Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Pacific Northwest Research Station | General Technical Report PNW-GTR-1005 | July 2022

Forest Resources of the Tanana Unit, Alaska: 2018

Technical Editors

Sean M.P. Cahoon and **Kathryn C. Baer** are research ecologists, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 161 E 1st Avenue, Door 8, Anchorage, AK 99501.

Contributing Authors

Kate Legner is a (former) supervisory biological scientist; **Loretta Winton** is a forest pathologist, **Garret Dubois** is a biological technician, U.S. Department of Agriculture, Forest Service, Forest Health Protection, 3700 Airport Way, Fairbanks, AK 99709; **Will Putman** is the forestry director, Tanana Chiefs Conference, 112 First Avenue, Suite 600, Fairbanks, AK 99701; **Patrick Sullivan** is director, Environment and Natural Resources Institute, University of Alaska Anchorage, 3151 Alumni Loop, Anchorage, AK 99508; **Kate C. Marcille** is a research associate, University of Montana, Bureau of Business and Economic Research, Gallagher Business Building, Suite 231, Missoula, MT 59812; **Hans-Erik Andersen** is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 400 N 34th Street, Suite 201, Seattle, WA 98103; **Jacob Strunk** is a statistician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, WA 98512; **Robert J. Smith** is a research ecologist, U.S. Department of Agriculture, Forest Service, Air Resource Management Program, 1400 Independence Avenue SW, Washington, DC 20250; **John Chase** is a geographer, **Glenn A. Christensen** is a forester, **Olaf Kuegler** is a statistician, and **Jane Terzibashian** is a supervisory biological scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 620 SW Main Street, Suite 502, Portland, OR 97205; **Andrew Gray** is a research ecologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331.

Cover: The Tanana unit encompasses a broad assortment of boreal forest and alpine tundra. This photo from a tundra community offers a dramatic view of North America's highest point, Denali (20,320 ft). Photo credit: Margaret Oliver.

Forest Resources of the Tanana Unit, Alaska: 2018

Sean M.P. Cahoon and Kathryn C. Baer, Technical Editors

U.S. Department of Agriculture, Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-1005
July 2022

Abstract

Cahoon, Sean M.P.; Baer, Kathryn C., tech. eds. 2022. Forest resources of the Tanana unit, Alaska: 2018. Gen. Tech. Rep. PNW-GTR-1005. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 92 p. https://doi.org/10.2737/PNW-GTR-1005.

This report provides detailed estimates and highlights key findings from Forest Inventory and Analysis (FIA) data collected across the Tanana unit in interior Alaska, 2014–2018. The Tanana unit encompasses much of the Tanana River basin and is one of six inventory units distributed throughout the expansive boreal forest that comprises much of Alaska. Estimates of forest area, volume, aboveground biomass, and ecosystem carbon are provided across land ownerships, forest types, and forest demographics throughout the unit. The Tanana unit covers approximately 33.4 million ac, of which 20.8 million ac (62 percent) were considered forest land managed mostly by state and local governments. Private landowners and state and local governments oversee most of the live-tree volume on timberland, where much of the region's forest management occurs. A majority of the unit, 10.8 million ac (52 percent), is composed of black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.) forests, while Alaska paper birch (*Betula neoalaskana* Sarg.) and white spruce (*Picea glauca* (Moench) Voss) forests comprised about 3.9 million ac (19 percent) and 3.4 million ac (16 percent), respectively. Unique to this inventory was the incorporation of soil carbon estimates, which comprised 76 to 90 percent of total ecosystem carbon pools among forest types. More than half of the total soil carbon was found in black spruce forests where cool, saturated soils limit organic matter decomposition. Understory vascular vegetation was primarily comprised of low-stature shrubs: lingonberry (*Vaccinium vitis-idaea* L.), bog Labrador tea (*Ledum groenlandicum*), bog blueberry (*Vaccinium uliginosum*), and resin birch (*Betula glandulosa*)—species frequently encountered in the most common forest type, black spruce. Resin birch, bog blueberry, and marsh Labrador tea (*Ledum palustre* ssp. *decumbens*) were the most common vascular plant species on nonforest plots. Ground layer biomass was dominated by nitrogen-fixing feather mosses in uplands and *Sphagnum* peat mosses in lowlands. This report summarizes the main outcomes of a detailed survey of forest and nonforest conditions throughout a region that has previously lacked a comprehensive inventory at such a scale, despite its global and regional importance.

Keywords: Biomass, boreal forest, carbon, interior Alaska, FIA, forest inventory, invasive plants, timber industry, understory vegetation, volume.

Summary

Key Forest Inventory and Analysis Statistics, Tanana Unit, Alaska: 2014–2018

- Inventory unit area: 33.4 million ac
- Estimated forest area: 20.8 million ac
- Most common forest type: black spruce, 10.8 million ac
- Largest tree (diameter at breast height): white spruce, 28 inches
- Estimated total live-tree volume: 6.4 billion ft^3
- Estimated total live-tree carbon: 124.9 million Mg
- Estimated total soil carbon: 637.2 million Mg

Contents

Background

Introduction to Forest Inventory and Analysis

The USDA Forest Service Forest Inventory and Analysis (FIA) program was established by the McSweeney-McNary Forest Research Act of 1928 to establish a national survey of the nation's timber resources. Today, FIA is responsible for monitoring the status and trends of all public and private forests in the United States and U.S.-affiliated Pacific Islands using a randomized grid of field plots and a nationally standardized set of core measurements. Guided by FIA users, stakeholders, and partners that insisted on more frequent reporting and greater consistency among states, FIA was restructured under the 1998 Farm Bill, which mandated that each state inventory 20 percent of its plots annually and issue statewide reports every 5 years (i.e., an annualized inventory). Because of additional cost and logistical challenges associated with implementing the new protocols in Western States, a 10 percent exemption was later granted. An annualized inventory was implemented in 2001 across the states and territories within the USDA Forest Service Pacific Northwest Region, with the exception of coastal Alaska, which implemented the annual inventory in 2004. With a spatially unbiased sample and routine remeasurements of forest resources, FIA data are widely used by policymakers, natural resource managers, private industry, and academic researchers to inform decisionmaking and deepen our understanding of forest ecology.

Forest Inventory and Analysis in Interior Alaska

The boreal forest of interior Alaska (roughly delineated as the region between the Alaska Range and Brooks Range mountains) occupies about 70 percent of the state's land area and makes up nearly 15 percent of total forest land in the United States (Andersen et al. 2017). Interior Alaska is also the last region to be fully inventoried using a systematic grid with standardized national protocols. Prior FIA inventories in interior Alaska consisted of sampling productive forest land along river valleys and targeted portions of the region (Hegg 1974, 1975a, 1975b, 1982, 1983; Hegg and Sieverding 1979; Mead 1995; Setzer 1987; van Hees 1999; Winterberger 1983). Implementing an annualized inventory throughout Alaska's vast and remote boreal forest presents substantial logistical and financial hurdles (fig. 1). Nevertheless, in 2014, Congress formally recognized the value of ecosystem services provided by the region and issued guidance and funding for the USDA Forest Service Pacific Northwest Research Station to begin a systematic inventory in interior Alaska. The interior Alaska FIA project began that same year as a pilot study that established 99 plots throughout the Tanana Valley State Forest and Tetlin National Wildlife Refuge (Pattison et al. 2018), with the dual goals of assessing the feasibility of field protocols and providing proof of concept that an accurate inventory could be executed in a logistically challenging region (see "Successful Interagency Partnerships in Interior Alaska" on page 10).

The successful 2014 pilot study led to full implementation of FIA survey protocols throughout interior Alaska. However, establishing a standard FIA plot grid of a single plot per 6,000 ac throughout the enormous area of interior Alaska where road access is limited would have incurred substantial financial investment and required excessively complicated logistics to complete 10 percent of all plots annually in a timely manner. Therefore, the plot network and inventory schedule were modified from national FIA protocols and differ from other states (as well as coastal Alaska) in several ways. First, the region was subdivided into six smaller inventory units broadly encompassing major watershed boundaries (fig. 2). Second, each inventory unit would be completed before moving to the next, resulting in a periodic rather than an annualized sample of interior Alaska. The full inventory of interior Alaska is estimated to require roughly 15 to 20 years to complete. Third, the plot resolution was reduced to one plot per 30,000 ac. Finally, FIA partnered with scientists from the National Aeronautics and Space Administration (NASA) to supplement the coarser plot grid with cutting-edge, airborne-based estimates of forest resources. Using this high-resolution imagery in the estimation phase improves the precision of estimates (i.e., lower standard errors) than would be possible with satellite imagery alone (Andersen et al. 2011). Goddard's LiDAR (light detection and ranging), hyperspectral, and thermal (G-LiHT) airborne imager system provided fine-scale (<3.28 ft [<1 m]), multi-spectral observations throughout the Tanana unit, which were subsequently used in model-assisted estimates of forest biomass, volume, and carbon (as described in the next section). Following rigorous scientific and statistical review of the modified methods, data collection in the Tanana unit resumed in 2016 and was completed in 2018.

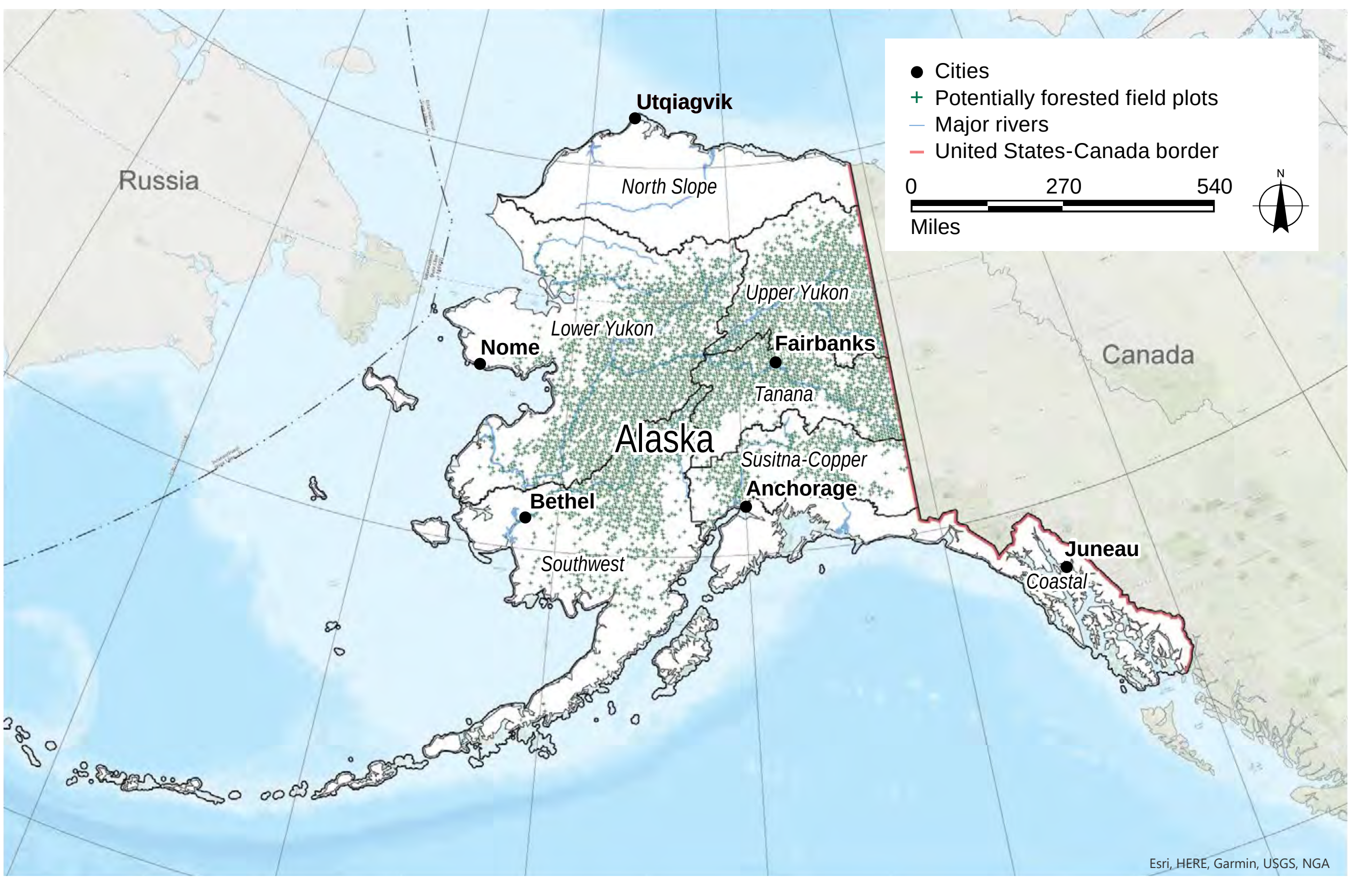
Remote Sensing and Model-Assisted Inventory Methods[1]

A new feature of the Tanana inventory is the inclusion of airborne remote sensing data into the sampling design. Given the decreased sampling intensity for the FIA inventory in interior Alaska (1 plot per 30,000 ac) and the somewhat inconsistent quality of high-resolution satellite imagery over Alaska, there was interest in using a dedicated source of low-altitude airborne remote sensing measurements to (1) support pre-field planning and field operations, (2) improve the precision of inventory estimates, and (3) provide an additional suite of measurements—complementary to field data—that would enable a broader scope and depth of ecological inquiry across this complex and dynamic boreal landscape. Through an

[1] Authors: Hans-Erik Andersen and Jacob Strunk, Pacific Northwest Research Station

USDA Forest Service

Figure 1—Helicopters are the primary mode of transporting crews to plots throughout interior Alaska. Here, a helicopter is shown en route to a FIA plot in the Tanana unit.



Thomas Thompson

Figure 2—Boundaries of the six inventory units and the distribution of potentially forested plots (green dots) throughout interior Alaska. This report summarizes data collected in the Tanana unit.

interagency agreement with scientists at NASA-Goddard Space Flight Center, in 2014 and 2018 airborne remote sensing data were collected with the G-LiHT instrument in a strip-sampling mode over the entire Tanana unit (fig. 3). This multi-sensor instrument provides (1) detailed forest structure and terrain morphology using LiDAR scanning, (2) forest composition and health measurements using imaging spectrometry, and (3) surface temperature measurements using thermal scanning (Cook et al. 2013, Pattison et al. 2018). The G-LiHT data were acquired in nominal 350-m-wide swaths along flight lines—spaced about 9200 m apart and oriented in a northeast-southwest direction—designed to cover every potentially forested FIA field plot. In the end, G-LiHT measurements were acquired over 906 out of 1,091 FIA plots in the Tanana unit (note that many of the plots without G-LiHT were in high-elevation, clearly unvegetated rock and ice areas of the Alaska Range). FIA data collection staff used LiDAR-based canopy height models in the Tanana unit to support pre-field logistical planning, such as determining plot accessibility (landing areas, etc.) and estimated time on plot for the field crews (tree density, stand size class, etc.). Several external partners are currently using G-LiHT data to support a variety of ecological studies, environmental planning, and forest management activities. In this section, we focus on the use of G-LiHT to improve the precision of inventory estimates.

When using the additional G-LiHT coverage to increase precision, regression analysis was applied to predict inventory parameters over 73,509 remote sensing plots spaced 200 m apart along each flight line, with LiDAR-derived mean canopy height as the sole predictor variable (fig. 3). This sampling configuration can be seen as a two-stage design in which remote sensing plots within G-LiHT strips represent the first stage of sampling (clusters) and the FIA plots within the strips represent the second stage (subsample), then using a post-stratified ratio estimator (Ringvall et al. 2016) to improve the precision of estimates (see app.). Although FIA staff are interested in a broader set of model-assisted approaches to efficiently incorporate remote sensing measurements into the design-based FIA estimation framework (McConville et al. 2020), use of model-assisted estimates has been limited to FIA's standard poststratification up to this point. Table 1 provides an example of model-assisted estimates of aboveground tree biomass by forest type in the Tanana unit.

