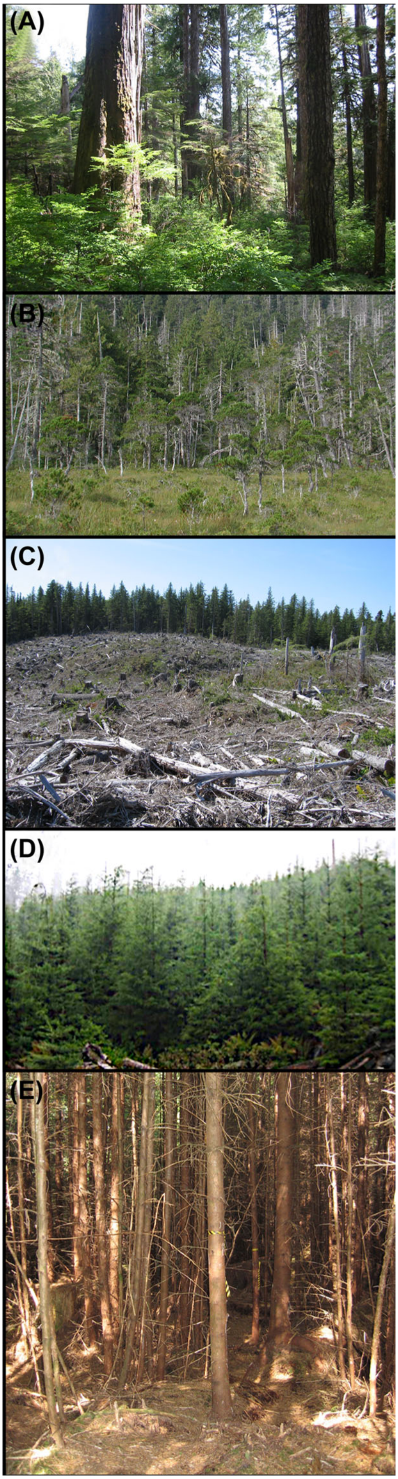

FIGURE 4 Common management stages and corresponding vegetation structure available to endemic small mammals in managed landscapes of the Tongass National Forest, southeast Alaska, USA: A) old-growth forest, B) peatland scrub forest, C) clearcut, D) young (<20 yr) second growth, and E) unthinned older (>40 yr) second growth.

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The second WCS component includes active management of the matrix (commercial clearcut logging). Land managed for timber production was expected to contribute little toward maintaining biological diversity (USFS 1997: appendix N). Within the matrix, forest-wide standards and guidelines were implemented to uphold remaining components of the old-growth ecosystem. A standard is a course of action or level of achievement that must be accomplished to achieve forest goals and are mandatory. A guideline is also a course of action that must be followed, but guidelines relate to activities in which site-specific factors might require flexibility and require further analysis. Therefore, forest-wide standards and guidelines serve as fine filters to protect specific resources (e.g., old-growth forests) and functions (e.g., streamside buffers), facilitate connectivity across old-growth forests, and to ensure sufficient habitat for individual sensitive species (USFS 1997: chapter 4). Thus, for wildlife populations to persist in heterogeneous landscapes, either individual habitat patches must be large enough to provide for viable populations in isolation (Smith and Person 2007, Crooks et al. 2017) or the juxtaposition of suitable habitat within the matrix must allow for interpatch movements that facilitate meta-population dynamics (Smith 2012*b*, Fahrig et al. 2021).

Habitat conservation areas

The northern flying squirrel (*Glaucomys sabrinus*) was selected as the design (proxy) species for small old-growth reserves (≥650 ha) in the 1997 TLMP (USFS 1997) because of its assumed dependency on POG. Northern flying squirrels are k-selected, omnivorous, mature-forest obligates (Smith et al. 2004, 2005*b*; Smith 2007, 2012*b*; Holloway and Smith 2011) with specialized gliding locomotion (Scheibe et al. 2006). The underlying premise was that if the Tongass conservation strategy maintained viable and widely distributed populations of flying squirrels across the planning area, it would support other small mammals with similar life histories and habitat needs (Swanston et al. 1996, USFS 1997). Northern flying squirrels inhabit forests along southeast Alaska's mainland coast and occur on ≥15 islands of the Alexander Archipelagos (MacDonald and Cook 1996, Smith 2005, Schoen et al. 2006). The Prince of Wales Island flying squirrel (*G. s. griseifrons*) is an island endemic with reduced genetic variation (Bidlack and Cook 2001) that is considered a subspecies of ecological concern in the Tongass National Forest (Schoen et al. 2006) and is listed by the International Union for the Conservation of Nature as potentially endangered (Hafner et al. 1998).

Small old-growth reserves were expected to function as habitat conservation areas that provide sufficient habitat to facilitate occupancy by flying squirrels, and functionally connected populations interspersed throughout the matrix would behave as a metapopulation (Fahrig and Merriam 1985, Fahrig et al. 2021). Although there was no design requirement to ensure physical connectivity among old-growth reserves or with other non-development land-use designations, the assumption was that POG retained through other features of the conservation strategy (larger old-growth reserves, standards and guidelines) will establish landscape connectivity to facilitate dispersal across the matrix (USFS 2008: D8).

Persistence in habitat conservation areas

Smith and Person (2007) examined whether flying squirrels are likely to persist in isolation over a range of time periods in small habitat conservation areas with varying compositions of old-growth spruce-hemlock and mixed-conifer forests (Figure 4A) consistent with forest plan guidelines for both preferred and minimum habitat objectives (USFS 1997: appendix K). Given these guidelines, Smith and Person (2007) models revealed that the probability of persistence over a planning horizon of 100 years in small habitat conservation areas with the preferred prescription (50%) of spruce-hemlock composition was 0.73–0.77 and for the minimum prescription (25%), probabilities were 0.66–0.71. Furthermore, to sustain isolated populations over long periods (100 yr) with a high level (≥0.95) of

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confidence, flying squirrels require very large (244,600 ha) reserves of 100% optimum habitat. Medium (2000 ha POG) and large reserves (8000 ha POG) as currently specified (USFS 1997: appendix K) have a <0.90 probability of sustaining viable populations of flying squirrels over the 100-year planning horizon (Smith and Person 2007). These persistence estimates have been evaluated in the field. For example, on Kosciusko Island, flying squirrels were apparently extirpated from a 50-ha remnant patch of old-growth forest surrounded by <50-year-old second growth (E. A. Flaherty, Purdue University, unpublished data), and Shanley et al. (2013) observed that flying squirrels were not found in patches <29 ha and only selected the largest fragments locally and at the landscape scale with the minimum patch size for occupancy of 48 ha. Both suggest that likelihood of persistence is low in these small, isolated patches.