In cases where the inventory parameter (e.g., plot-level biomass) and the auxiliary variable (e.g., LiDAR height) are strongly correlated (R^2 = 0.78), there can be a significant increase in precision through use of the poststratified ratio estimator (e.g., 38 percent reduction in standard error for total biomass), while in cases where the auxiliary variable is not as strongly correlated (LiDAR height versus plot-level biomass by forest type), the gains in precision are more modest

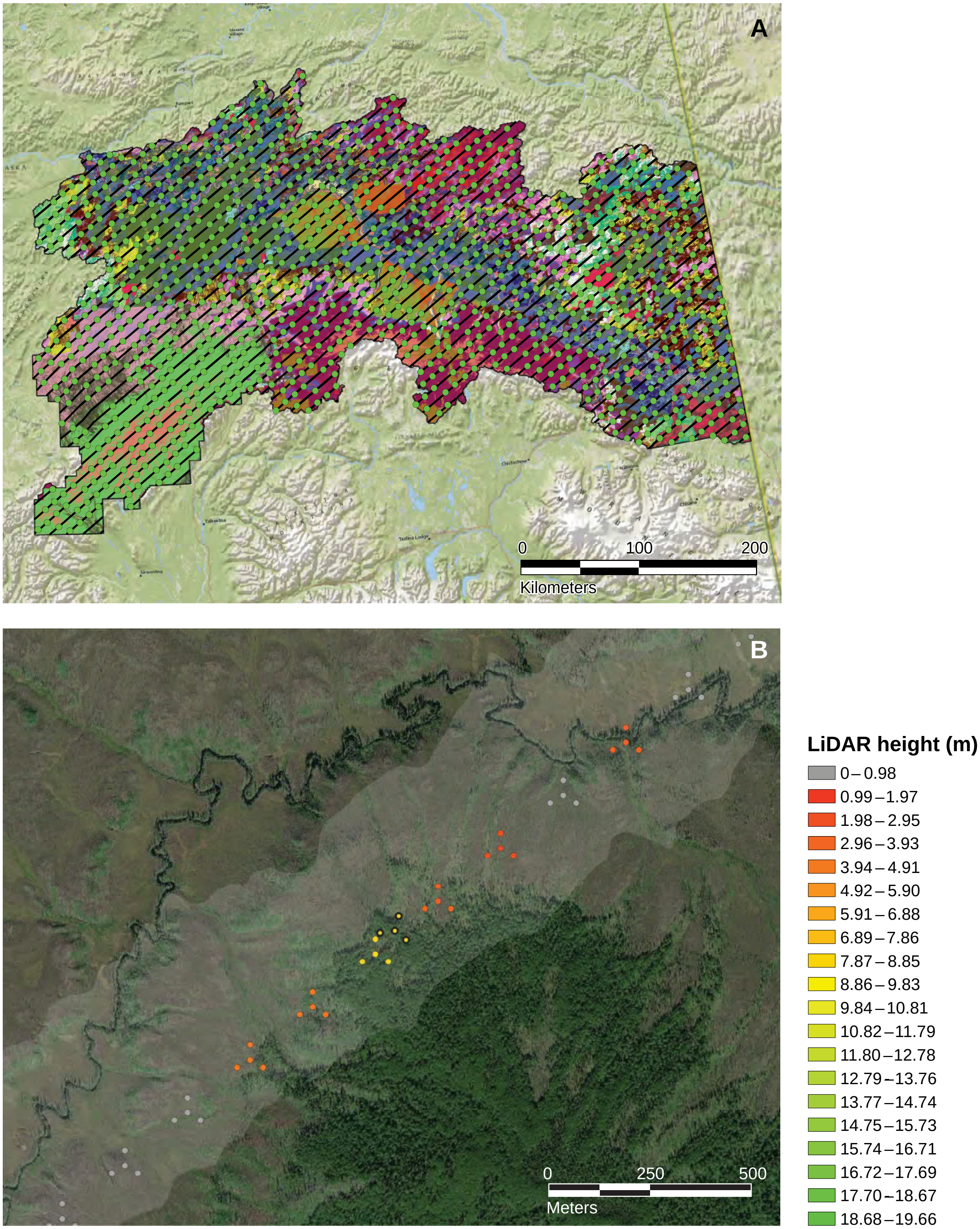


Figure 3—(A) Tanana unit with Forest Inventory and Analysis (FIA) plots (dots), Goddard's LiDAR, hyperspectral and thermal (G-LiHT) flight lines (black), and standard FIA stratification (various colors). (B) Nominal 350-m swath where G-LiHT data were collected (dark outline) over remote sensing plots and FIA plots (dots). Colors indicate canopy height (m) determined by high-resolution LiDAR.

(22 percent reduction in the standard error for softwoods and 27 percent reduction in the standard error for hardwoods). In estimating other forest attributes—such as area by forest type where LiDAR height alone provides little, if any, explanatory power—there are virtually no gains in precision when using the poststratified ratio estimator (however, it is expected that future inclusion of hyperspectral metrics could contribute here). The poststratified ratio estimates are all slightly lower than the standard poststratified estimates, although they are all quite close to and well within the 95 percent confidence intervals of the standard estimates. Scientists from FIA and NASA are currently working to better understand this discrepancy. In general, model-assisted estimation provides a means of incorporating auxiliary information collected in a two-stage sampling framework (FIA plots and G-LiHT strip sample) into a design-based inferential framework that is comparable to standard FIA estimation. Research among FIA scientists and their collaborators is underway to incorporate the richer set of G-LiHT measurements, including hyperspectral and thermal imagery, into the model-assisted estimators, potentially further improving domain-level estimation.

Table 1—Comparison of standard Forest Inventory and Analysis poststratified and model-assisted estimates of aboveground biomass by forest type in the Tanana unit, Alaska, 2014–2018

	Poststratified		**Poststratified model-assisted**	
Forest type	**Total**	**SE**	**Total**	**SE**
	Thousand tons			
Softwoods				
White spruce	71,113	9,151	68,807	7,767
Black spruce	101,820	6,368	99,948	5,761
Tamarack	527	309	522	399
Total softwoods	173,460	9,811	169,277	7,654
Hardwoods				
Paper birch	74,553	8,370	70,140	5,667
Aspen	22,114	4,631	20,375	4,711
Balsam poplar	5,118	2,323	4,850	1,503
Total hardwoods	101,786	9,244	95,390	6,769
Nonstocked				
<10% live trees	25	16	25	360
Total	275,271	12,008	264,667	7,407

SE = standard error.

Regional Description

Concern about the effects of climate change on forest distribution and health, permafrost thaw, fire dynamics, and wildlife habitat in boreal forests has grown in past decades. This concern is spurred partially by the fact that subarctic regions including interior Alaska play an important role in global biogeochemical cycles (Bonan 2008). Encompassing an area between 110 million ac (Andersen et al. 2017) and 113.2 million ac (van Hees 2009), the boreal forest of interior Alaska is a sparsely populated and largely inaccessible region characterized by long, cold winters (-18.6 °F January mean minimum temperature in Fairbanks, 1930–2020 [Alaska Climate Research Center, 2021]) and short, warm summers (72.0 °F July mean maximum temperature in Fairbanks, 1930–2020 [Alaska Climate Research Center, 2021]) (fig. 4) with nearly 24 hours of daylight. With the exception of some coastal regions in

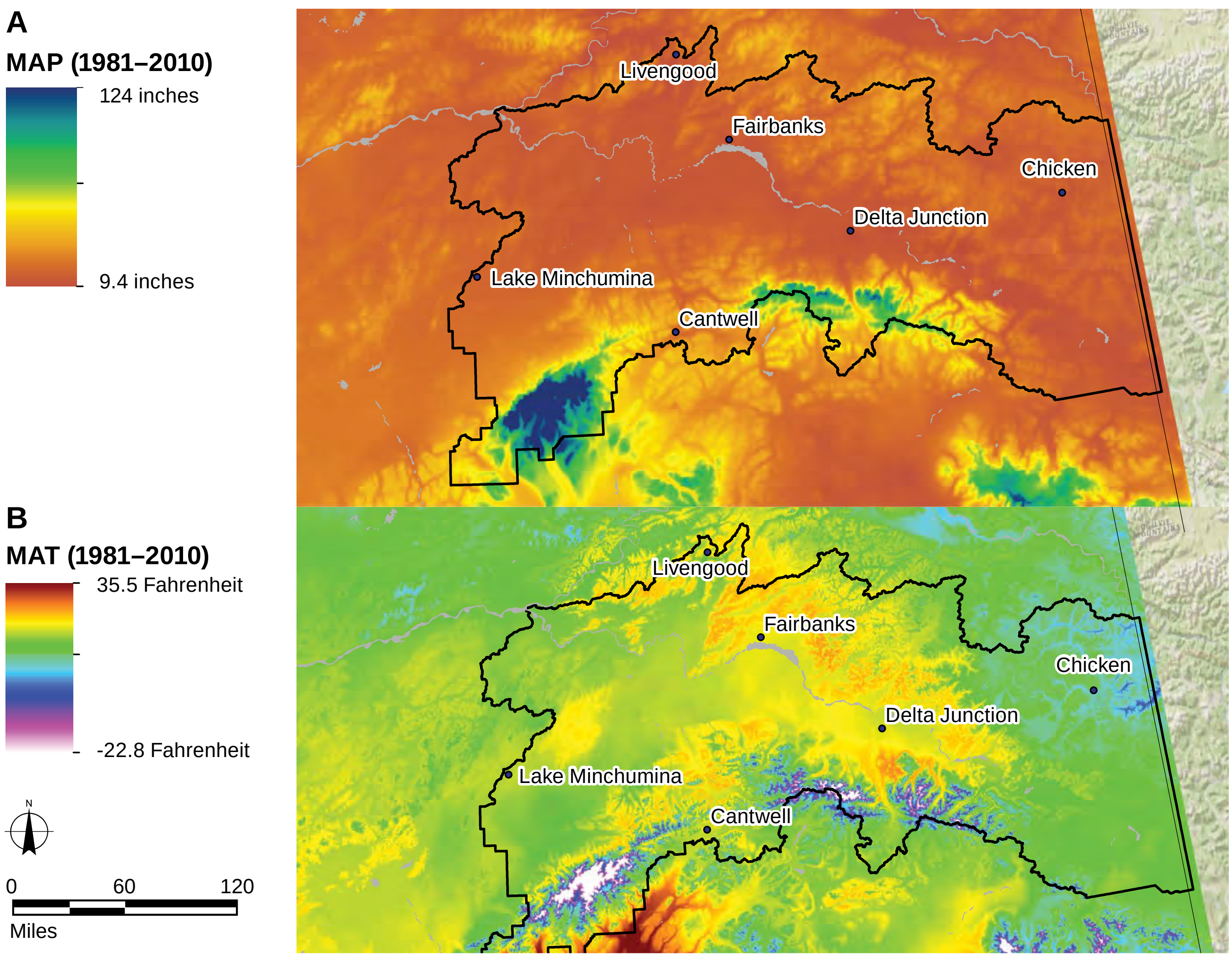


Figure 4—(A) Regional climatology using 30-year normal mean annual precipitation (MAP) and (B) mean annual temperature (MAT) for 1981–2010. Data were generated using the parameter-elevation regressions on independent slopes model (PRISM) at 800 m resolution (PRISM Climate Group, 2018). The solid black line denotes the Tanana unit inventory boundary.

western Alaska, summer precipitation is generally low, and drought conditions are common (2.0 inches mean total July precipitation in Fairbanks, 1930–2020 [Alaska Climate Research Center, 2021]) (fig. 4).

Permafrost is continuous in the northern portions of the boreal forest but discontinuous and sparse farther south. The active layer (upper portion of the soil profile that thaws and refreezes seasonally) is an integral component of forest structure and function, affecting hydrology, thermal properties, and physical disturbance through annual freeze-thaw cycles (fig. 5). Among ecoregions encompassed in this inventory, wildfire is the major disturbance in boreal forests (fig. 6), with fire-return intervals ranging between 118 and 187 years (Kasischke et al. 2010). Fire severity and area burned have increased in recent decades (Ryan et al. 2013, Turetsky et al. 2011) and could increase five-fold by the end of the 21st century (Balshi et al. 2009). A warming climate has accelerated permafrost degradation in much of the region (Lara et al. 2016, Smith et al. 2010), initiating dramatic changes in forest composition and biogeochemical cycles. Although the boreal region is relatively low in biodiversity, moose, bears (black and grizzly), caribou, and wolves are abundant. Smaller animals include voles, foxes, mustelids (members of the weasel family), snowshoe hares, marmots, and lynx. Boreal forests also provide important habitat for migrating and resident birds, such as hawks, waterfowl, finches, warblers, and others.

The unit is home to the ancestral lands of the Tanana Dene peoples, with a rich and diverse set of cultural, linguistic, and social practices.

The Tanana unit broadly overlaps with the Tanana River watershed in the southeastern portion of interior Alaska and shares many features with the broader boreal forest (fig. 2). Much of the watershed is a broad alluvial plain underlain by loose deposits of gravel, sand, and loess. Mature soils are found on well-drained upland sites, whereas poorly drained sites often restrict forest productivity. The unit is mainly composed of the Tanana-Kuskokwim Lowlands and Yukon-Tanana Uplands ecosections (Nowacki et al. 2002). The Tanana-Kuskokwim Lowlands are in the rain shadow of the Alaska Range, but maintain abundant surface water because of limited topographic variation and more prevalent permafrost. The Yukon-Tanana Uplands are composed of low elevation, rolling mountains where permafrost is limited to valley bottoms and north-facing slopes. The unit is home to the ancestral lands of the Tanana Dene peoples, with a rich and diverse set of cultural, linguistic, and social practices. Today, many residents in the region live intimately with the land, often relying on subsistence hunting and fishing for much of the year. Forest products harvested and used in the region include logs for home building and firewood. Nontimber forest products harvested for personal, subsistence, or cultural use include berries, mushrooms, bark, and Christmas trees (Maher et al. 2013).

Kate Legner

Figure 5—Forest Inventory and Analysis field crew encounters a site with significant active layer disruption and permafrost thaw, making travel difficult. Dead trees in background were likely killed by wildfire, while the disruption to the ground surface shows the effects of thermokarst processes. Fire can often trigger rapid permafrost degradation, preventing forest recovery for many years.

USDA Forest Service

Figure 6—A Forest Inventory and Analysis field crew member investigates ground layer composition in a stand of recently burned black spruce in interior Alaska.

Successful Interagency Partnerships in Interior Alaska[1]

Modern Forest Inventory and Analysis (FIA) surveys of forested plots in interior Alaska began with a 2011 collaboration between FIA, the University of Alaska Fairbanks, and the Bonanza Creek Long Term Ecological Research site. This early inventory of about 100 plots spread throughout the Bonanza Creek Experimental Forest and the Caribou-Poker Creeks Research Watershed offered the opportunity to evaluate established FIA inventory methods and new methods specific to interior Alaska before implementing them on a larger scale in the subsequent pilot study. The Interior Alaska FIA project began in earnest the summer of 2014 with a pilot inventory under the authority and direction of the 2014 Farm Bill. Interior Alaska contains almost no lands administered by the USDA Forest Service; the land is mostly managed by various other federal and state agencies and several Alaska Native corporations. The size and remoteness of interior Alaska coupled with its unique ownership mosaic makes collaboration among the Forest Service and key partners a necessity. The State of Alaska Department of Natural Resources, Division of Forestry (Alaska DOF) in particular provided critical cooperative resources required to successfully implement a comprehensive forest inventory in the region (fig. 7).

Starting in 2014 with the pilot study, Alaska DOF and the Forest Service joined forces to conduct field work in interior Alaska. The Alaska DOF contributed significant planning, logistical support, and data collection field crews to the project. The University of Alaska Fairbanks contributed field data collection crews in 2014. The Forest Service also partnered with the USDI Fish and Wildlife Service to conduct portions of the 2014 pilot study in areas managed by Tetlin National Wildlife Refuge. The goals of the 2014 pilot study were to (1) assess the feasibility of data collection methods for forest resource information specific to interior Alaska and (2) provide proof of concept that the vast and remote region could be successfully surveyed given the challenging logistics and high cost associated with the interior Alaska inventory.

Interior Alaska was divided into six discrete units for the project; the Tanana unit was chosen for the pilot study because it has the most developed road network. This allowed access to inventory plots first by road and then by air as capacity increased and ease of access decreased over time. Aviation hubs will be critical as the Alaska inventory progresses into more remote units in subsequent field seasons, where eventually staff and materials will be flown into tent camps accessible only by helicopter. Relatively abundant population hubs in the Tanana unit presented the most convenient opportunities for auto transport, helicopter support, aviation fuel distribution, and field camp provisioning in the early stages of the project. This allowed the joint Alaska DOF-Forest Service team to better assess and adapt to the unique requirements and objectives of the Interior Alaska inventory project and initially build collaborative capacity under the least challenging conditions in preparation for more difficult units to follow.

Following successful completion of the 2014 pilot study, interagency field crews executed full implementation of the Interior Alaska FIA inventory protocol in 2016 in the Tanana unit. The next 3 years (2016–2018) were the ramp-up phase in which field crews intensified the rate of inventory data collection and adapted to increasingly difficult plot access logistics. In 2018 alone, interior Alaska FIA crews inventoried 268 plots compared to just 99 plots in 2014 (17 plots sampled in 2014 were excluded from this analysis because they were installed at a higher resolution than the remainder of the Tanana unit plots). As the project progressed, plots became more difficult to access and culminated with work in the most remote portions of Denali National Park in cooperation with the USDI National Park Service. When the project was completed in 2018, interagency field crews had visited and installed more than 700 research plots across the entire forested area within the Tanana unit (table 2).

[1]Authors: Kate Legner and Kathryn Baer, Pacific Northwest Research Station.

Kate Legner

Figure 7—State of Alaska Division of Forestry and USDA Forest Service Interior Alaska Forest Inventory and Analysis crew members operated out of Tetlin National Wildlife Refuge Headquarters during the 2018 field season.

Table 2—Summary of sampled and nonsampled plots in the Tanana unit, 2014, 2016–2018

Plot status	Count
Sampled, forested	690
Sampled, nonforest	33
Total sampled	723
Nonsampled	
Denied access	19
Hazardous	13
Skipped	4
Other	1
Total nonsampled	37

Collaborative science and outreach efforts extend beyond on-the-ground data collection within the context of the interior Alaska inventory project. Alaska FIA has developed long-term partnerships with the Forest Soils Lab at the University of Alaska Fairbanks, and the Sullivan Tree Core Lab at the University of Alaska Anchorage to analyze soil and tree cores, respectively. Also unique to interior Alaska FIA is a close collaboration with the National Aeronautics and Space Agency to collect high-resolution, remotely sensed imagery and light detection and ranging (LiDAR) data using the Goddard LiDAR, hyperspectral, and thermal (G-LiHT) airborne imager. The G-LiHT acquisition missions are flown on a schedule integrated with upcoming field work in interior Alaska. Once acquired, the data are processed and used for pre-visit assessment and visualization of the plot location, field season logistics planning, and model-assisted landscape characterization and estimation of forest attributes (see “Remote Sensing and Model-Assisted Inventory Methods” on page 2).

In addition to partnerships directly related to data collection, interior Alaska FIA staff have the unique experience of working and living in small Alaskan communities as operational hubs for extended periods of the summer. Working with local landowners and community members provides insight into local forest conditions and concerns, traditional uses of and relationships with forest resources, and enhances FIA program understanding of end-user data needs and practices. Interior Alaska FIA staff also engage with local stakeholders via collaborative citizen science initiatives in interior Alaska communities (see “Citizen Science in the Tanana Unit” on page 46).

The interior Alaska FIA program depends on its critical long-term relationships with partners and stakeholders to conduct and enhance the interior Alaska forest inventory. FIA staff will continue to develop and rely on cooperative interagency data collection strategies in increasingly remote areas throughout the remaining inventory units of interior Alaska that comprise about 3,856 forested or potentially forested plots slated for installation and measurement. Following completion of the initial inventory of Interior Alaska, interagency crews will return to the Tanana unit to begin remeasuring plots to assess forest landscape trends and changes. Alaska’s boreal forest ecosystems are already experiencing transformations associated with rapidly changing climatic conditions. Data collected in these forests as an outcome of interagency cooperation will help local communities, land managers, and scientists better understand and monitor trends at enhanced spatial and temporal scales in finer detail, enabling them to better predict and plan for future conditions in interior Alaska forests.

Forest Resources of the Tanana Unit, Alaska

Interior Alaska's forests provide several resources throughout the region, from local timber production in rural communities to carbon storage at the landscape scale. The interior Alaska FIA program provides detailed assessments of forest attributes, such as forest area, forest biomass and volume, and aboveground and belowground carbon estimates. Although black spruce is the iconic boreal tree species, the Tanana unit is composed of several forest types yielding substantial spatial heterogeneity in forest resources.

Forest Area

The Tanana unit is broadly characterized by expansive forests, wide floodplains, and remarkable topographic relief (fig. 8), bounded by the Alaska Range and Wrangell Mountains to the south and the White Mountains to the north. The inventory unit is broadly based on the Tanana River watershed boundary, but was adjusted to include all of Denali National Park and exclude all of Wrangell-St. Elias National Park to minimize the years over which data would be collected within a USDI National Park Service unit. The total area of the inventory unit is approximately 33.4 million ac, comparable in size to the state of Louisiana (fig. 9). Almost two-thirds (20.8 million ac) of the unit is considered forested (≥10 percent canopy cover, 1 ac in size and minimum width of 120 ft), while only 8.8 percent (2.9 million ac) is classified as timberland (capable of producing merchantable timber at culmination >20 ft^3 $acre^{-1}$ $year^{-1}$). This estimate of timberland area is similar to that produced by Hanson (2013) for the same general area (2.15 million ac). Most forest land is managed by state and local governments (12.8 million ac [61.8 percent]), followed by the Bureau of Land Management (2.3 million ac [10.9 percent]) and private landowners (2.2 million ac [10.7 percent]) (fig. 10). Private landowners include Alaska Native corporations and villages, individuals, corporate and noncorporate companies, and nonprofit enterprises. Combined, less than 3.5 million ac of forest land are managed by the U.S. Department of Defense, U.S. Department of Energy, U.S. Fish and Wildlife Service, and U.S. National Park Service.

Black spruce forests are adapted to recurring, stand-replacing fires, which are often bolstered by the species' flammable foliage, retention of dead lower branches, and understory vegetation composition.

Although many forest stands in interior Alaska contain a mixture of tree species, FIA designates forest type by the species with the plurality of live individual trees on the plot. Forest types in the Tanana unit are predominantly black spruce (10.8 million ac [51.9 percent]), while Alaska paper birch and white spruce occupy 3.9 million ac (18.7 percent) and 3.4 million ac (16.3 percent), respectively (fig. 11). The combined area of aspen, tamarack, and balsam poplar forest types totaled about 2.2 million ac (10.3 percent). Black spruce is a widely distributed, often late-successional species that occurs across a variety of conditions (Hollingsworth et al. 2006, Mann et al. 1995), but is particularly dominant on poorly drained, cool soils that are often underlain by permafrost. Black spruce plays an important role in

USDA Forest Service

Figure 8—Forest Inventory and Analysis field crew members navigate from a helicopter landing zone to a plot near Tok, Alaska.

Thomas Thompson

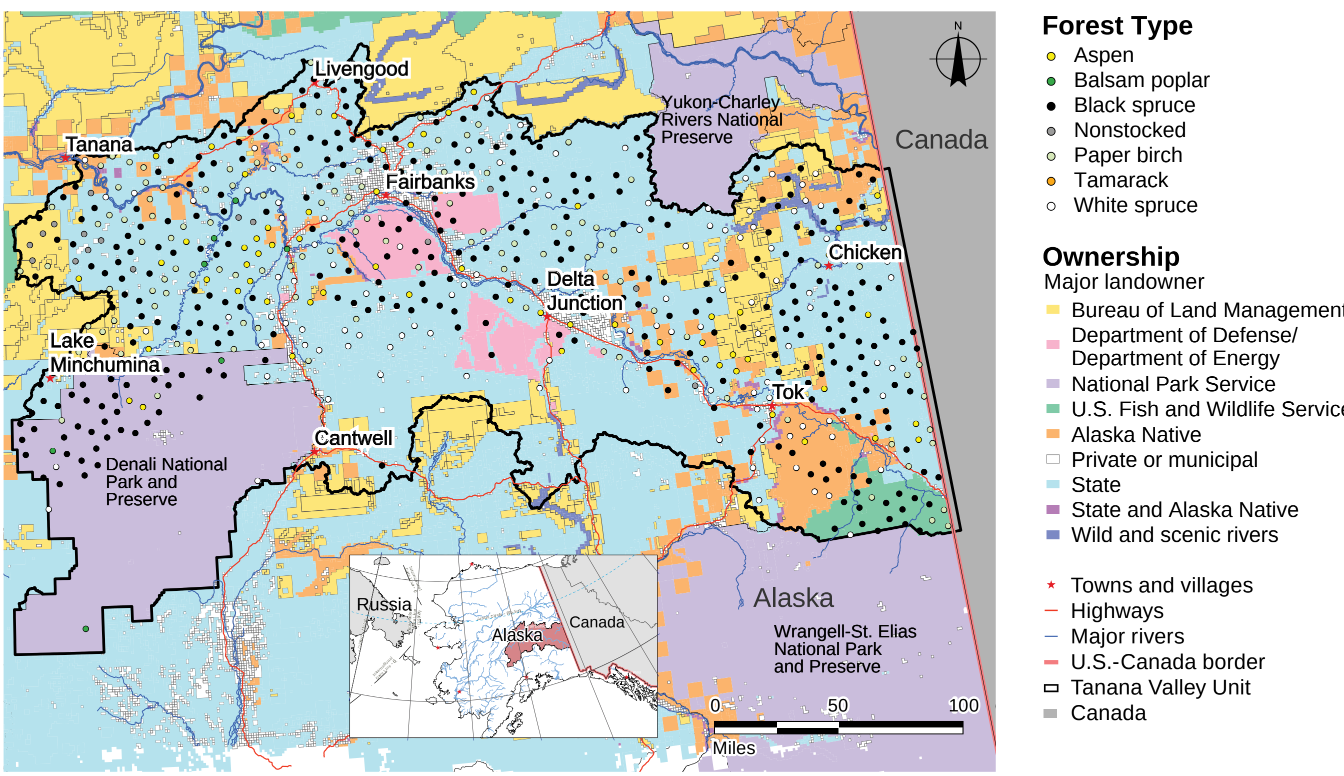


Figure 9—Major land managers and owners throughout the Tanana unit and distribution of FIA plots, colored by forest type.

the ecology of the landscape, particularly between succession and fire. Black spruce forests are adapted to recurring, stand-replacing fires, which are often bolstered by the species' flammable foliage, retention of dead lower branches, and understory vegetation composition (Johnson 1992, Viereck 1983). Semiserotinous cones facilitate postfire stand regeneration in organic soil. Depending on site conditions (slope, aspect, soil moisture) and burn severity, hardwoods and white spruce can colonize black spruce stands in the early and mid-successional stages, creating a mosaic of forest types and spatial heterogeneity of forest productivity throughout the region (fig. 12).

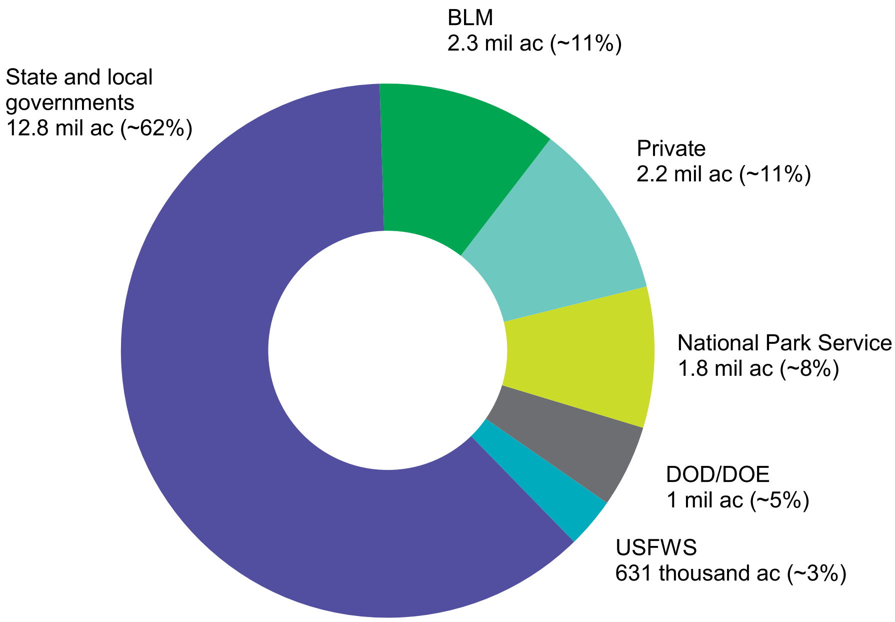


Figure 10—Distribution of forest land among major land managers and owners in the Tanana Unit. Percentages are of total forest area, which is about 20.8 million ac. BLM = Bureau of Land Management; DOD/DOE = Department of Defense and Department of Energy; USFWS = U.S. Fish and Wildlife Service.

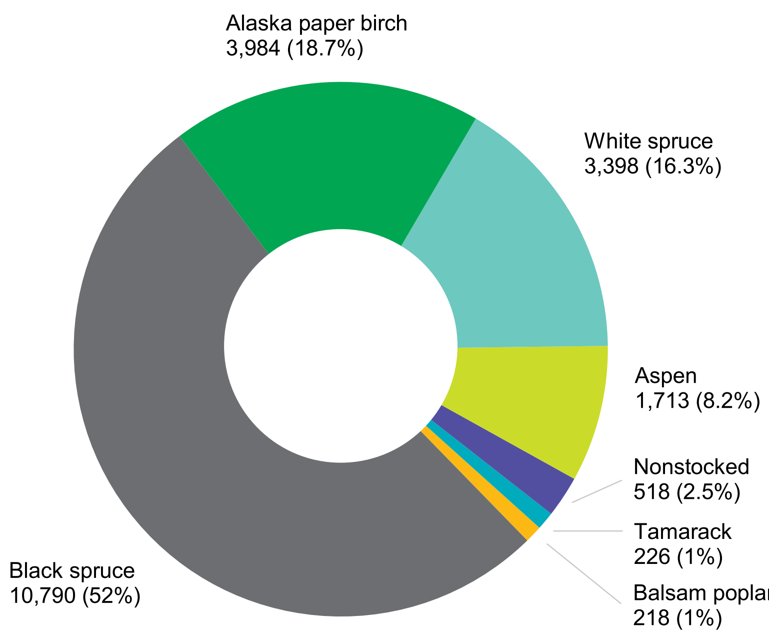


Figure 11—Distribution of forest area by forest type. Values are in thousand acres and percentage of total forest area. Nonstocked includes areas less than 10 percent stocked with live trees.

Figure 12—Much of interior Alaska is characterized by a mosaic of deciduous and evergreen forest types, interspersed with nonforest patches.

Integrating Tree-Ring Research with Forest Inventory and Analysis in Interior Alaska[1]

The boreal forest of interior Alaska is experiencing rapid changes in climate that may be driving shifts in forest composition, tree growth, and biogeochemical cycles. Numerous ecological, remote sensing, and tree-ring studies have suggested that the combination of increasing fire frequency and intensity, along with a warming climate, may lead to a "biome shift" in the region whereby deciduous species will outcompete and replace the dominant coniferous species (Beck et al. 2011, Hansen et al. 2021). In 2014, Pacific Northwest Research Station researchers and University of Alaska Anchorage scientist Patrick Sullivan seized the opportunity to address this hypothesis during the Forest Inventory and Analysis (FIA) Tanana pilot inventory by analyzing tree cores that would have otherwise been discarded. The FIA plot network is an unbiased sample of the landscape, which broadens inferences to include the full breadth of conditions in which trees grow. This was a departure from many previous tree-ring studies that have relied on targeted sampling and may not represent growth in various parts of the forest. Using the inventory-based tree core collection, our goals were to (1) determine which climate variables are correlated with tree growth; (2) assess the relative importance of site characteristics for black and white spruce growth; and (3) compare long-term trends among white spruce, black spruce, Alaska paper birch, and quaking aspen.

(continued on next page)

[1]Authors: Sean Cahoon, Pacific Northwest Research Station and Patrick Sullivan, University of Alaska Anchorage.

(continued from previous page)

Aligning black and white spruce ring width data with long-term climate data from Fairbanks, we detected a significant positive correlation with summer precipitation and negative correlation with summer air temperature in both species, indicating that growth was limited during warm and dry summers (Sullivan et al. 2017). Building upon these results, we used plot-level variables collected by FIA crews (slope, aspect, basal area, groundcover, soil depth, etc.) to determine which factors were associated with greater growth. Black spruce grew best where the slope was >15 percent and moss cover was >60 percent. In contrast, white spruce growth was greatest where moss cover was <50 percent and duff depth was <10 cm (fig. 13). Moreover, trees growing in "poor" habitats were generally more sensitive to climate than those growing in "good" habitats. We suspect that the spatial factors contributing to growth may serve as indicators of habitat quality with limited direct influence on tree growth. For example, greater black spruce growth may be associated with cool, moist soils, whereas white spruce growth is greater on moderately well-drained, warm soils.