Functional connectivity and dispersal in managed landscapes

Given this uncertainty, Smith et al. (2011) evaluated the efficacy of small reserves as a functionally connected network that provided temporary suitable habitat for flying squirrels dispersing among large and medium reserves. They estimated the number of immigrants required to persist in small reserves for 25 and 100 years, landscape resistance to movement, and maximum effective dispersal distance via least-cost path analysis among small and larger reserves to ensure the required number of immigrants (Pyare and Smith 2005). Landscape resistance and risk of predation were higher in clearcuts (Figure 4C) than mature forests (Smith 2012*b*). Similarly, unthinned second growth (Figure 4E) obstructed visibility of suitable habitat (perceptual range) and impeded gliding (Flaherty et al. 2008, Smith 2012*b*). These dispersal barriers are a significant concern when an estimated 162 dispersers/year are needed to sustain populations for 100 years in small reserves comprising 25% primary habitat and ≥6 juvenile dispersers/year are needed to achieve a 0.95 probability that a breeding pair would reach a patch in which flying squirrels were recently extirpated (Smith et al. 2011).

Considerations of dispersal distance across managed matrix habitat is also important for maintaining persistence of flying squirrels. The maximum effective dispersal distance (Pyare and Smith 2005) for a 0.95 probability persistence over 100 years ranged from 844 m for small old-growth reserves with 25% primary habitat to 1,151 m for small old-growth reserves that comprise 100% primary habitat. Corresponding values for persistence in small old-growth reserves over 25 years were 1,172 m and 1,174 m (Smith et al. 2011). Remarkably, the maximum value of 1,174 m fell well within the distance that juveniles can move through intact landscapes (~7 km) over short time periods (Smith 2012*b*). Unfortunately, most of northern Prince of Wales Island has been clearcut logged (Figure 5), and ≥50% of small old-growth reserves prescribed in the 1997 TLMP for northern Prince of Wales (Figure 5) were isolated and not functionally connected to a source population (Smith et al. 2011).

These results underscore the vital role of immigration in rescuing sinks or facilitating metapopulation viability of northern flying squirrels among unsustainable fragmented populations, and the extent to which permeability of landscape elements can influence dispersal and functional connectivity of subpopulations in a managed matrix (With and Crist 1995, Richards et al. 2002, Pyare and Smith 2005, Smith et al. 2011, Trapp et al. 2019). The expectation that the Prince of Wales Island flying squirrel will function as a metapopulation with successful dispersal among old-growth fragments or reserves in managed landscapes is not supported by the findings of multiple studies examining this island endemic's habitat relations, population dynamics, and dispersal capability, including perceptual limitations, locomotion, energetics, and diet (Smith 2012*b*). Without large trees to facilitate gliding (Vernes 2001), flying squirrels must use quadrupedal (walking or running) locomotion, which is energetically more expensive than gliding (Scheibe et al. 2006, Flaherty et al. 2010*a*) and increases travel time (Byrnes and Spence 2011), leading to increased risk of predation (Smith 2012*b*). Additionally, flying squirrels cannot replenish energy stores by foraging as they disperse across clearcuts and second-growth stands because of the absence of preferred food resources (Flaherty et al. 2010*b*, Price et al. 2017). Finally, flying squirrels are unable to perceive old-growth forests across managed stands and are therefore unlikely to initiate movements across these more energetically expensive and risky land cover types (Flaherty et al. 2008).

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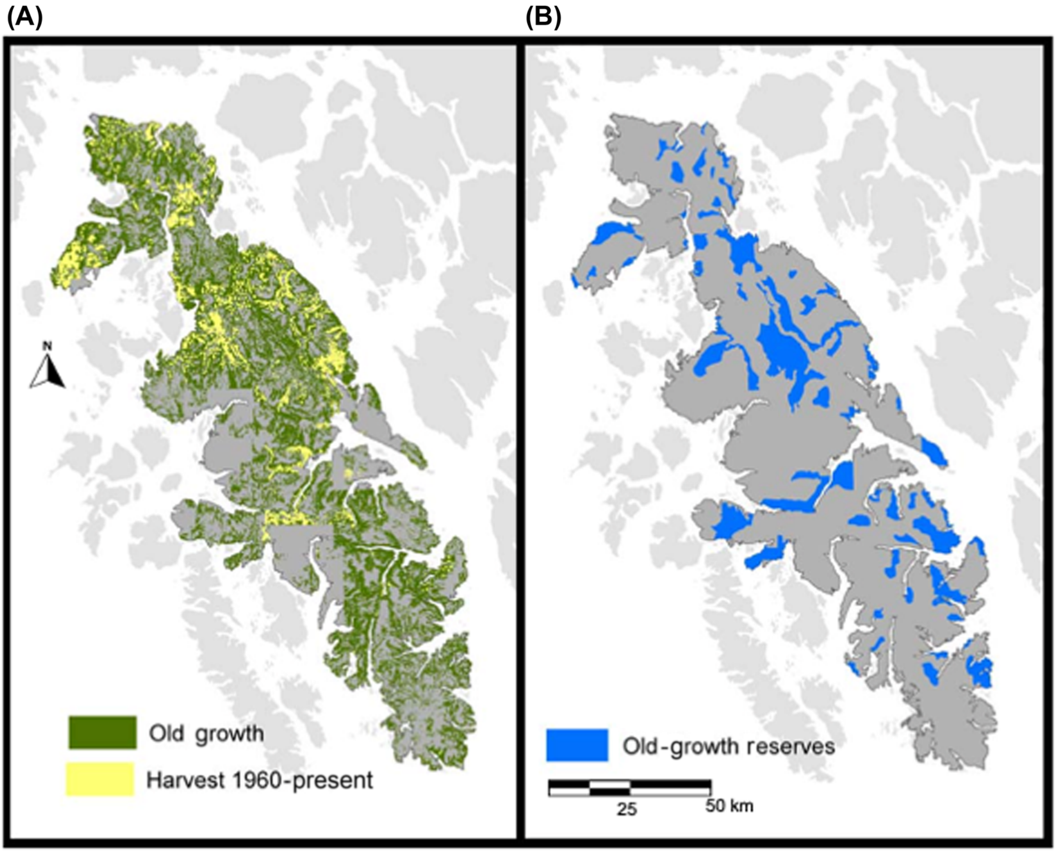

FIGURE 5 Prince of Wales Island, Alaska, USA, depicting the distribution of A) old-growth rainforest and areas logged since 1960 and B) old-growth reserves (USFS 1997).