After scrutinizing the black and white spruce data, we broadened the scope of our analysis to address potential differences in radial growth among coniferous and deciduous species by incorporating tree cores from Alaska paper birch and quaking aspen (Cahoon et al. 2018). We detected similar growth trends in black spruce, white spruce, and Alaska paper birch that were characterized by a growth peak in the mid-20th century followed by a return to the long-term mean in recent decades (fig. 14). This differed

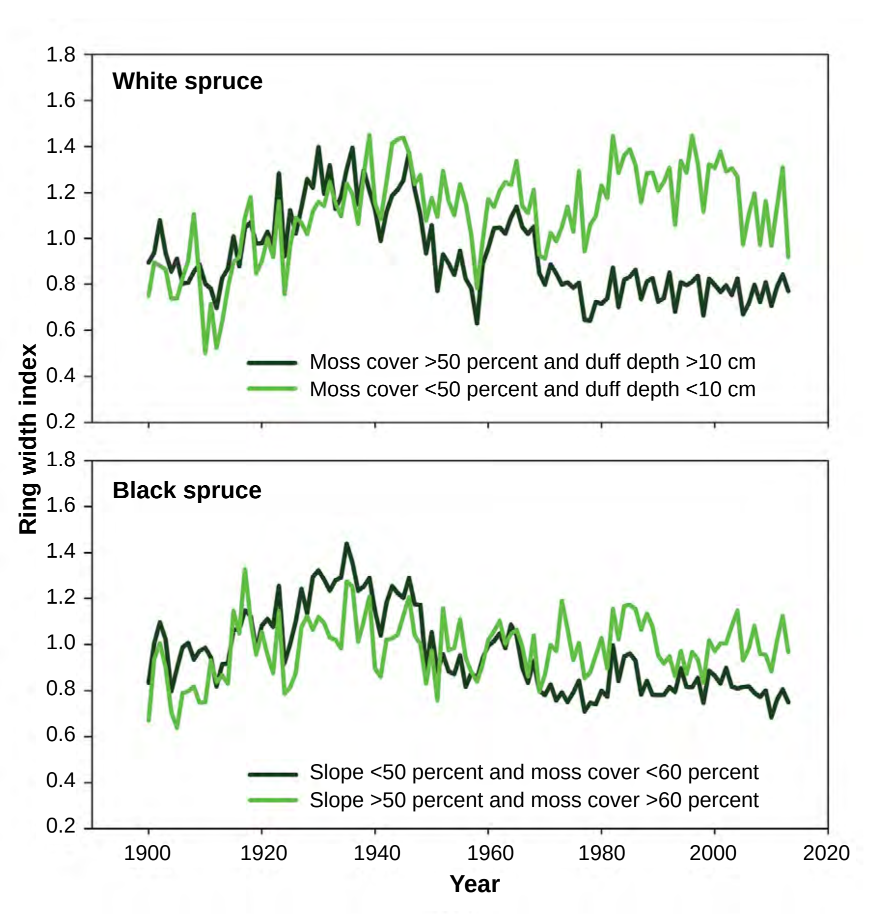


Figure 13—Chronologies of white spruce and black spruce growing in good habitats (light green) and poor habitats (dark green) during the 20th century. Habitat quality was determined by examining partial dependence plots from a boosted regression tree-core analysis relating plot locational and structural variables to recent growth of both species. Sample sizes for white spruce are 86 trees from good habitats and 44 trees from poor habitats, while sample sizes for black spruce are 41 trees from good habitats and 53 trees from poor habitats. The trees and habitats selected represent the extremes of the population in terms of recent growth.

from previous studies in that we did not find a sharp decline in coniferous growth, nor was there evidence of increasing Alaska paper birch growth. Aspen showed a similar growth peak, but a substantial decline in growth in the latter part of the 20th century and early 2000s. Climate-growth correlations for this species were weak; however, we detected a strong negative relationship between growth and abundance of aspen leaf miner (*Phyllocnistis populiella*), an herbivorous moth. Aspen leaf miner larvae consume guard cells, thus disrupting stomatal activity and reducing both photosynthetic capacity and productivity (Wagner and Doak 2013, Wagner et al. 2020). The highlight from this research was detecting a strong biotic interaction in a widespread sample of the aspen population in interior Alaska.

Combining tree-ring research with rigorous FIA inventory methods has created a unique opportunity to merge two related but separate disciplines to yield novel and exciting insights into the ecology of Alaska's boreal forest. Building on the success of the 2014 pilot inventory-based dendrochronology research, tree core collection and analysis has continued throughout the interior Alaska FIA project. Future investigations will capitalize on the much larger dataset from throughout the region to address the complex and nuanced interactions between Alaska's changing climate and forest productivity.

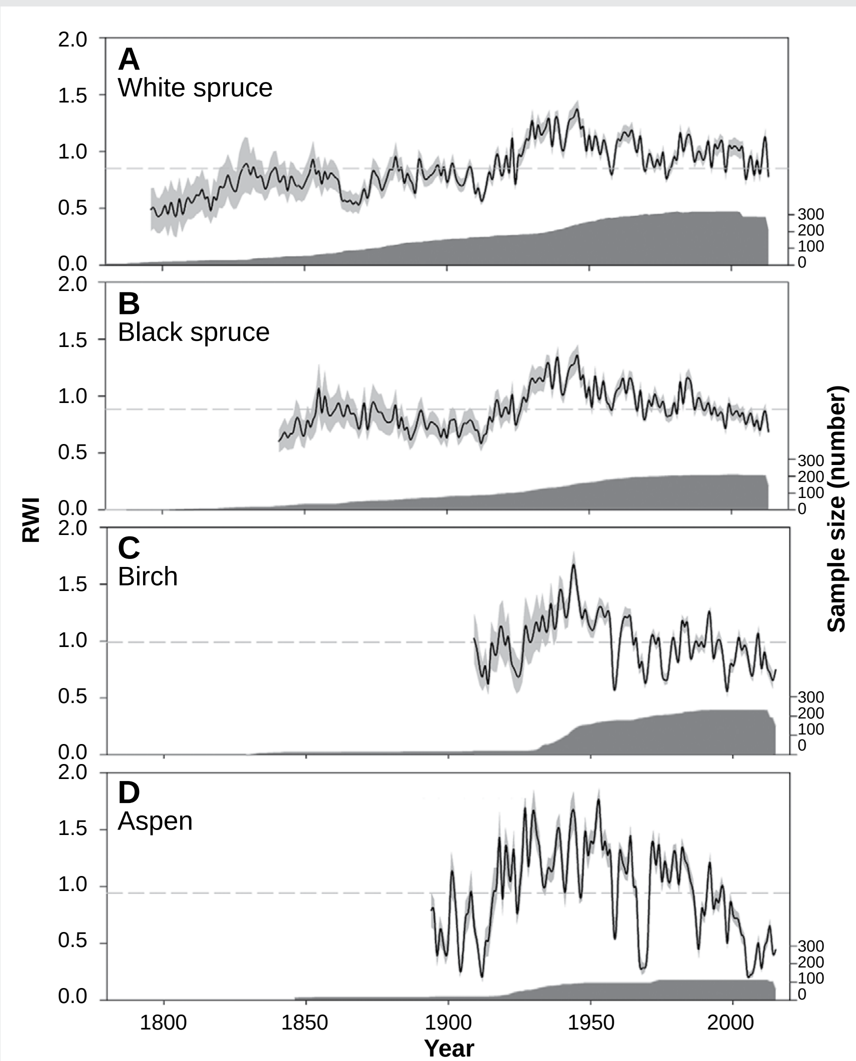


Figure 14—Growth chronologies for (A) white spruce, (B) black spruce, (C) birch and (D) aspen sampled throughout the Tanana Valley of interior Alaska. The solid line represents the mean ring width index (RWI) and the gray shading shows the 95 percent confidence interval; the solid fill at the bottom of each panel represents the sample size for each species and the dashed line is the mean RWI for the length of the chronology.

Forest Volume

Live-tree volume is often used to assess the commercial value and productivity of forests. In the Tanana unit, total live-tree net volume (≥5 inches diameter at breast height [d.b.h.]) was estimated at 6.4 billion ft^3 (table 3). To illustrate the contrast between Alaska's boreal and coastal forests, total net volume of live trees in southcentral and southeast Alaska (i.e., the Coastal unit) was about 57 billion ft^3 (Cahoon et al. 2020), despite a forest area in the Coastal unit less than half that of the Tanana unit. The relatively low live-tree volume in the Tanana unit is due in large part to the predominance of low-productivity black spruce forests in the region. Black spruce often grows quite slowly under poor site conditions common to these forest types in the Tanana unit. Consequently, a large proportion of black spruce stands may be made up of trees that are decades old but do not meet the 5-inches d.b.h. threshold used to estimate live-tree volume. However, biomass and carbon mass estimates capture live trees ≥1 inch d.b.h. (see below). Net volume of live trees (≥5 inches d.b.h.) on timberland, the most productive portion of the forest, was about 2.2 billion ft^3, or 34 percent of total volume on all forest land. However, the proportion of timberland volume compared with net live-tree volume differed among forest types (fig. 15). Timberland volume was highest in Alaska paper birch

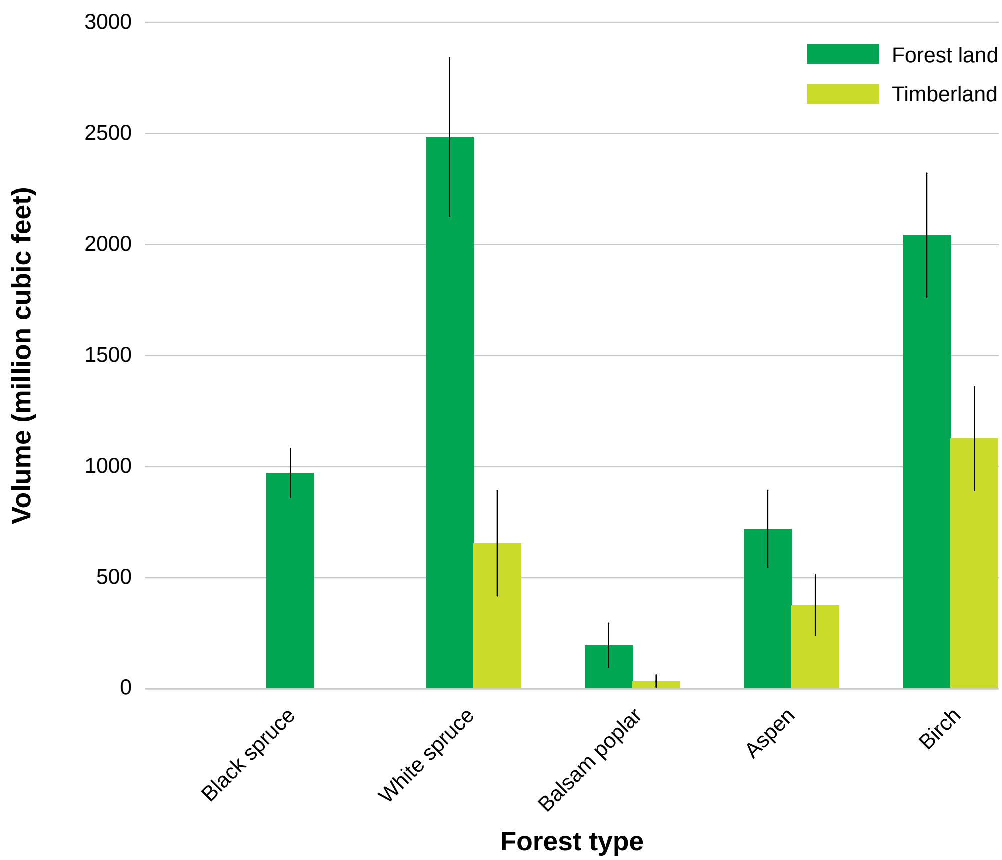


Figure 15—Net live-tree volume (≥5 inches diameter at breast height) among forest type on forest land and timberland (capable of producing >20 ft^3 ac^{-1} $year^{-1}$) in the Tanana unit.

Table 3—Net volume of live trees[a] on forest land by ownership group and land status in the Tanana unit, Alaska, 2014–2018

	Land status													
	Unreserved forests						Reserved forests							
	Timberland		Other forest		Total		Productive		Other forest		Total		All forest land	
Ownership	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Million cubic feet													
Federal government:														
Bureau of Land Management	45.0	47.0	300.4	89.1	345.3	99.7	—	—	5.0	3.8	5.0	3.8	350.3	99.7
Departments of Defense and Energy	160.4	88.0	154.5	59.6	314.9	97.3	—	—	—	—	—	—	314.9	97.3
National Park Service	—	—	—	—	—	—	17.2	20.9	303.4	92.1	320.6	93.9	320.6	93.9
Fish and Wildlife Service	—	—	—	—	—	—	34.4	36.8	78.7	36.0	113.1	48.4	113.1	48.4
Total	205.3	99.7	454.9	107.1	660.2	139.3	51.6	42.3	387.2	98.7	438.8	105.4	1,099.0	173.3
State and local government	1,987.6	340.6	1,994.7	239.2	3,982.3	386.7	266.1	150.6	11.7	10.2	277.8	150.9	4,260.1	403.9
Private	511.1	170.0	544.3	121.2	1,055.4	196.5	—	—	—	—	—	—	1,055.4	196.5
All owners	2,704.1	387.9	2,993.8	284.3	5,697.9	439.1	317.7	156.4	398.9	99.2	716.6	184.1	6,414.5	464.9

SE = standard error; — = less than 50,000 cubic feet was estimated.

Note: Totals may not sum because of rounding; data are subject to sampling error.

[a] Includes all live trees ≥5 inches in diameter at breast height, consisting of growing stock, rough cull, and rotten cull tree classes.

forest types (1,126 ± 233 million ft^3), about 55 percent of total Alaska paper birch forest volume, whereas none of the black spruce stands were considered timberland. Summarized by area, average net live-tree volume per acre across the entire unit was 309 ± 22.4 ft^3 ac^{-1} (580 ± 75.3 board ft ac^{-1}). Among forest types, white spruce contained the greatest amount of live-tree volume per acre (fig. 16). White spruce is commonly used as a source of firewood by many residents (Marcille et al. 2021) and much of the timber industry in interior Alaska is based on white spruce harvest (Morimoto and Juday 2019) (fig. 17). The distribution of volume among diameter classes differed substantially among forest types (fig. 16). White spruce, aspen, and Alaska paper birch were similar to one another in the 5.0 to 6.9 inches and 7.0 to 8.9 inches diameter classes, with a peak in the 7.0 to 8.9 inches class. Aspen volume per acre dropped sharply in the larger classes (>9 inches), while white spruce contained the greatest volume per acre among most diameter classes. In contrast, black spruce volume was highest in the smallest diameter class (5 to 6.9 inches), then declined in the larger stand classes. Among landowners, state and local governments manage most of the live-tree volume across all species (4.26 billion ft^3 [66 percent]), followed by private landowners (fig. 18). However, live-tree volume per acre was highest among private landowners (475 ± 80.7 ft^3 ac^{-1}), followed by lands administered by state and local governments (331 ± 31.1 ft^3 ac^{-1}).

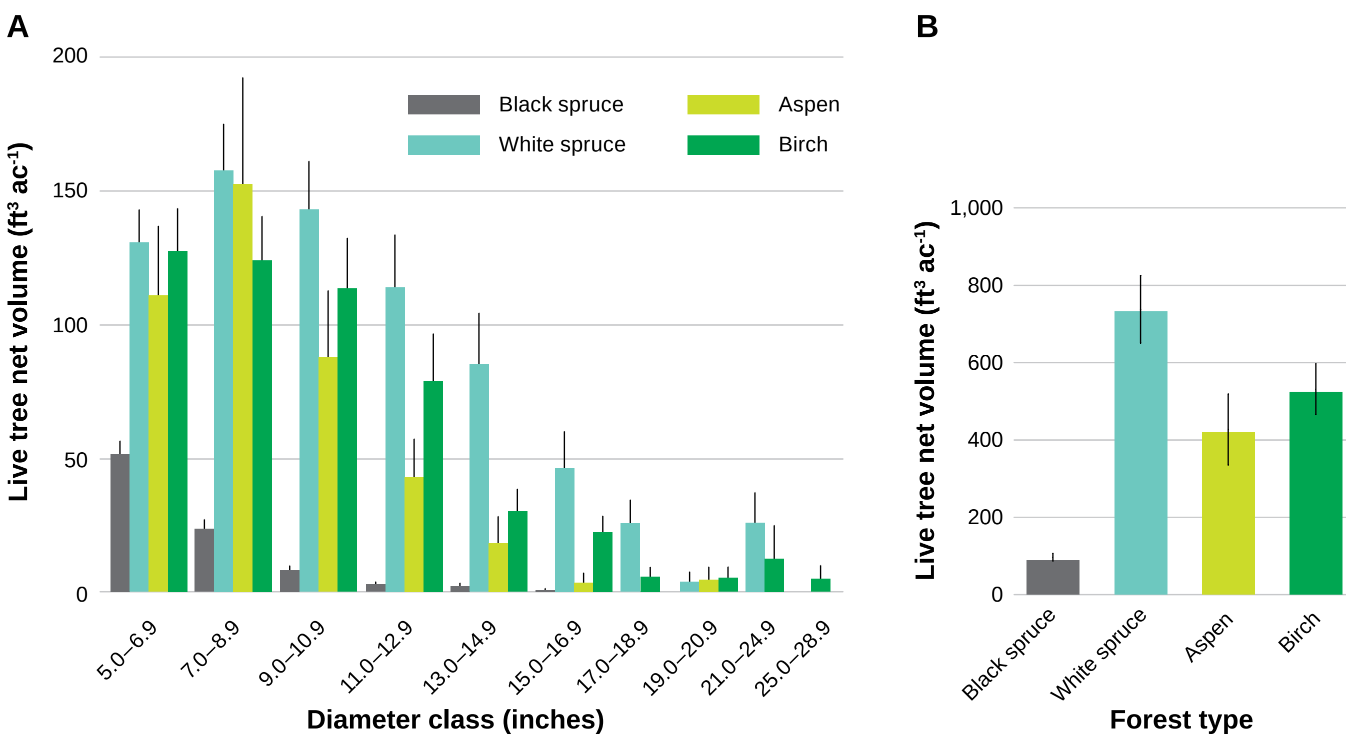


Figure 16— (A) Distribution of live-tree net volume (ft^3 ac^{-1}) among diameter classes for the five most common forest types in the Tanana unit. (B) Average live-tree net volume (ft^3 ac^{-1}) across all diameter classes for the same forest types. Excludes trees <5 inches diameter at breast height.