Forest-wide standards and guidelines (objective 4)

The second component of the WCS uses forest-wide standards and guidelines, which are implemented for the protection or management of different forest resources (USFS 1997: chapter 4). Standards and guidelines apply to all or most areas of the Tongass, are organized by resource conservation status, and are used in conjunction with additional standards and guidelines included within each management prescription (USFS 1997: chapter 3). Standards and guidelines were established to manage locally important habitat for native wildlife (USFS 1997: chapter 4) and sensitive species (USFS 1997: 4–87), especially those that were not explicitly considered by viability assessment panels (Shaw 1999) or selected as ecological proxies in the design of the old-growth reserve network (Iverson and Renè 1997, USFS 1997, Smith 2013).

The northern goshawk was designated a sensitive species and underwent viability risk assessment (Shaw 1999). Goshawks received special consideration on the Tongass largely because of concerns over populations of the endemic Queen Charlotte goshawk (Iverson et al. 1996). Formally described as a metapopulation (Sonsthagen et al. 2012), the Queen Charlotte goshawk's distribution includes Prince of Wales and barrier islands and coastal British Columbia and nearby islands. The United States Fish and Wildlife Service listed all areas with known nests, except Prince of Wales Island, as threatened subpopulations in 2012 (U.S. Fish and Wildlife Service 2012), although all subpopulations are deemed essential for long-term viability (Sonsthagen et al. 2012) and ≥33% of POG on Prince of Wales Island has been converted to second growth (USFS 2008: appendix E; Albert and Schoen 2012). The most

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imminent threats to breeding populations are loss or fragmentation of nesting or foraging habitat from logging (Figure 2B) without ensuing intermediate stand management (Figure 4E), which eliminates nest trees and reduces prey diversity and availability (Reynolds et al. 1992, Finn et al. 2002, McGrath et al. 2003, Mahon and Doyle 2005, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008).

In western North America, breeding home ranges of northern goshawks are spatially configured as a hierarchical sequence of 3 areas (Andersen et al. 2005), all of which need to be considered simultaneously in land use planning (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008): nest area, post-fledging area, and foraging area. Nest areas provide alternate nest trees, roost trees, and prey plucking posts, and serve as centers of essential breeding behaviors or life-history events (Reynolds et al. 1992, 1994, 2006). Post-fledging areas surround active nest trees, average 800 ha in southeast Alaska (Iverson et al. 1996), and represent the core-use area of adult female and young goshawks after fledging but before becoming independent of adults and dispersing (Kenward 1982, Kenward et al. 1993, Kennedy et al. 1994). McClaren et al. (2005) suggested the biological role of post-fledging areas and nest areas are similar and to consider them as one functional component. Regardless, the habitat composition of post-fledging areas should be similar to nest areas (Reynolds et al. 2008). Foraging areas comprise the majority of northern goshawk breeding home ranges and are especially important for adults providing food to young and for juveniles prior to natal dispersal. Breeding home ranges in southeast Alaska average 21 km^2 (Iverson et al. 1996). The combined home range of breeding pairs can be much larger than that of individual birds (Boal et al. 2003).

The 1997 TLMP did not incorporate concepts of nest area, post-fledging area, and foraging area habitat management, which underpin conservation planning to sustain viable populations of northern goshawks across its distribution (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008). Still, Tongass forest-wide policy is focused on protecting confirmed and probable goshawk nests (USFS 1997: chapter 4); standards and guidelines propose to accomplish this by maintaining an area of ≥40 ha of POG generally centered over the nest tree or probable nest site (Figure 6). Another stated objective is to manage foraging habitat to retain essential features of forest stand structure in areas of timber harvest (Figure 2B) because tree density of unmanaged second growth (Figure 4E) reduces prey abundance and diversity and prevents aerial pursuit of prey by goshawks (Reynolds 1983, Salafsky et al. 2007).

Despite a substantial increase in knowledge since the 1997 TLMP revision, the implications of those new insights to goshawk conservation and land-use policies in southeast Alaska had not been revised in forest plan amendments (Smith 2013). Without long-term monitoring, it has remained unclear whether a network of reserves designed explicitly for other wildlife species (USFS 1997) or protection of goshawk nest trees in landscapes intensively managed for timber, would provide sufficient habitat to sustain breeding populations of the northern goshawk across the planning area (Finn et al. 2002). What is clear from the literature is neither coarse-filter nor fine-filter components of the WCS appear relevant to northern goshawk life history or conservation planning; 40-ha nest buffers (Figure 6) and habitat conservation areas distributed across expansive landscapes of even-aged second growth have never been applied as mitigating measures elsewhere in its distribution (Smith 2013).

Smith (2013) conducted a spatially explicit analysis of contributions of the Tongass WCS to the breeding home ranges of northern goshawks across southeast Alaska. He used 136 confirmed nest-tree locations and empirically derived estimates (Iverson et al. 1996) to delineate corresponding virtual post-fledging areas and female breeding home ranges, within which they calculated the area of 4 cover types and 4 land-use categories. They derived preferred habitat from empirical studies in southeast Alaska (Iverson et al. 1996). About 30% of nests had >51% of post-fledging areas in preferred habitat but >91% of post-fledging area was in an unsecure (unprotected from development) land-use designation; 60% of post-fledging areas had >51% in an unsecure designation, whereas only 16% had >51% in the protected old-growth forest. Among cover types, preferred habitat comprised an average of 39.4% of the post-fledging area. Smith (2013) obtained similar results from an analysis of the female breeding home range but with notable differences. The percentage of the broader landscape that consisted predominantly (>75%) of lands available for development was greater than in post-fledging areas (Smith 2013). The percentage of the total