Figure 17—A timber harvest site in the Tanana Valley, Alaska.

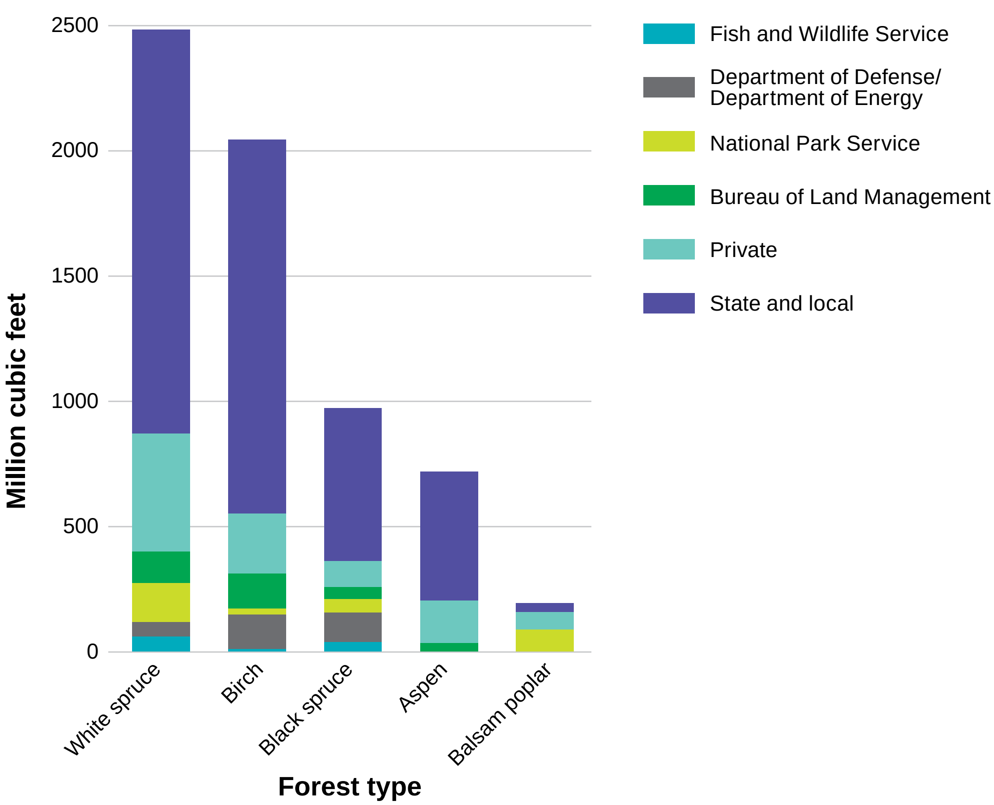


Figure 18—Net live-tree volume (≥5 inches diameter at breast height) among forest types and major landowners in the Tanana unit.

Forest Biomass

Across the entire unit, live-tree biomass was estimated to total 275 (± 12) million tons, with an additional 41 (± 2.6) million tons in standing dead-tree biomass.

Aboveground biomass is a key attribute of forest inventory studies and is influenced by an array of factors, including topography, climate, disturbance, and biotic interactions such as herbivory and disease. Field measurements of tree height and diameter are converted into dry mass to examine long-term trends in primary productivity at multiple scales. Allometric equations developed in the region (see app.) were used to estimate live-tree and standing dead-tree (snag) biomass for the Tanana unit (fig. 19). Across the entire unit, live-tree biomass was estimated to total 275 (± 12) million tons (table 4), with an additional 41 (± 2.6) million tons in standing dead-tree biomass. Total live-tree and standing dead-tree biomass was much higher on state and local government lands than those managed by other landowners. However, the density of biomass (tons per acre) was highest on land managed by private landowners and the Department of Defense and the Department of Energy (fig. 20).

Among forest types, the density of biomass was greatest in balsam poplar (23.5 ± 6.9 tons ac^{-1}), white spruce (20.9 ± 2.1 tons ac^{-1}), and Alaska paper birch forests (19.2 ± 1.8 tons ac^{-1}). The distribution of biomass among age classes varied by forest type (fig. 21). Aspen biomass peaked in the 81 to 100 year age class, with a dramatic decline thereafter that is typical of this short-lived species.

Vic Anderson

Figure 19—Interior Alaska forest biomass is often a collection of live trees, standing dead trees, and down woody material in densely packed stands.

Table 4—Aboveground biomass of live trees[a] on forest land, by ownership and land status in the Tanana unit, Alaska, 2014–2018

Ownership	Unreserved forests						Reserved forests						All forest land	
	Timberland		Other forest		Total		Productive		Other forest		Total			
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Thousand tons													
Federal government:														
Bureau of Land Management	1,624	1,629	14,505	3,228	16,128	3,573	7	8	908	523	916	523	17,044	3,595
Departments of Defense and Energy	6,116	2,988	10,317	2,492	16,433	3,264	—	—	—	—	—	—	16,433	3,264
National Park Service	—	—	—	—	—	—	704	691	14,821	2,058	15,525	2,102	15,525	2,102
Fish and Wildlife Service	—	—	—	—	—	—	1,437	1,282	5,939	1,989	7,376	2,213	7,376	2,213
Total	7,740	3,403	24,821	4,076	32,561	4,839	2,148	1,456	21,668	2,823	23,816	2,991	56,377	5,552
State and local government	60,215	8,987	114,118	7,556	174,333	10,309	6,485	3,533	667	349	7,152	3,550	181,486	10,501
Private	14,261	4,313	23,056	3,495	37,317	4,965	—	—	91	94	91	94	37,408	4,965
All owners	82,216	10,302	161,996	9,010	244,212	11,561	8,633	3,821	22,426	2,846	31,059	4,643	275,271	12,008

SE = standard error; — = less than 50 bone-dry tons was estimated.

Note: Totals may not sum because of rounding; data are subject to sampling error.

[a] Includes all live trees ≥1 inch diameter at breast height, consisting of growing stock, rough cull, and rotten cull trees. Aboveground biomass from ground to tip, includes stem wood, bark, and branches; calculated with regional biomass equations.

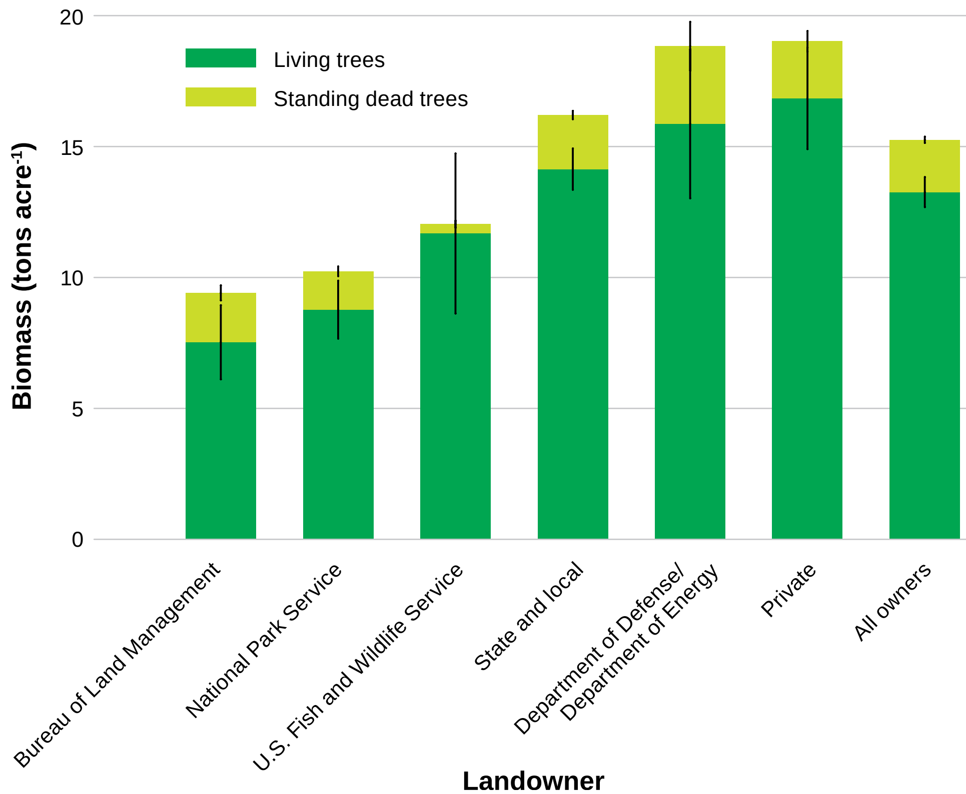


Figure 20—The distribution of live-tree and standing dead-tree biomass (tons acre^{-1}) among major landowners in the Tanana unit. Solid bars represent the mean; error bars are ±1 standard error.

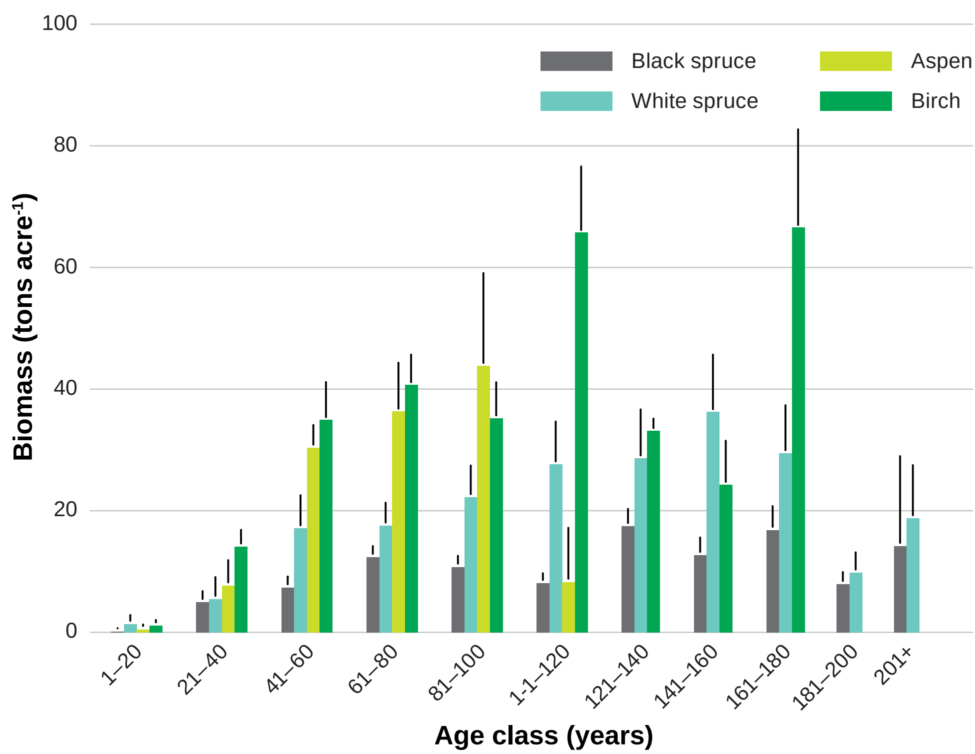


Figure 21—The distribution of live-tree biomass (tons acre^{-1}) among age classes of the dominant forest types in the Tanana unit. Solid bars represent the mean; error bars are ± 1 standard error.

Alaska paper birch showed a similar pattern to aspen through the 81 to 100 year age class, although there was considerable biomass in age classes greater than 100 years, with the oldest stand reaching 175 years old. The biomass distribution in hardwoods contrasts with that of white spruce, which showed a gradual increase in biomass until the 141 to 160 year age class. The difference in age-related trajectories likely reflects the common successional pattern in interior Alaska, whereby fast-growing deciduous species quickly colonize recently burned or disturbed areas with abundant germination sites on mineral soil, but are eventually replaced by shade-tolerant spruce (van Cleve et al. 1991). Although this stand-replacing pattern of succession has maintained spruce dominance throughout the region, changes in climate and fire regime may benefit Alaska paper birch and aspen growth and enable these species to retain dominance for longer periods (Johnstone et al. 2010, Mekonnen et al. 2019).

Forest Carbon Pools[2]

Soil Carbon—

A defining feature of boreal forest ecosystems is the vast amount of carbon (C) stored belowground (fig. 22). Globally, the boreal biome contains about 27 percent of the global soil C pool (Jackson et al. 2017). The combination of plant inputs and centuries of cool and saturated soil conditions have hampered organic matter decomposition, creating deep and extensive C pools (Ping et al. 2015). However, recent dramatic increases in temperature in northern latitudes have raised concerns that a substantial portion of this pool could rapidly mobilize through increased decomposition and return to the atmosphere as greenhouse gases, accelerating global climate change (Koven et al. 2011, Schuur et al. 2015).

Recognizing the scientific and societal value of quantifying belowground C, the Pacific Northwest Forest Inventory and Analysis (PNW-FIA) program developed a protocol for FIA crews to collect soil cores from all interior Alaska plots. During the 2014 pilot study, one subplot was sampled. From 2016 onward, the protocol was expanded to include soil cores from three subplots (subplots 2, 3, and 4). In the field, crews measured the thickness of discernible layers, including litter, identifiable plant parts (ID parts), unidentifiable plant parts (Un-ID parts), and mineral soil. These layer definitions differ slightly from USDA Natural Resources Conservation Service soils nomenclature in which the Oi layer (roughly equivalent to FIA ID part layers) comprises slightly decomposed compacted litter and other identifiable plant parts. The Oe and Oa layers, comprised of moderately and highly decomposed organic material, respectively, are roughly equivalent to FIA Un-ID part layers. In

[2] Values of forest carbon are presented in metric units in accordance with international reporting standards.

moss-covered areas, the top of the soil was differentiated from the bottom of the moss at the interface between ID parts and Un-ID parts. Distinguishing between organic horizons and mineral soil in moss-covered areas can be difficult. Crews distinguished Un-ID parts from mineral soil using soil texture and based upon the relative proportions of decomposing organic matter and material derived from weathered mineral sources.

Vic Anderson

Figure 22—A Forest Inventory and Analysis crew member displays a soil core extracted from a plot in interior Alaska. Note the transition from green moss at the top of the core to decomposing organic material in the center and organic-rich mineral soil at the bottom of the core.

Soil cores were sent to the Forest Soils Lab at the University of Alaska Fairbanks for processing and elemental analysis (a detailed description of soil collection methods is provided in the appendix and in PNW-FIA field manuals) (PNW-FIA 2019). Collection of soil samples in permafrost regions is complicated by the presence and status of the active layer, defined as the upper portion of the soil profile that freezes in the winter and gradually thaws during the summer months. Soil core samples that encountered frozen soil above the mineral soil layer may introduce a bias by under sampling near-surface organic layers. Therefore, this analysis was limited to soil cores that included a sample of mineral soil at the bottom of the soil core to ensure a complete sample of the uppermost organic layers. While this method may have undersampled colder soils with very thick organic horizons (>3.28 ft [>1 m]), the tools and time needed to sample thick peat layers were beyond the scope of this inventory. Of the 1,991 cores collected, 1,529 (77 percent) contained a sample of mineral soil and were used in population estimates. Of the cores excluded, 27 were from subplots where thaw depth exceeded 1 m and mineral soil was not sampled. Finally, because the thickness of the mineral layer varied and did not represent a complete sample, mineral horizon samples were standardized to a thickness of 3 inches (7.62 cm), which was the mean thickness of all mineral soil samples. Total soil organic C (SOC) for each core was derived from the sum of all layers sampled. There was no attempt to standardize other layers or model SOC to a common depth.