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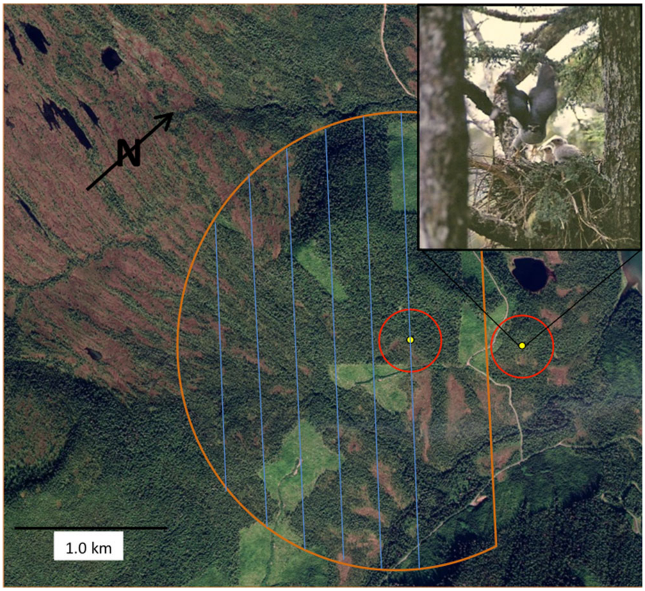

FIGURE 6 Northern goshawk nest sites (yellow spheres) during 1999 to 2001 in managed landscapes of the Tongass National Forest in southeast Alaska, USA (image courtesy of Google Earth), with an active nest (photo by Craig Flatten) in the canopy of old-growth rainforest. Red circles represent circular 40-ha old-growth buffers (360-m radius) prescribed for active goshawk nests by forest-wide standards and guidelines in the Tongass Land Management Plan (USFS 1997, 2008, 2016). Area with blue lines within the orange semi-circle depicts half the typical goshawk post-fledging area (PFA); the mean radius of goshawk PFAs is 1,600 m, whereas the radius of breeding female home ranges averages 2,600 m (Smith 2013). Light green areas along logging roads are recent clearcuts; light brown areas are muskegs.

home range with 26–50% of the total area in preferred habitat also increased compared with post-fledging areas, whereas about half as many home ranges had ≥51% of this broader landscape in preferred habitat as compared with the post-fledging area (Smith 2013). From these analyses, it is clear that the Tongass WCS is not contributing sufficient secure habitat to sustain breeding pairs of the northern goshawk across southeast Alaska.

RESULTS

Based on this review, we conclude that the Tongass Land Management Plan is not meeting expectations of ≥4 essential assumptions of the WCS. Additional empirical evidence from the literature supports a conclusion that the WCS has not met expectations of maintaining an interconnected old-growth forest ecosystem. Extensive high-grading and disproportional harvest of the most productive forest have substantially reduced old-growth forest abundance and diversity (Albert and Schoen 2012). Expansive even-aged clearcuts produced landscapes that support a fraction of the old-growth obligate species and provide little functional connectivity, isolating wildlife communities in many of the remnant old-growth patches (Smith et al. 2011).

The Tongass WCS was implemented as an experimental conservation plan composed of numerous elements, some of which are founded in sound ecological science and theory and were successfully implemented elsewhere with different wildlife species and circumstances. A systematic, comprehensive long-term monitoring scheme was proposed as a means to document implementation of management actions and conservation measures, and to record responses and outcomes of select forest resources (i.e., to evaluate if the WCS was functioning according to

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expectations). In the absence of monitoring data, we chose to use the results of wildlife studies on the Tongass that were designed to examine the robustness of vital underlying assumptions.

The enormity and complexity of the Tongass present unprecedented management and conservation challenges, most notably the highly fragmented and isolated nature of southeast Alaska. Empirical evidence from the literature provides examples of isolated ecological communities, varying in composition, ecological roles, and relationships among members, and the potentially irreversible consequences of cumulative broad-scale anthropogenic disturbances on old-growth obligate species, many of which are endemic. The Wrangell Island vole and Prince of Wales Island flying squirrel are examples of endemics for which a substantial part of their historical distribution has been clearcut logged, local populations have become extirpated or isolated, and total populations are reduced, all of which influence persistence. Given the proclivity for endemism, the discontinuity of landscapes further stratified among 21 biogeographic provinces, and the diversity of unique plant and animal assemblages with varied ecological functions and dependencies, it is unrealistic to expect that the Tongass can be managed as a single rainforest ecosystem or according to a conservation strategy that relies on isolated old-growth forest remnants scattered across vast landscapes of unmanaged, even-aged second growth (coarse filter) and uninformed, ineffective fine-filter mitigation measures.

The conceptual framework and procedures used by planners to assess the risk to viability of native wildlife underestimated the effects of implementing each of 10 forest plan alternatives across the planning area. Consequently, when forest management planning and implementation are considered in the context of widespread fragmentation, isolation and endemism, ecological scale, variation and complexity of ecological communities, and an incomplete monitoring plan with substantial gaps in data and analyses, serious questions arise about the effectiveness of the WCS in maintaining widely distributed, viable populations of native wildlife, especially old-growth obligate endemics.

A network of old-growth reserves functioning as habitat conservation areas across intensively managed landscapes can be effective in sustaining viable populations of sensitive, old-growth obligate species. Establishing small, medium, and large habitat conservation areas, each designed to sustain proxy species operating at appropriate ecological scales and collectively establishing functionally connected landscapes, is an empirically based coarse-filter approach. Nonetheless, demographic analysis revealed that the size of a habitat conservation area (with 100% POG) required to sustain viable northern flying squirrel populations in isolation over the planning horizon exceeds the size of medium and large old-growth reserves, the preferred prescriptions of which contain only 50% POG. Further analysis demonstrated that landscapes within the matrix were not functionally connected and incapable of facilitating demographic or genetic rescue among small-mammal endemics. Despite having comparably high densities, the viability risk of the Prince of Wales Island flying squirrel is higher today because subpopulations have become isolated, local extirpations have occurred, and the overall population is reduced. Furthermore, because the northern flying squirrel was selected as a proxy, the effects of cumulative habitat loss and functionally discontinuous landscapes have implications for other old-growth obligate small mammals, especially island endemics.

The WCS also includes forest-wide standards and guidelines as a fine-filter approach to retain, replace, or mitigate essential conditions, mostly in managed landscapes. Forest-wide standards and guidelines are essential for sensitive species such as the Queen Charlotte goshawk that require a diversity of land cover types, including mature or old-growth forest. Forest management guidelines throughout its distribution invariably prescribe rotational management of the entire planning area, which produces landscapes that are a mosaic of cover types varying in stand age, structure, and spatial extent, thereby supporting a wide range of potential avian and mammalian prey species. Landscapes across the Tongass are a sharply contrasting dichotomy of old growth and expanses of even-aged second growth, most of which were logged during a few decades with little (<20%) ensuing intermediate stand management. Unfortunately, neither the reserve network nor the prescribed standards and guidelines accomplish the objective of providing sufficient breeding habitat to sustain northern goshawks across the Tongass.

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DISCUSSION

To address apparent deficiencies and meet expectations of the 1982 viability rule of the 1976 National Forest Management Act, we propose 3 revisions to forest management and conservation policies. First, further commercial harvests of old-growth forests should emulate the primary natural disturbance regime (wind) in size of canopy gaps, frequency of occurrence, and landscape conditions (e.g., forest stand composition and exposure, canopy structure) and circumstances (e.g., slope, aspect, wind severity and direction; Nowacki and Kramer 1998), which will prohibit commercial broad-scale clearcut logging. This policy will reduce further negative effects to old-growth obligate wildlife, especially island endemics (Cook et al. 2006, Smith and Person 2007, Smith et al. 2011, Smith and Fox 2017), and acknowledge the contribution of southeast Alaska's rainforest in mitigating climate change (DellaSala et al. 2022). Second, restoration of forests throughout the matrix through intermediate stand management of second growth should become a forest management priority, especially on Prince of Wales Island and other islands that support island endemics whose native distributions have been substantially reduced by clearcut logging. Priority should be given to landscapes in which old-growth forests are isolated and to second-growth forests along anadromous streams.

Intermediate stand management will reduce midstory density and expedite ecological succession toward achieving mature forest conditions (Nowacki and Kramer 1998) that will benefit the federally listed Queen Charlotte goshawk (Smith 2013) and increase functional connectivity of managed landscapes for endemic small mammals (Flaherty et al. 2008, 2010*a*, *b*; Smith et al. 2011; Howard 2022). Healthy anadromous streams support salmon populations that provide vital marine nutrients required for forest regeneration and development (Quinn et al. 2018, Schoen 2020). Restoration of riparian forests will directly contribute to the health and diversity of the old-growth forest ecosystem (Schoen 2020).

Thirdly, we recommend the Tongass National Forest undertake a formal review of WCS elements that appear incapable of achieving mandated or desirable expectations because of extensive historical timber harvests, misimplementation of proposed or established policies, or untenable assumptions. The review will require an updated assessment of forest resources to accurately inventory and map habitats (Shanley et al. 2021), and extensive research to document the diversity and life-history needs of southeast Alaska's unique ecological communities (Cook et al. 2006), with an initial focus on populations and habitat of the Queen Charlotte goshawk and island endemic mammals that have experienced substantial broad-scale disturbance (Smith et al. 2011, Smith 2013). Conservation measures need to consider the unique life-history attributes of sensitive species. Recognizing the hierarchical structure of goshawk breeding home ranges is fundamental to designing and implementing an effective conservation plan.

MANAGEMENT IMPLICATIONS

Future conservation and management policies and actions will require consideration of recent research findings (especially from the Tongass) and a comprehensive long-term monitoring plan to evaluate implementations and corresponding responses and outcomes. Clearly, an adaptive management approach that explicitly acknowledges and considers the uniqueness of southeast Alaska's varied landscapes and spatial context, geological history, fauna, and ecological communities will provide insights into the complexities and limitations of imposing established forest management policies and actions. A new paradigm that employs new knowledge with systematically scheduled assessments from monitoring programs will provide timely, meaningful evaluations of the consequences of management actions that can remedy existing deficiencies and improve WCS effectiveness.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

The work summarized in this manuscript did not analyze new data collected from studies of wildlife or humans.

DATA AVAILABILITY STATEMENT

Data sharing not applicable because we did not generate new data. All data referenced in this review are included in published articles cited in the manuscript.

ORCID

Winston P. Smith http://orcid.org/0000-0002-0217-064X

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USDA Southeast Alaska Sustainability Strategy Investment Recommendations

Appendix E - Regional Economic Overview

The Southeast Alaska panhandle extends 500 miles along the coast from Metlakatla to Yakutat, encompassing approximately 33,500 square miles of land and water. More than 1,000 islands make up 40% of the total land area. The region is sparsely settled with an estimated 71,946 people living in 34 towns and villages in 2020, most of which are located on islands or along the narrow coastal strip (Alaska Department of Labor [DOL] 2018). The remote nature of the region is reflected in a population density of approximately two persons per square mile, much lower than the United States' average of 92 persons per square mile. The three largest communities—Juneau, Ketchikan, and Sitka—together are home to 75% of the regional population. The dominant culture in the region is indigenous. Alaska Natives—the Tlingit, Haida, and Tsimshian—make up nearly a quarter (27%) of the region's population. The Tlingit have resided in the region for 11,000 years, propelled by the region's mild climate, abundant food and raw materials. A lack of privately-owned land is unique to Southeast Alaska and impacts the ability of the region to support the private sector. Many residents depend heavily on subsistence hunting and fishing to meet their basic needs. Land ownership is dominated by the federal government, which manages 94% of the land base. Most of this (78% or 16.75 million acres) is the Tongass National Forest.

One USDA USDA agency actions contribute to regional economy in Southeast Alaska in a variety of ways. Since most of the land in the region is publicly managed, the Tongass National Forest's stewardship activities are important to communities and the overall regional economy. The communities of Southeast Alaska depend on public lands in various ways, including employment in the commercial fishing and fish processing, recreation, visitor, wood products, and mining and mineral development sectors. Rural Development provides federal assistance resources throughout rural Alaska and has invested $2.16 billion dollars in 236 rural communities in the last eight years. Since 2017, the Natural Resources Conservation Service has invested over $16 million in conservation program assistance to address resource concerns on more than 20,000 acres of private agricultural and forest land in southeast Alaska.

Employment Southeast Alaska regional employment from 2016 to 2020 is summarized by economic sector in Table 1 (Southeast Conference, 2015 to 2021). Overall, employment in the region declined by 28%. The government and the visitor sectors are consistently the largest employers, accounting for 30% and 15%of total employment, respectively. The most significant gains occurred in the warehousing, utilities, and transportation (162%) and social services (47%) sectors while losses were most profound in the information (-75%), financial (-65%), and seafood (-49%) sectors. The five-year average proportion of jobs in timber, seafood, and visitor sectors represented one, 10, and 15% of regional employment, respectively.