Across all forested conditions, total SOC was estimated at about 637.2 (± 11.3) million Mg (0.637 Pg: 1 Pg C = 1.0^9 Mg C) and varied considerably from 7.7 (± 4.2) million Mg in tamarack forests to 362.8 (± 18.2) million Mg in black spruce forests (fig. 23A), due in part to the relative abundances of these forest types within the Tanana unit (fig. 11). When expressed on a per hectare basis, on average, SOC was 81.9 (± 1.8) Mg ha^{-1} and ranged from a minimum of 51.9 (± 5.8) Mg ha^{-1} in aspen forests to a maximum of 115.7 (± 32.4) Mg ha^{-1} in tamarack forests (fig. 23B). Black spruce forests had the second highest mean SOC (Mg ha^{-1}) among forest types (91.6 ± 2.5 Mg ha^{-1}), but much lower variation (standard error) than tamarack forests. Among landowners, state and local governments manage lands containing nearly 400 million Mg of SOC (59 percent)—more than five times the total estimated SOC on National Park Service land, which contains the next most abundant pool of SOC. Overall, these estimates compare favorably with those reported across various aspects, vegetation types, and landforms in the Intermontane Boreal ecoregion in central Alaska (Johnson et al. 2011). For comparison, total SOC in the Tanana unit (637.2 million Mg) is roughly 17.2 million Mg greater than the most recent assessment of total aboveground C in live trees throughout the coastal Alaska FIA unit (620 million Mg). This finding illustrates the extent to which the amount and location of belowground versus aboveground carbon storage differs among Alaska's

State and local governments manage lands containing nearly 400 million Mg of soil C, more than five times greater than the next most abundant pool of soil C.

boreal and coastal forest ecosystems (Cahoon et al. 2020); it also highlights the importance of SOC as a substantial source of carbon sequestration in the region represented by the Tanana unit.

The distribution of SOC in soil layers differed among forest types, but generally increased with depth (fig. 24). SOC in each soil horizon was consistently higher in black spruce forests than in the other forest types, with the exception of the litter layer where SOC was lowest in black spruce (0.46 ± 0.05 Mg ha^{-1}). Although some layer SOC values in tamarack and balsam poplar forest types were larger than in black spruce, these estimates are based on cores collected from just eight and ten plots, respectively. The larger SOC pools in black spruce forests is likely due to the synergistic effects of poor substrate quality of both black spruce litter (Flanagan and van Cleve 1983) and ground layer moss (particularly *Sphagnum* species) (Turetsky et al. 2010), and physiographic characteristics (cool, wet soils) common to black spruce forests that limit organic matter decomposition. Indeed, the identifiable plant parts horizon in black spruce was the thickest among layers and forest types (8.7 ± 0.3 cm). SOC in mineral soil was highest in all forest types, which primarily was driven by a substantial increase in bulk density (g cm^{-3}), as percentage of mineral soil C concentration was significantly less than other layers. The large amount of SOC in mineral soil likely reflects the often ambiguous delineation between organic and mineral layers that can result from pedogenic processes (i.e., repeated deposition, leaching, and cryoturbation) that

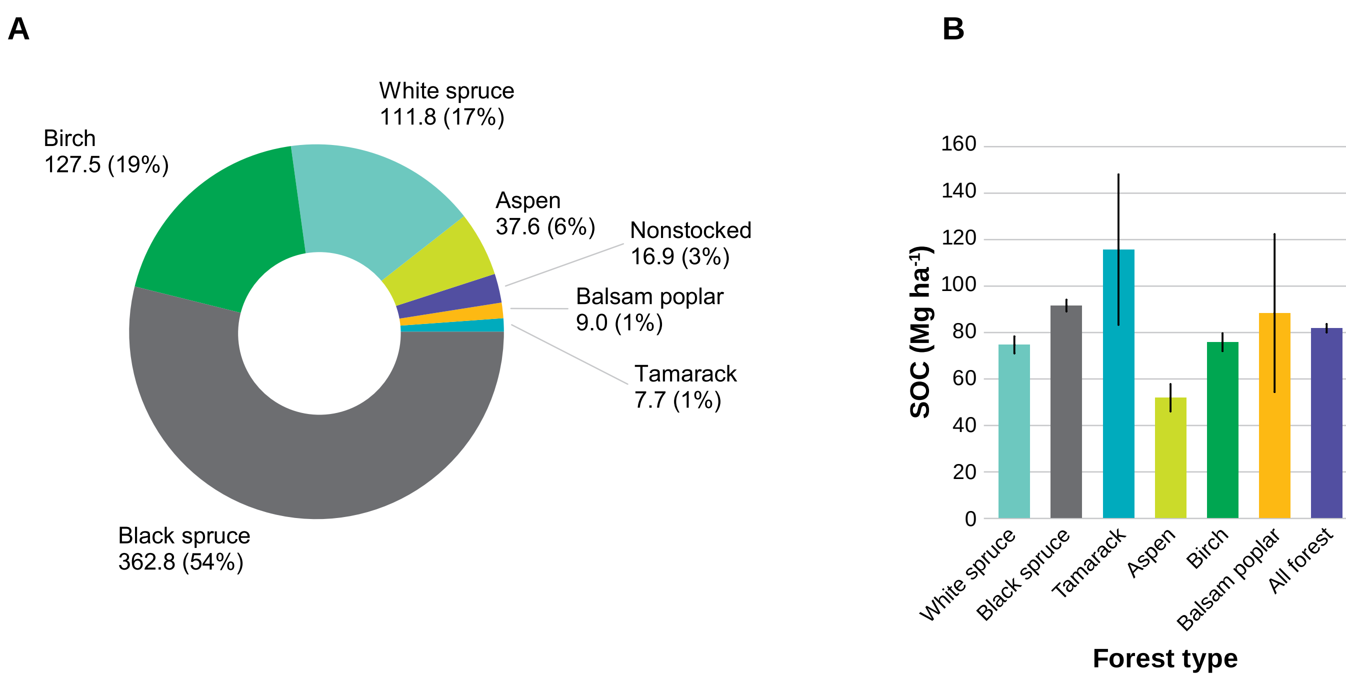


Figure 23—(A) Total soil organic carbon (SOC) among forest types; values are in million Mg and percentage of total SOC throughout the forested portion of the Tanana unit. (B) Distribution of SOC density (Mg ha^{-1}) among forest types; solid bars represent the mean; error bars are ± 1 standard error.

transport organic materials to deeper horizons in permafrost soils (Tarnocai et al. 2009). Indeed, SOC likely declines with depth beyond the sampling interval in this inventory (Harden et al. 2012, Ping et al. 2015). Thus, these samples should not be considered a complete inventory of SOC for the entire soil profile. Rather, the results presented here should be viewed as an assessment of SOC in near-surface layers, which are the most vulnerable belowground C pool as the climate warms and permafrost degrades (Harden et al. 2012, Schuur et al. 2008).

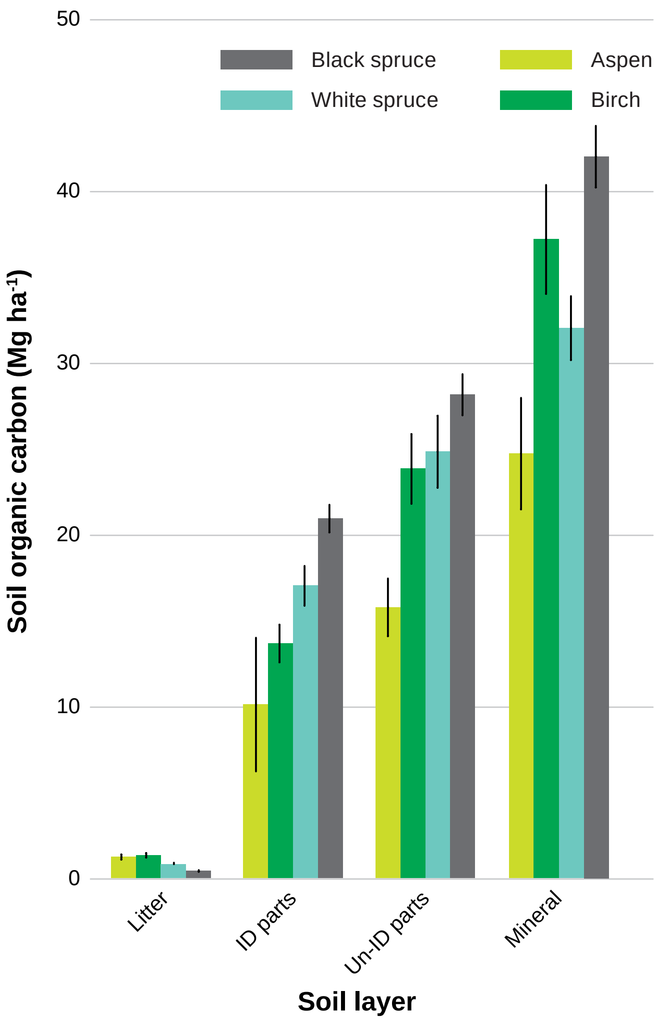


Figure 24—Distribution of soil organic carbon (Mg ha^{-1}) by soil layer among forest types. For consistency, mineral soil samples were standardized to a thickness of 3 inches (7.62 cm). Soil organic carbon in all other layers was based on thickness measured in the field. Solid bars represent the mean; error bars are ± 1 standard error. ID parts = identifiable plant parts; Un-ID parts = unidentifiable plant parts.

Carbon in live and standing dead trees—

Live trees play a fundamental role in many ecosystem services, including the sequestration of atmospheric carbon dioxide through the process of photosynthesis. Carbon estimates presented here are directly proportional to biomass, as C is approximately 50 percent of living tissue (Chapin et al. 2002, Fahey et al. 2005). Carbon in live trees (>1 inch d.b.h. [2.54 cm]) in the Tanana unit was estimated to total 124.9 (± 5.4) million Mg. Among forest types, black spruce contained the greatest total amount of live-tree C (46.2 ± 2.9 million Mg), but due to their low productivity and widespread coverage, had the second-lowest live-tree C per hectare (10.6 ± 0.56 Mg ha^{-1}). State and local governments managed the largest amount of live-tree C (82.3 ± 4.8 million Mg), about two-thirds of total live-tree C in the unit (fig. 25). Private lands contained about 16.9 (± 2.3) million Mg of C (13.6 percent) in live trees, although C per hectare was highest in this category (18.9 ± 2.3 Mg ha^{-1}). When assessed in the form of fossil fuel emissions to the atmosphere, the total live-tree C pool in the Tanana unit would be the equivalent of nearly 1.06 billion barrels of oil (US EPA 2020). In total, the live-tree C pool in the Tanana unit was small compared with the most recent assessment of live-tree C in coastal Alaska (620 ± 16.9 million Mg) (Cahoon et al. 2020). The relatively small pool of live-tree C is characteristic of the region, which experiences short growing seasons, discontinuous permafrost, and repeated widespread fire-driven tree mortality. In fact, Genet et al. (2018) estimated that 10 years of C gains among boreal forest vegetation can be lost in 1 fire year (fig. 26).

Standing dead trees (snags) are an ecologically important component of boreal ecosystems as they provide habitat for many forest animals and can represent a substantial component of terrestrial C because the decomposition rate in northern latitudes is slow (Harmon et al. 2020). Total C among standing dead trees was about 18.8 (± 1.2) million Mg, with estimates ranging from 0.07 (± 0.07) million Mg in tamarack forests to 3.9 (± 0.65) million Mg in Alaska paper birch forests. Overall,

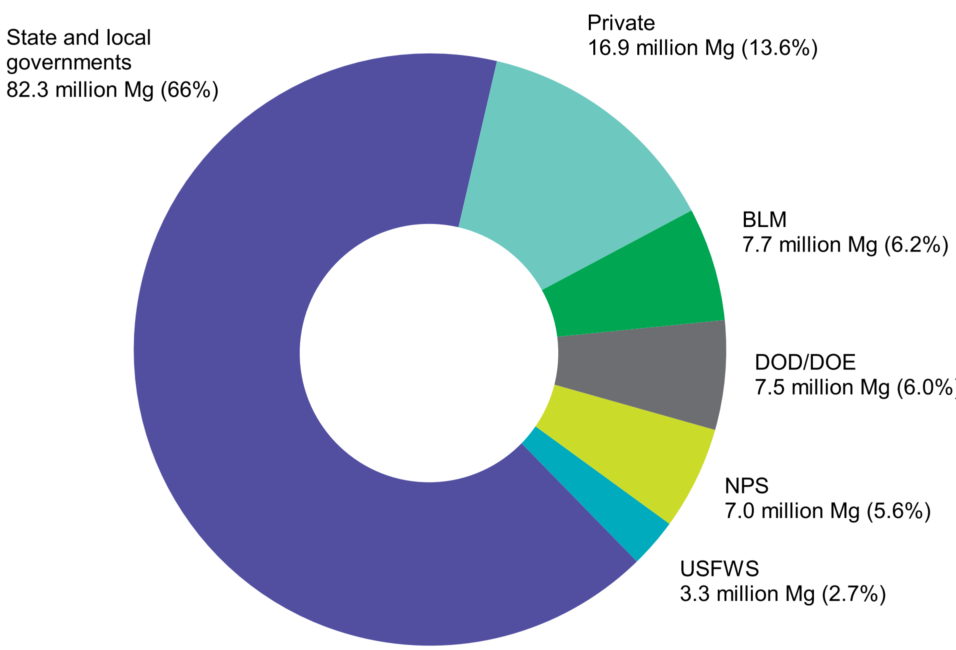


Figure 25—Total live-tree carbon (≥1 inch diameter at breast height [2.54 cm]) among land ownerships in the Tanana unit of interior Alaska. BLM = Bureau of Land Management; DOD/DOE = Department of Defense and Department of Energy; USFWS = U.S. Fish and Wildlife Service.

USDA Forest Service

Figure 26—Smoke from a distant fire creates a plume many miles long in interior Alaska. Fire is a major disturbance regime and contributes substantially to annual carbon dioxide emissions.

C per hectare in standing dead trees was highest in aspen stands (4.5 ± 0.83 Mg ha^{-1}) and lowest in tamarack (1.4 ± 0.51 Mg ha^{-1}), balsam poplar (1.5 ± 0.6 Mg ha^{-1}) and black spruce forest types (1.7 ± 0.13 Mg ha^{-1}). Estimates for tamarack and balsam poplar stands may not be reflective of these stands throughout the boreal forest, as these forest types were encountered only on eight and ten plots, respectively. Overall, carbon in standing dead trees accounted for about 13 percent of total tree C (live-tree C + standing, dead-tree C) (fig. 27). Aside from tamarack, black spruce and aspen forest types contained the highest percentage of standing dead-tree C (14 and 24 percent, respectively). Among black spruce stands, the high proportion of standing dead-tree C is likely a remnant of the most recent fire, which can result in very high mortality, with some standing dead-tree C persisting for 50 to 60 years after fire (Viereck 1983). The high amount of snag C in aspen stands could also reflect the relatively high amount of dead spruce remaining on the plot after fire, and FIA classification of forest type. Plot conditions are classified by forest type based on the plurality of live-tree species (see glossary for definition of "forest type"). Because aspen are often the first tree species to colonize recently burned areas, these plots would have been classified as aspen; however, the large portion of standing dead-tree C could have been attributed to black or white spruce snags remaining after the most recent fire. Indeed, among plots classified as aspen forest type, the ratio of dead white spruce (79 trees) plus black spruce (547 trees) to

Overall, carbon in standing dead trees accounted for about 13 percent of total tree C (live-tree C + standing, dead-tree C).

live aspen (817 trees) was about 0.76, indicating nearly three-quarters of the trees tallied in aspen stands were dead spruce trees. Other sources of mortality in mature aspen stands could be attributed, in part, to the aspen running canker, a disease that can rapidly kill aspen trees that has spread swiftly in interior Alaska since 2015 (USDA FS 2019) (see "Forest Health Conditions in Interior Alaska" on page 37).