The ongoing coronavirus pandemic has resulted in significant economic impacts throughout the region. The regional economy was already stressed from the loss of 1,140 state government jobs from 2012 through 2020 and the impacts of declining oil production and prices on the state budget. With the addition of Covid-19, the region lost nearly 7,000 jobs, or 17% of the total workforce between 2019 and 2020. Hardest hit were sectors providing tourism services; transportation, leisure, and hospitality shed 4,025 jobs. An estimated 191 thousand people visited Southeast Alaska in 2020, down almost 89% from arrivals in 2019. Job losses in the seafood industry across Southeast Alaska were exacerbated by poor salmon returns and low seafood prices as the pandemic impacted global seafood demand. The seafood processing sector was down by 27% (425 jobs) between April and July compared to 2019. Only the timber and mining sectors have not experienced workforce losses because of COVID-19 (Southeast Conference 2020).

There is tremendous uncertainty moving forward. It is too early to measure full impacts of COVID-19, but after a second summer of cruise ship cancellations in 2021 and a continued lack of resolution to the state budget crisis, ongoing economic concerns echo across the region.

Table 1. Number of jobs by economic sector, Southeast Alaska, 2016-2020

Economic Sector	2016	2017	2018	2019	2020	5-year average	5-year average percent of total employment	5-year percent change
Government (includes Coast Guard)	13,052	13,256	13,148	12,994	12,501	12,990	30.21%	-4.22%
Visitor	3,854	7,739	8,004	8,394	4,599	6,518	15.16%	19.33%
Seafood	7,752	3,829	3,711	3,743	3,305	4,468	10.39%	-57.37%
Retail and Wholesale Trade	4,350	4,474	4,490	4,472	4,131	4,383	10.19%	-5.03%
Health Care (private only)	2,033	2,732	2,852	3,025	2,674	2,663	6.19%	31.53%
Construction	2,448	1,932	1,909	1,903	1,362	1,911	4.44%	-44.36%
Financial	2,972	1,964	1,830	1,833	1,038	1,927	4.48%	-65.07%
Professional and Business Services	1,688	2,869	2,910	2,941	1,503	2,382	5.54%	-10.96%
Social Services	798	1,580	889	934	1,175	1,075	2.50%	47.24%
Mining	1,006	886	1,476	1,414	855	1,127	2.62%	-15.01%
Information	1,703	571	541	535	431	756	1.76%	-74.69%
Timber	584	354	337	372	321	394	0.92%	-45.03%
Warehousing, Utilities, Transportation	313	903	943	977	820	791	1.84%	161.98%
Other	2,707	2,551	2,602	2,560	1,507	2,385	5.55%	-44.33%
Total	**45,260**	**45,640**	**45,642**	**46,097**	**32,359**	**43,000**	**100.00%**	**-28.50%**

Notes:
Source: Southeast Conference, 2016-2020.
1 These data were compiled on behalf of Southeast Conference based on data collected by the Alaska DOL and the U.S. Census Bureau. .
2 The Information sector, as defined here, includes publishing, broadcasting, and telecommunications.
3 Includes non-visitor-related transportation only. Visitor-related transportation is included in the visitor sector.

Communities and Equity Using standard socioeconomic indicators to characterize communities in Southeast Alaska is challenging due to the small population sizes, alternative lifestyle choices and values, and the mixing of cash and subsistence economies. What may be perceived as a low-income community by standard economic metrics may instead have residents that practice subsistence activities, value a homestead culture, and earn seasonal or project-based income. Table 2 contains community-level socioeconomic statistics for 32 towns and villages located in Southeast Alaska (Table 2). Population by community ranged from less than 20 to almost 32,000 in 2019. Twelve of the 32 communities identified lost population between 2010 and 2019, ranging from less than 10 residents to more than 100. Population losses have been most dramatic in Juneau, due to cuts in state government employment. Wild foods account for a large share of the diet for residents in Southeast Alaska communities. Marine resources, including fish, mammals, and plants, comprise the majority of subsistence harvest in all communities when measured by food weight and account for more than half of total per capita harvest in all Southeast Alaska communities.

Alaska Natives made up an estimated 15% of total regional population in 2019 and an estimated 21 percent for rural communities (excluding Juneau and Ketchikan). These rural communities include places that are predominately Native, where Alaska Natives make up an estimated 72% (Hydaburg and Kake) and 71% (Saxman and Metlakatla) of the population; other communities that are predominately non-Native and places with mixed ethnicity where Alaska Natives range from about one-third to two-thirds of the population. U.S. Census estimates identified 12 communities in

Southeast Alaska with 10% or more of population below the poverty line in 2018. All but three communities identified in Table 2 had estimated median household income below the state average. Juneau, Gustavus, and Haines were the exception.

Table 2 Southeast Alaska community statistics

	Population			Median household income			
Community	**2019[1]**	**Percent Change 2010 to 2019**	**Percent Native in 2018[2]**	**2018[2]**	**Percent of State Median[3]**	**Percent below Poverty Line in 2018[2]**	**Subsistence Use (lbs per capita)[4]**
	404	-12	43	43,542	59	17.4	182
Coffman Cove	174	-1	5	56,250	76	0.0	276
Craig	1,074	-11	19	64,853	87	14.7	232
Edna Bay	47	12	0	na	na	91.2	383
Elfin Cove	11	-45	33	na	na	na	263
Gustavus	537	21	8	80,000	108	1.7	241
Haines	1,784	4	11	75,833	102	4.0	137
Hollis	132	18	8	na	na	7.9	169
Hoonah	782	3	54	63,750	86	11.1	343
Hydaburg	397	6	72	34,028	46	39.1	531
Hyder	78	-10	0	na	na	na	345
Juneau	31,986	2	11	88,213	119	7.9	na
Kake	570	2	72	54,625	73	9.4	179
Kasaan	85	73	31	45,000	61	14.7	452
Ketchikan	8,103	1	16	59,132	80	12.6	na
Klawock	761	1	42	54,821	74	19.5	350
Kupreanof	17	-37	0	na	na	na	na
Metlakatla	1,359	-3	71	53,409	72	14.4	70
Naukati Bay	137	21	7	na	na	25.0	242
Pelican	69	-22	44	70,500	95	8.6	355
Petersburg	2,963	1	7	69,514	94	8.1	161
Point Baker	12	-20	0	na	na	na	289
Port Alexander	57	10	0	69,375	93	9.3	312
Port Protection	29	-40	0	na	na	73.7	451
Saxman	434	6	71	42,083	57	16.2	217
Sitka	8,532	-4	12	71,534	96	7.5	205
Skagway	1,045	14	4	71,500	96	5.6	48
Tenakee Springs	140	7	0	55,833	75	3.9	330

Thorne Bay	562	19	2	55,682	75	6.9	118
Whale Pass	57	84	0	41,154	55	na	247
Wrangell	2,400	1	17	57,583	77	7.8	168
Yakutat	540	-18	28	65,833	89	6.9	386

na = not available

Source: ADF&G 2018; Alaska DOL 2019a; U.S. Census Bureau 2019a, 2019b, 2019c

[1] Population estimates are from the Alaska DOL (2019).

[2] Estimates are annual totals developed as part of the 2014-2019 American Community Survey (ACS) 5-Year Estimates. Total population estimates developed as part of the ACS differ in some cases from those prepared by the Alaska DOL.

[3] Median state income in Alaska was $74,346 in 2018 (U.S. Census Bureau 2019b).

[4] The year these data were collected varies by community, as follows:

1987: Elfin Cove, Gustavus, Hyder, Metlakatla, Pelican, Port Alexander, Skagway, and Tenakee Springs; 1996: Kake, Point Baker, Port Protection, and Sitka.
1997: Craig and Klawock.
1998: Coffman Cove, Edna Bay, Hollis, Kasaan, Naukati Bay, and Thorne Bay. 1999: Saxman
2000: Petersburg, Wrangell, and Yakutat.
2012: Angoon, Haines, Hoonah, Hydaburg, and Whale Pass.

Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Alaska Region | April 2022

Southeast Alaska Sustainability Strategy

Forest Management

On July 15, 2021, the U.S. Department of Agriculture (USDA) announced the new *Southeast Alaska Sustainability Strategy* (SASS) to help support a diverse economy, enhance community resilience, and conserve natural resources in Southeast Alaska. The strategy to be undertaken on the Tongass National Forest and in Southeast Alaska includes four primary components:

- Ending large-scale, old-growth timber harvest and focusing resources to support forest restoration, recreation, climate resilience, and sustainable young-growth management.
- Proposing to restore 2001 Roadless Rule protections.
- Engaging in meaningful consultation with Tribal Nations.
- Identifying short and long-term opportunities for investments that reflect the diverse opportunities and needs in the region.

In alignment with SASS, the Forest Service is refocusing resources on the Tongass National Forest to implement an integrated forest management program that includes watershed and wildlife habitat restoration, sustainable young-growth harvest, and old-growth harvest for small timber sales and cultural uses. The Forest Service is implementing other SASS components including investments, recreation assets and opportunities, and proposed roadless protections independent of specific plans for forest management. This document focuses only on the forest management aspects of SASS.

This *SASS Forest Management* strategy describes an integrated approach to shift from a singular objective of timber management to integrated management actions that include terrestrial and aquatic restoration, young-growth timber management, and small and micro old-growth timber sales. Within the framework of the 2016 Tongass Land and Resource Management Plan (Forest Plan), the Forest Service will intentionally design integrated forest management projects that support a diverse economy, enhance community resilience, conserve natural resources, and retain climate-resilient forests. The Forest Service will also address limitations in workforce capacity, industrial and community infrastructure, and agency policies in order to plan and implement projects more efficiently. This *SASS Forest Management* strategy aims to strengthen the ability of the Tongass National Forest, Tribal Nations, and other partners to collaboratively manage natural resources for the benefit of Southeast Alaska.

Integrated Forest Management

Integrated forest management uses an interdisciplinary approach to identify desired resource conditions and incorporate multiple resource and restoration objectives with timber management objectives. In the context of SASS, the Forest Service will continue to implement active and proposed watershed and habitat restoration projects to improve forest resilience and will further develop a long-term sustainable timber program that provides old growth for small timber sales and new opportunities for young-growth harvest and development of healthy, resilient stands that meet identified desired conditions. Project planning will consider subsistence objectives; traditional and customary uses including cultural wood; needs for non-timber forest products such as firewood, mushrooms, and berries; and other traditional cultural uses.

During the next 10 years, forest growth and yield projections indicate there will be limited commercial young-growth timber available for harvest, scattered geographically across the Tongass. In addition to a small old-growth timber program that supports a key sector of the timber industry, the Forest will leverage investments in watershed restoration and habitat improvement to support a diverse economy, promote partnership opportunities, and maintain and grow a local workforce. Restoration opportunities will also be integrated with timber harvest activities to optimize heavy equipment mobilization. Restoration byproducts may benefit new and existing industry such as biomass facilities. In limited areas where restoration priorities and timber opportunities are geographically isolated, projects may proceed independently to meet individual resource management objectives.

As the viability of commercial young growth opportunities increases, the Forest Service will focus forest management projects in areas where industry has transitioned to young-growth timber harvest, where processing can occur locally, and where activities can provide benefits to local communities.

Watershed and Wildlife Habitat Restoration

The Forest Service will work with partners to restore key ecological processes, improve resilience to hydrologic variability, provide fish passage, restore riparian and instream habitats, implement young-growth forest restoration treatments, and control invasive species. Activities will be strategically identified and managed at the Forest-scale and implemented at the watershed-scale based on site-specific needs.

Aquatic and riparian restoration approaches will include:

- Manage riparian vegetation to promote a sufficient density of large trees available for instream recruitment in perpetuity.
- Implement travel analysis recommendations to reduce risk to water quality and restore aquatic and riparian habitat.
- Improve stream connectivity across all roads and provide aquatic organism passage (AOP) where fish are present.
- Identify stream reaches at risk of degrading function, and design restoration actions to maintain or improve habitats with a goal of long-term resilience.
- Locate and eradicate invasive species to promote natural succession. Integrate invasive species control with restoration and forest management activities.

Wildlife habitat restoration approaches will include:

- Implement habitat restoration activities to accelerate development of old-growth conditions within the Old-growth Habitat land use designation (LUD), riparian management areas, and beach and estuary fringe.
- Implement noncommercial and commercial thinning treatments that maintain or improve deer winter range and habitat connectivity by promoting accessible forage and snow

interception. Evaluate and remediate past impacts to deer winter range and habitat connectivity, where appropriate.

- Integrate remnant patch and residual tree conservation and road density planning for vulnerable wildlife species into young-growth forest management activities.

Timber Management

The Tongass National Forest will maintain an old-growth timber program focused on small sales and microsales and will continue to develop a young-growth timber program. Timber management and restoration activity objectives will be met using a full range of silvicultural prescriptions available in the Forest Plan, ranging from even-aged (clearcut) to uneven-aged management.