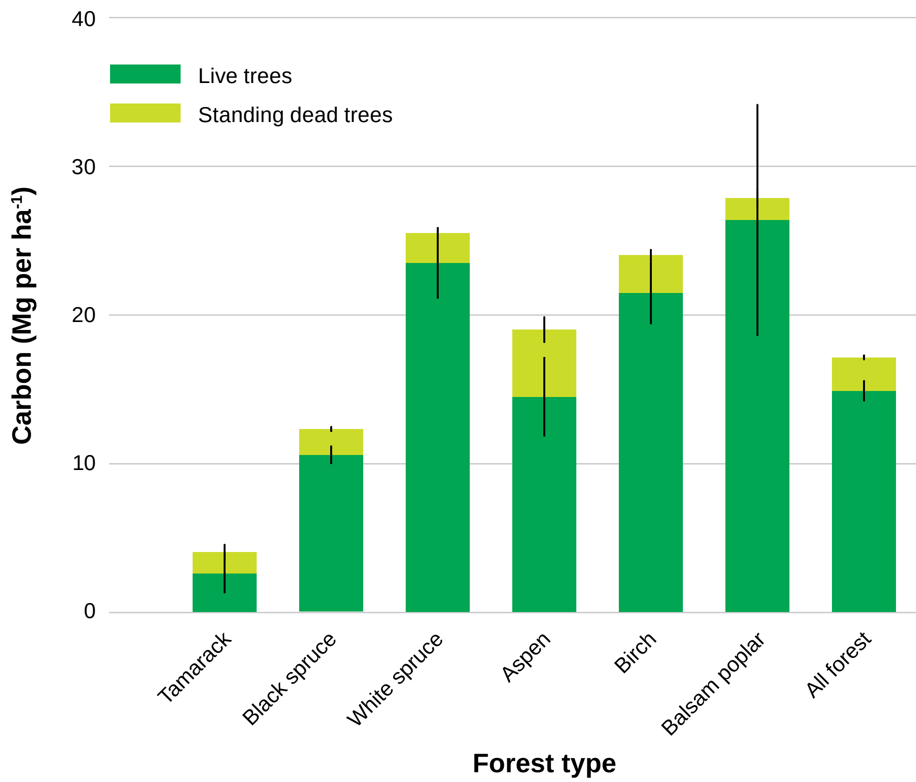


Figure 27—Carbon pools among forest types in the Tanana unit, separated by standing dead and live trees (>1 inch diameter at breast height [2.54 cm]). Solid bars represent the mean; error bars are ± 1 standard error.

Carbon in down woody material—

Down woody material (DWM) includes dead woody plant material on the ground in various stages of decay. Not only is DWM an important source of organic material available for decomposition, it also serves as habitat for small mammals, invertebrates, and birds. DWM can also be an important factor in fuel loads and fire behavior. Down woody material is measured on forested plots along eight, 24-ft transects (two transects per subplot) and includes coarse woody debris (≥3 inches diameter) and fine woody debris (<3 inches diameter) intersected by the transect. In total, C in DWM was estimated at about 26.6 (± 1.5) million Mg and 1.4 (± 0.08) Mg ha^{-1}. In general, the hardwood forest types contained a greater amount of total C and C per hectare in DWM than the softwood species. Carbon mass in DWM was highest in Alaska paper birch forest types (3.03 ± 0.3 million Mg). Among all forest types, C mass in DWM was highest in the youngest stands, likely as a result of mortality from a recent natural disturbance (fire, insects, etc.). Overall, the amount of C in DWM was about 7.7 million Mg larger than the amount of C in snags, and one-fifth the amount of C in live trees.

Ground layer carbon—

Estimates of ground layer carbon were generated from 32 nondestructive Daubenmire microquad frames (1000 cm^2) (Daubenmire 1959) arranged along the eight coarse woody debris transects on each plot. Ground-dwelling mosses and lichen depth and cover were estimated visually by functional groups within each microquad and converted to C mass by applying calibration equations developed in the region (Smith et al. 2015). When summed among all functional groups, the largest pool of ground layer C was estimated to occur in black spruce forest types (38.8 ± 1.8 million Mg), followed by white spruce (7.9 ± 0.9 million Mg) and Alaska paper birch (3.8 ± 0.5 million Mg). The forest ground layer showed a distinct increase in C per hectare with stand age, as C in stands 50 to 99 years old (8.9 ± 0.5 Mg ha^{-1}) was more than double that of stands 20 to 49 years old (3.7 ± 0.4 Mg ha^{-1}), reflecting the recovery and stabilization period after fire (fig. 28). For more detail on ground layer composition and biomass, see “Ground Layer Biomass and Composition.”

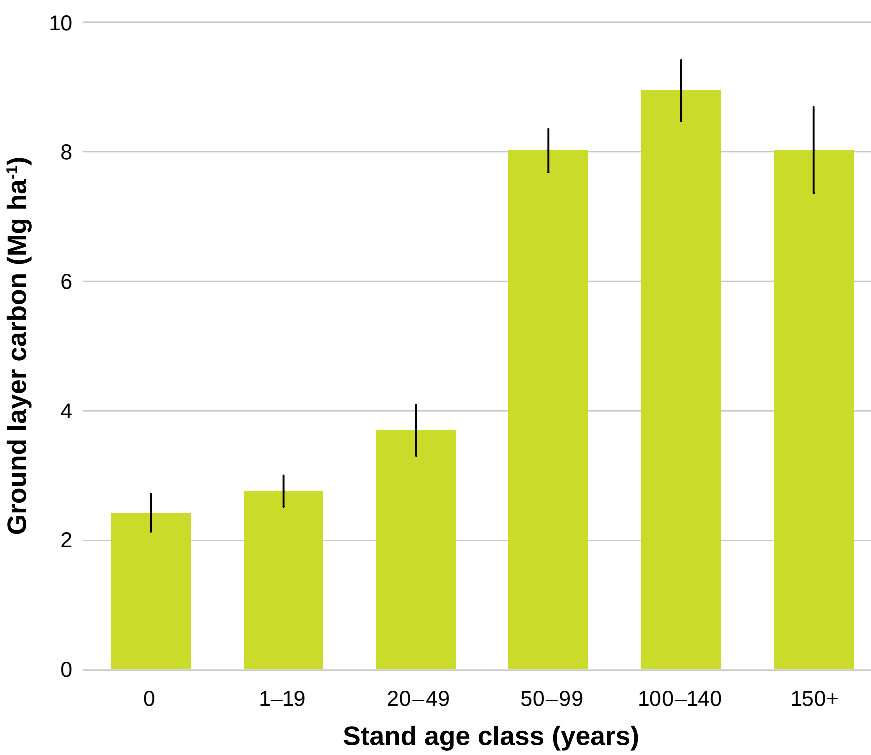


Figure 28—Distribution of carbon in the ground layer among forest stand age classes. Bars represent the mean of all forest types and ground layer functional groups within each age class. Error bars are ± 1 standard error.

The Tanana unit contained approximately 0.896 (± 0.02) Pg of C, more than half of which was found in black spruce forest types.

Ecosystem carbon—

Separating ecosystem C into different pools (e.g., aboveground DWM, ground layer, and belowground) provides insight into the distribution of C among and within forest types (fig. 29). When summed across all pools, average forest C per hectare was 106.7 (± 2.0) Mg ha^{-1}. Tamarack contained the highest total C per hectare (126.3 ± 20.8 Mg ha^{-1}). Among the more common forest types, black spruce was estimated to contain the most C per hectare (113.5 ± 2.4 Mg ha^{-1}), followed by white spruce (107.7 ± 3.9 Mg ha^{-1}) and Alaska paper birch (105.6 ± 4.5 Mg ha^{-1}). Across all forest types, SOC accounted for approximately 76.7 percent of total ecosystem C. The highest proportion of total ecosystem C in soil was in black spruce (about 90 percent). In contrast, white spruce had one of the lowest proportions of SOC (76 percent), revealing the dramatic difference in habitat types between these two dominant spruce forest types in the region (table 5). When summed across all forest types and ecosystem components, the Tanana unit contained approximately 0.896 (± 0.02) Pg of C, more than half of which was found in black spruce forest types (fig. 30).

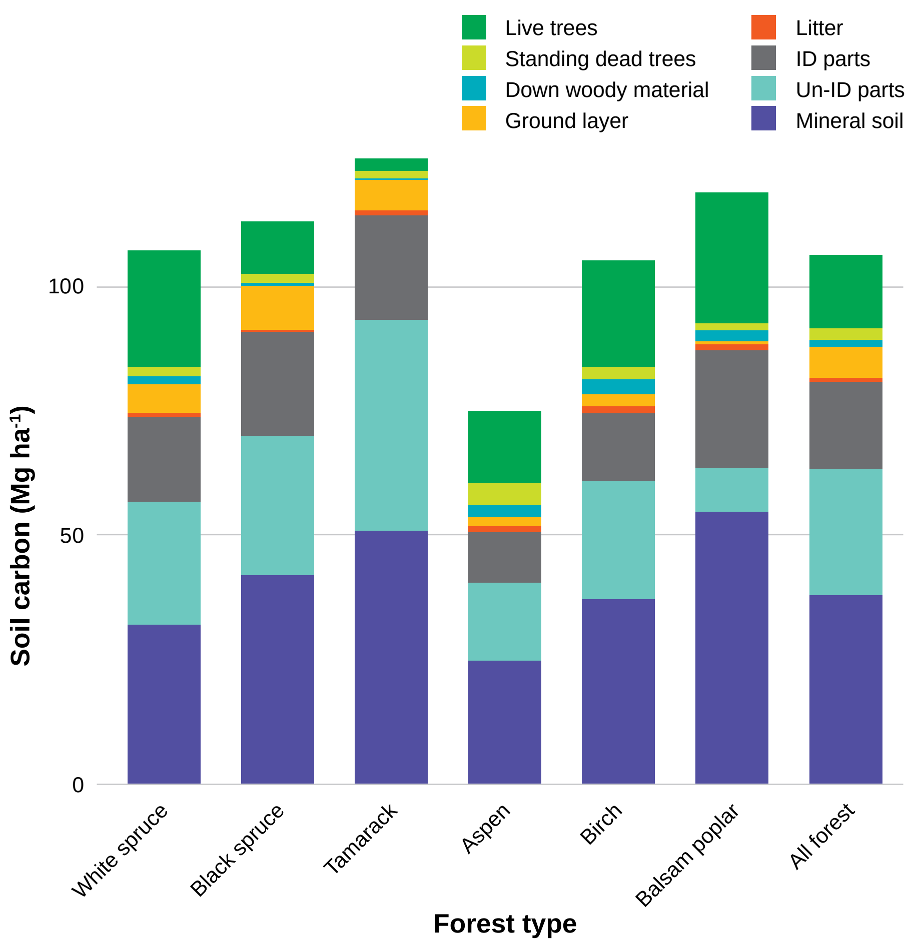


Figure 29—Distribution of ecosystem carbon among below- and aboveground pools in each forest type. Stacked sections of each bar represent the mean for that pool. Error bars have been omitted for clarity. ID parts = identifiable plant parts; Un-ID parts = unidentifiable plant parts.

Table 5—Average carbon content (Mg ha^{-1}) among forest types and major ecosystem components in the Tanana unit, Alaska, 2014–2018. Units are provided in metric in accordance with international reporting standards.

	Ecosystem component									
	Live trees[a]		Standing dead[a]		DWM		Ground layer		Soil[b]	
Forest type	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE
					Megagrams per hectare^{-1}					
Black spruce	10.60	0.56	1.73	0.13	0.65	0.05	8.82	0.27	91.62	2.51
White spruce	23.51	2.34	2.00	0.31	1.58	0.17	5.80	0.38	74.73	3.64
Tamarack	2.62	1.27	1.42	0.51	0.33	0.12	6.17	2.14	115.73	32.36
Aspen	14.50	2.61	4.53	0.83	2.45	0.32	1.80	0.17	51.90	5.84
Balsam poplar	26.40	7.74	1.46	0.60	2.20	0.41	0.63	0.27	88.37	33.98
Paper birch	21.51	2.05	2.53	0.35	3.03	0.30	2.44	0.23	75.88	3.84
All forest	14.90	0.65	2.25	0.14	1.42	0.08	6.26	0.18	81.87	1.81

DWM = down woody material; SE = standard error.

[a] Includes all trees >1 inch (2.54 cm) diameter at breast height.

[b] Includes the sum of soil layers and mineral soil standardized to a thickness of 3 inches (7.62 cm).

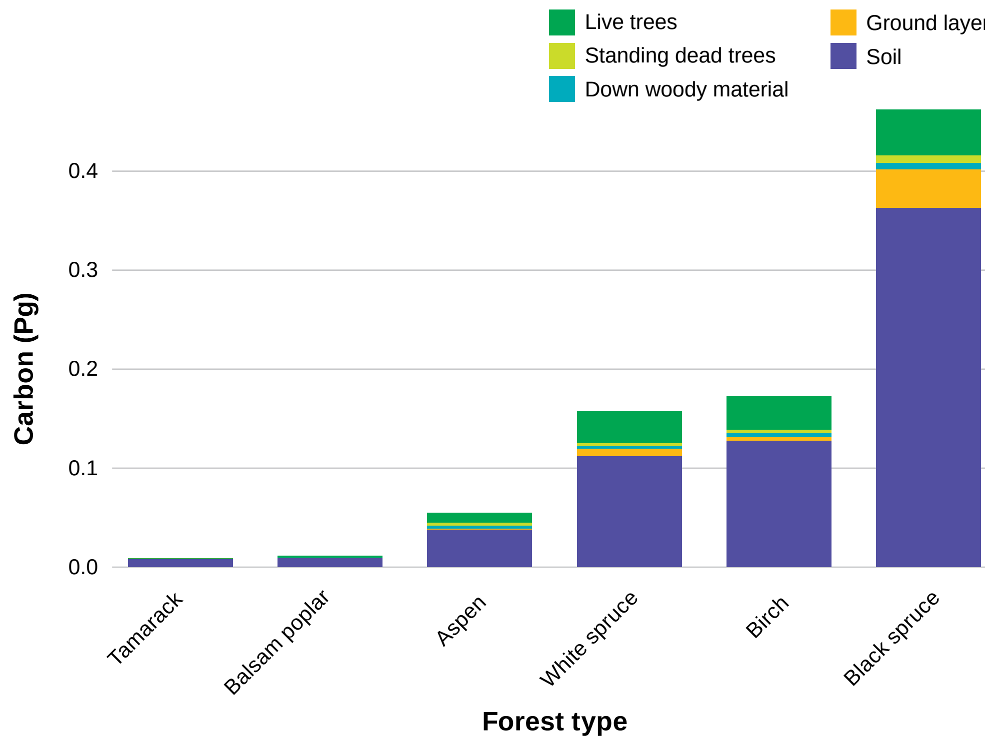


Figure 30—Total carbon (Pg) among forest types and ecosystem component pools in the Tanana unit, Alaska. Standing dead and live trees are ≥1 inch diameter at breast height (2.54 cm).

In fact, estimated SOC in black spruce forest types (0.36 ± 0.02 Pg) was greater than that in white spruce, Alaska paper birch, and aspen combined (0.28 ± 0.02 Pg). Ground layer C comprised a larger percentage of total ecosystem C (about 7.6 percent) in black spruce than other forest types, highlighting the important role this pool plays in boreal forest C dynamics.

Estimates of forest C provided in this report contribute novel insight into the spatial distribution of ecosystem C pools from a distinct region of the boreal forest. These estimates are a snapshot of ecosystem C in a dynamic landscape and represent the culmination of decades and sometimes centuries of biological and physical processes. As climate in northern latitudes continues to change rapidly, there is urgent need to improve estimates of boreal forest soil C stocks to better understand how this pool may influence global feedback processes. Recent modeling efforts have indicated that Alaska's boreal region may have been a net source of C to the atmosphere in the latter part of the 20th century, partly due to emissions from fire (McGuire et al. 2018), which have increased dramatically in recent decades (Kasischke et al. 2010). Although the future of boreal forest C dynamics is unclear (Genet et al. 2018, McGuire et al. 2018, Pastick et al. 2017, Yarie and Billings 2002), the data presented here offer a detailed inventory of forest C that could be used to parameterize future projections and help inform management and policy decisions aimed at mitigating the effects of global climate change.

Forest Health Conditions in Interior Alaska[1]

The USDA Forest Service Forest Health Protection program is responsible for surveying and monitoring the health of all forest lands in the United States. In Alaska, Forest Health Protection performs annual ground and aerial surveys for forest tree damage throughout the state (USDA FS 2015a, 2015b, 2016, 2017, 2018). The most notable insect and disease damages in the Tanana Valley during the inventory of the Tanana unit are described below.