The young-growth timber management program will be implemented based on the collaboratively developed 2016 Forest Plan Amendment. In addition to management approaches documented in the Forest Plan, young-growth timber management approaches will include:

- Implement silvicultural treatments that will meet resource objectives and may provide opportunities to utilize new and existing techniques and equipment to increase the effectiveness and capacity for both timber and restoration-based projects.
- Upgrade and restore roads to improve aquatic organism passage and hydrologic function as they are opened for young-growth management activities.
- Plan the timing and extent of young-growth harvest within a watershed to minimize effects on water yield and maintain natural variability in streamflow conditions.
- Thin young-growth stands to promote resilience, vigorous growth, and favorable species composition to achieve desired future condition. Focus on treating stands nearing the upper age limit of the “thinning window.”
- Seek stand improvement opportunities to enhance growth and recruitment of Alaska yellow-cedar, where appropriate, to combat the effects of climate driven yellow-cedar decline.
- Improve stands suitable for timber management outside of the Old-growth Habitat LUD and beach and estuary fringe by cutting areas exhibiting stagnant growth or with unfavorable species compositions. Design silvicultural treatments to regenerate favorable tree species and allow for future precommercial thinning to control density, maintain tree vigor, provide more commercial volume, and benefit wildlife habitat through the next rotation.

Old-growth timber management approaches will include:

- Maintain an average of 5 MMBF of old-growth timber volume awarded annually through small and micro sales to benefit local communities.
- Conduct planning efforts that provide a 3-year supply of old-growth timber to create a predictable source for local operators and contribute to community resilience. Settlement sales and permits (including fuelwood and cultural use) would not count toward the 5 MMBF annual average.
- Conduct environmental analyses to build on existing field surveys and analysis of old-growth timber stands.
- Utilize the 5-year Tongass National Forest Timber Sale Plan to illustrate the planned offerings of both young and old-growth timber.

- Continue engagement with local tribal governments to provide old-growth trees for cultural uses through no-cost permits.

Collaboration and Tribal Engagement

Integrated forest management projects will be identified and prioritized in collaboration with partners including industry, local communities, conservation organizations, and other landowners and will be informed through meaningful consultation with Tribal Nations. Tribal Nations will be provided opportunities to describe, identify, or remove cultural wood to maintain for future generations or for uses such as totem poles, canoes, and tribal artisan use. These opportunities will be provided both within identified forest management project areas and independent of projects.

Workforce Capacity Needs

- Align the Forest Service staff organizations with the skills needed to increase capacity for planning and implementing restoration activities, as well as monitoring activities.
- Increase capacity of contracting and grants and agreements staff to better support partnership and project development.
- Invest in workforce training for natural resource surveys, aquatic and terrestrial habitat work, young-growth timber removal, and resource monitoring. Work with Tribes, partners, and community groups to build workforce capacity and collaborate on training and work opportunities.
- Work with existing industry to determine how Forest Service restoration and improvement projects can be used to provide local employment opportunities while developing a restoration economy.

Industry and Infrastructure Needs

- Work with the All-Landowners Group to provide a 10-year integrated project plan including timber sale, restoration, and infrastructure contract offerings across all landownerships in Southeast Alaska. This will inform the local forest products industry, including support businesses which are linked by service or supplier relationships, of upcoming timber projects to plan, maintain and improve their operations.
- Assist local operators and sawmills with finding opportunities to adapt or retool to harvest and process young-growth sawlogs.
- Assist local operators in finding funding to facilitate investment in innovative restoration equipment.
- Develop strategic short- and long-term access management plans to determine transportation network needs and efficient use of Federal road maintenance funding.
- Explore long-term stewardship contract opportunities to create a predictable pipeline of projects that enable a contractor to acquire new equipment, maintain a viable business model, and allow for restoration-based workforce skill development.

Policy Needs

- Provide time and materials contract opportunities for AOP projects and in-stream work. This allows contractors to spend the time needed to meet design standards.

- Reduce matching requirements for agreements with our partners. Stringent match requirements limit their ability to engage in projects on the Forest.
- Provide specific exemptions to allow advertising young growth timber sales that may appraise deficit when using a residual value appraisal. This will improve flexibility in meeting community needs for low-value timber products such as biomass.

Investment Needs

To realize the Forest Management Strategy objectives, these investments in the next 10 years will be critical:

- LiDAR (light detection and ranging) acquisition and interpretation across the Forest to increase effectiveness of restoration and timber planning projects. LiDAR will enable the Forest to improve initial planning efforts, including potential for identification of habitat for species.
- Transportation infrastructure. This includes road construction, reconstruction, maintenance, and decommissioning. Develop modular bridge infrastructure for short-term access.
- Reconstruction of log transfer facilities for young growth.
- Updates to the Tongass Resource Use Cooperative Survey (TRUCS) identifying subsistence use areas.
- Additional subsistence management monitoring and subsistence use gap analysis and studies on the Tongass.
- Precommercial thinning in young-growth stands (approximately 8,000 acres per year). These funds will cover the backlog of existing unthinned stands in suitable timber.
- Riparian and terrestrial forest restoration treatments (approximately 1,400 acres per year). These funds will cover the backlog of existing untreated clearcuts in conservation areas, allowing for short- and long-term habitat benefits during a critical treatment window.
- Stream restoration projects using heavy equipment and hand tools.
- AOP road/stream crossing improvements, adding or increasing the size of culverts to restore hydrologic connectivity, and workforce development for road assessments.
- Invasive species management, including inventory and treatment Tribes and other partners.
- Research related to vegetation management and water yield for managing young-growth forests.
- Collaboration with US Forest Service State and Private Forestry to identify new opportunities for forest products such as biomass. This will likely require additional research on harvest methods, product testing, and market research.

Next Steps

The Forest Service will continue to work in partnership with communities and Tribes across Southeast Alaska to intentionally design forest management projects that engage community and support local industry. More specifically focus areas will include:

- Research and development of biomass opportunities.
- Workforce development and training.
- Integration of forest management to contribute to community and ecosystem resilience.

- Engagement with Tribes and local communities on cultural and community uses of forest products.
- Capitalizing on opportunities for collaboration, engagement, and management of resources of high interest.
- Showcasing past, present, and future forest management projects to highlight their benefits to Southeast Alaska communities.
- Conducting a review of this strategy with Forest Plan reviews scheduled for 2026.