Aspen running canker has been documented throughout Alaska's boreal forest since it was first noted in 2015. This very aggressive canker disease can rapidly kill the cambium as it spreads along the tree bole (fig. 31). The University of Alaska Fairbanks and Forest Health Protection studied 88 sites across six ecoregions of Alaska's road-accessible boreal forest. Aspen running canker was found at 72 of the sites across all six ecoregions. Among these ecoregions, the Tanana-Kuskokwim Lowlands had the largest proportion of trees (30-percent average) infected with this canker. On average, over 70 percent of trees with canker were dead and invariant across ecoregions. Although it is occasionally found on large trees, the disease is most damaging on small-diameter trees in intermediate-age stands where the lesions can girdle and kill trees within a single season. The disease is almost absent from similar-size young and vigorously growing trees in recently fire-scarred terrain. Cooperative Alaska Forest Inventory permanent plots provide the longest record of mortality and show a steady increase since 2000. The causal fungus of this disease has not yet been identified.

Figure 31—Tree damage caused by aspen running canker in interior Alaska.

Spruce broom rust is one of the most conspicuous fungal diseases in interior Alaska where it has been recorded since the 1950s. Infected white and black spruce trees have dense clusters of branches with a yellow or orange appearance on the branches or the main tree bole. In midsummer, yellow or orange spores erupt from pustules on the needles. Needles are often shed in the fall, giving the broom a bare, dead appearance, but the twigs in brooms do not normally die. The following spring, brooms produce new, yellowish needles. This disease does not kill trees directly but can lead to bole breakage.

Aspen leaf miner is a native moth found across the range of aspen. Larvae feed on the epidermal layer of leaves, giving them a silvery appearance with serpentine mines. Disruption of photosynthesis and water regulation leads to growth loss but does not typically cause tree mortality. The first recorded aspen leaf miner outbreak in Alaska occurred in the late 1970s, and several multiyear outbreaks that began in 2002 persist in the interior region. Damage mapped during annual aerial surveys has ranged from 70,000 to 700,000 ac depending on the year.

Amber-marked birch leaf miner damage becomes obvious in late July to early August after much of the leaf has been mined. Larval feeding under the leaf epidermis creates a flattened dry blister filled with feces. Though unsightly, the damage does not cause mortality. This sawfly is believed to have entered eastern North America in the early 1900s and reached Alaska in the early 1990s. In Fairbanks, it was first detected in 2002 where populations continue to intensify. Patterns of spread between Fairbanks and Anchorage suggest anthropogenic-aided dispersal. Recent surveys have detected activity extending beyond the road system into forests.

[1]Authors: Loretta Winton and Garret Dubois, USDA Forest Service, Forest Health Protection.

Forest and Nonforest Vascular Vegetation[3]

Vegetation provides a host of ecosystem services, including wildlife forage, habitat for additional flora and fauna, contributions to energy and biogeochemical cycles, and important subsistence resources (see "Citizen Science in the Tanana Unit" on page 46). The FIA vegetation profile protocol (PNW-FIA 2019) was implemented on all field-visited forested and nonforested plots within the Tanana unit to characterize dominant vegetation in addition to forest type. From the 2014 pilot study to the completion of the inventory in 2018, crews carried out this protocol on a total of 690 forested or partially forested plots and 33 nonforested plots (fig. 32). In most cases, FIA performs an inventory on forested or partially forested plots only and does not survey plots determined to be nonforest. However, because of the logistical challenges inherent in visiting field plots in the Tanana unit, if a plot was determined to be nonforest when it received a ground visit by the field crew, it was surveyed in its entirety (where possible). Surveys that include nonforest land can provide insight into the most common categories of vegetation beyond forested areas and the most common species encountered in each.

At each subplot, crews recorded the species identity, aerial cover, and growth habit of up to four dominant species whose covers exceeded 3 percent in each of five **species** growth habits: (1) large trees (≥5 inches d.b.h.), (2) saplings and seedlings (<5 inches d.b.h.), (3) shrubs, (4) graminoids (including grasses, sedges, and rushes), and (5) forbs. Crews also assigned each recorded species a code corresponding to one of four height classes (hereafter, layers) in which the majority of the species' cover occurred: 0–2 ft (layer 1), 2.1–6 ft (layer 2), 6.1–16 ft (layer 3), or >16 ft (layer 4). Furthermore, crews collected data on the structural character of each subplot, which described the total aerial cover of all species falling into one of five **structural** growth habits across each layer: (1) tally trees (all trees, saplings, and seedlings expected to reach 13 ft at maturity that were included on the list of species that are tracked and measured for Interior Alaska); (2) nontally trees (all trees, saplings, and seedlings expected to reach 13 ft at maturity that were **not** included on the list of tracked and measured species for interior Alaska, primarily Bebb and Scouler's willows—*Salix bebbiana* and *S. scouleriana,* respectively); (3) shrubs; (4) graminoids; and (5) forbs. Along with data describing the species composition and structural attributes of vegetation on each visited subplot, crews recorded the identity and cover of any invasive species occurring in the subplot.

[3]Author: Kathryn Baer, Pacific Northwest Research Station.

Vic Anderson

Figure 32—A Forest Inventory and Analysis crew awaits transportation from a nonforest site in the Tanana unit, Alaska.

Vegetation Structure and Dominant Vegetation Composition of Forest Lands

In black spruce forests, canopy cover of tally trees was greatest in layers 2 and 3 (15.7 ± 0.7 and 12.6 ± 0.7 mean percentage of aerial cover, respectively), in keeping with the often stunted stature of black spruce trees and relatively high cover of black spruce seedlings where they were found. The same general pattern held for tamarack forests. In contrast, the majority of tally tree coverage occurred in layer 4 in white spruce, Alaska paper birch, and balsam poplar forests, and in layers 4 and 2 in aspen forests, indicating a pattern of taller trees in these forest types.

Shrubs tended to have greater cover than other growth habits in all forest types except Alaska paper birch forests (fig. 33); the majority of shrub cover occurred in layers 1 and 2. Shrubs were generally followed in abundance by tally trees, while nontally trees tended to have little to no canopy cover in any of the forest types with the exception of balsam poplar forests. The relative cover of forbs and graminoids

Tussock cottongrass is often an indicator of hydric conditions found in black spruce bogs that are common throughout interior Alaska.

were similar to one another across most forest types, but substantially lower than that of shrub and tally tree cover. One notable exception was observed in balsam poplar forest types where forb cover (dominated by field horsetail [*Equisetum arvense*]) was much higher than graminoid cover. In contrast, graminoid cover was slightly greater than forb cover in black spruce and tamarack forest types, where tussock cottongrass (*Eriophorum vaginatum*) and bluejoint (*Calamagrostis canadensis*) were among the most commonly recorded understory vascular plants. Bluejoint is a ubiquitous species in Alaska's boreal forest, while tussock cottongrass is often an indicator of hydric conditions found in black spruce bogs that are common throughout interior Alaska.

Black spruce was the most common tree species observed in forests of the Tanana unit, followed by Alaska paper birch and white spruce. The four most common understory species were all low-stature shrubs: lingonberry (*Vaccinium vitis-idaea*), bog Labrador tea (*Ledum groenlandicum*), bog blueberry (*Vaccinium uliginosum*), and resin birch (*Betula glandulosa*) (fig. 34). Bluejoint, tall cottongrass,

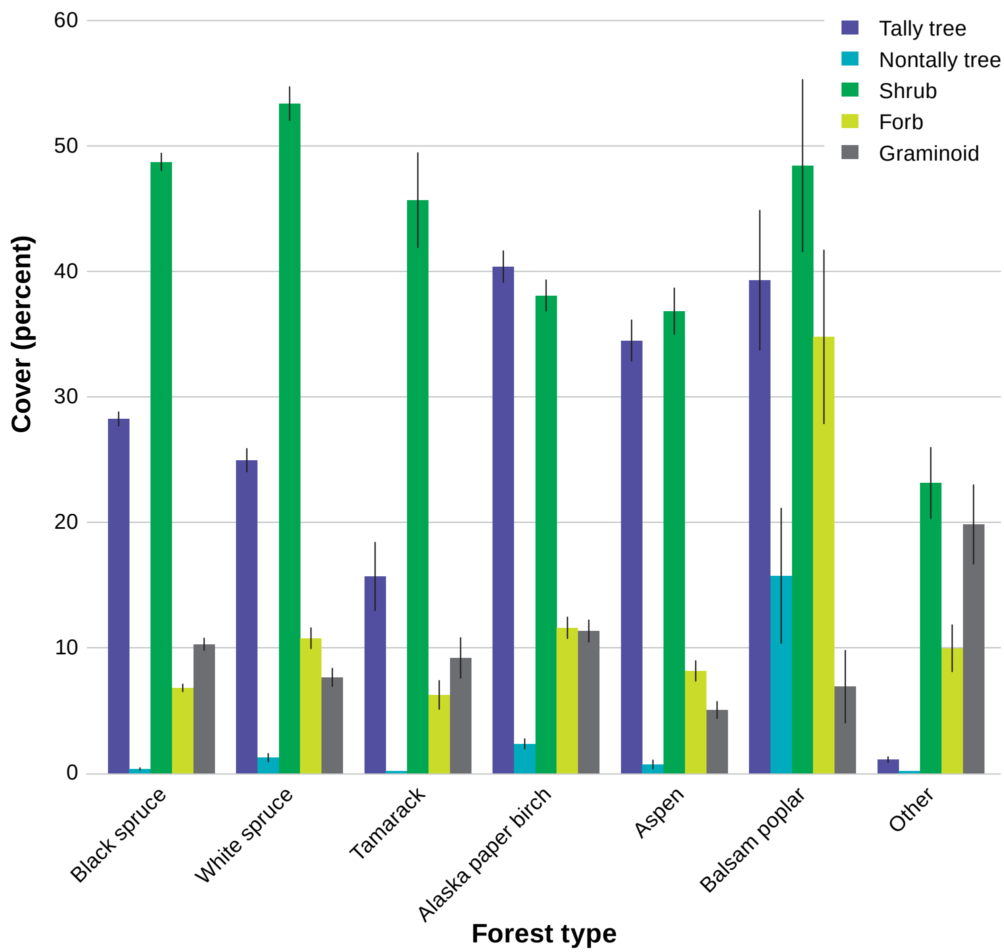


Figure 33—Mean percentage cover of tally trees, nontally trees, shrubs, forbs, and graminoids in each forest type. Error bars are ± 1 standard error.

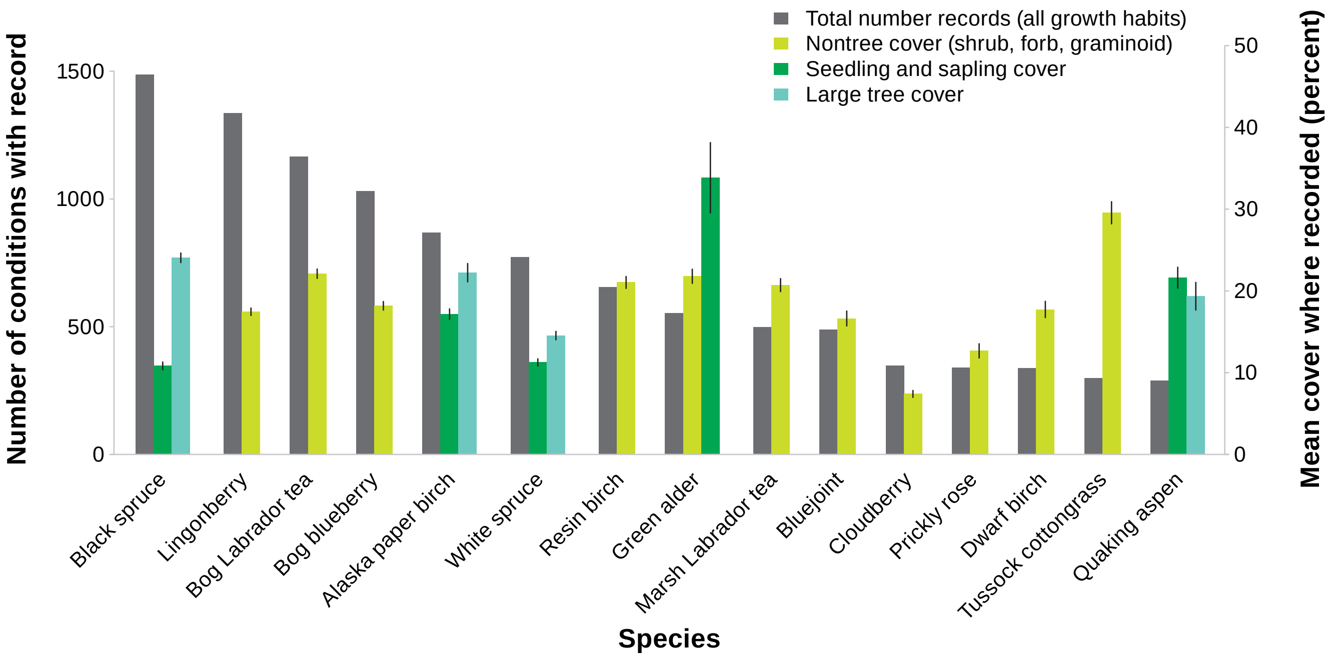


Figure 34—Total number of conditions in which the species was recorded and mean percentage of aerial cover where the species was recorded for the 15 most commonly recorded vascular species on forested plots. No error bars are presented for growth forms of a species recorded only once. Error bars are ± 1 standard error.

and Bigelow's sedge (*Carex bigelowii*) were the most commonly recorded graminoid species across all forest types. The most common forbs were cloudberry (*Rubus chamaemorus*, which was also recorded as a shrub in some forested conditions), woodland horsetail (*Equisetum sylvaticum*), bunchberry dogwood (*Cornus canadensis*), and false toadflax (*Geocaulon lividum*).

On plots where they were recorded, tussock cottongrass and green alder (*Alnus viridis*) had the highest mean cover observed among all species, although they were recorded on fewer plots than several other common species (fig. 34). Where they were recorded, large trees (>5 inches d.b.h.) tended to have greater cover than smaller diameter seedlings and saplings for most tree species, except in the case of quaking aspen.

The most dominant understory species in black spruce forests were also observed across a variety of other forest types, with the exception of balsam poplar forests. For example, lingonberry and bog Labrador tea were among the most frequently recorded species in all forest types except for balsam poplar forests. In contrast, the shrub prickly rose (*Rosa acicularis)* was common to several of the forest types found in the Tanana unit, but it was not among the dominant species in black spruce forests. Prickly rose did occur in some black spruce forests, but it was less common in these forest types than several other low-stature shrubs, such as marsh Labrador tea (*Ledum palustre* ssp. *decumbens*), cloudberry, and resin birch.

The understory vegetation community of balsam poplar forests was generally quite distinct from that of other forest types. Balsam poplar forests tend to occur on floodplains and slopes with shallow soil (Viereck et al. 1992), a tendency borne out in the FIA inventory of the Tanana unit: seven of the eight records of balsam poplar forests were located in broad floodplains. These forests tended to have far more records of riparian and disturbance-associated shrubs such as thinleaf alder and several willow species than other forest types. In addition to these disturbance-associated shrubs, balsam poplar forests were dominated by prickly rose, field horsetail, squashberry (*Viburnum edule*), and bluejoint.

The presence of multiple tree species within most forest types hints at the fact that many forests in the Tanana unit are not completely dominated by a single tree species. Stands with a mix of white spruce, Alaska paper birch, and quaking aspen are quite common in drier sites throughout the region. In addition, 57 percent of white spruce forest conditions also contained records of black spruce seedlings or saplings and 15 percent contained records of black spruce trees ≥5 inches d.b.h. Similarly, roughly 29 percent of black spruce forests also contained white spruce seedlings or saplings and 21 percent contained large white spruce trees. Data from the Tanana unit also suggested that co-occurrence of black spruce and Alaska paper birch was common; this may occur under drier conditions that can support both species.

Vegetation Structure and Dominant Vegetation Composition on Nonforest Lands

As the primary mission of FIA is to inventory forested lands, nonforest plots visited by FIA crews were only those vegetated plots whose forested or nonforest status could not be determined from remote imagery data. Nonforest conditions were also surveyed where they were encountered on partially forested plots, provided that the condition was accessible. It is important to note that descriptions of vegetation on nonforest conditions described in this report are not intended to represent the vegetation composition of all nonforest conditions within the Tanana unit. For the purposes of this report, we divided nonforest conditions encountered by crews on subplots into dominance classes based upon level II and level III dominance classes described in the Alaska vegetation classification (Viereck at al. 1992: app.). These included two tree dominance classes (tally tree seedlings and saplings, and nontally tree seedlings and saplings), three shrub dominance classes (dwarf shrub, low shrub, and tall shrub), and four nonshrub dominance classes (forb herbaceous, graminoid herbaceous, bryophyte, and lichen). Low shrub and dwarf shrub were the most common dominance classes among nonforest conditions (39 and 36 percent, respectively) followed by graminoid herbaceous (9 percent), tall shrub (7 percent), nontally tree seedlings and saplings and forb herbaceous (3 percent

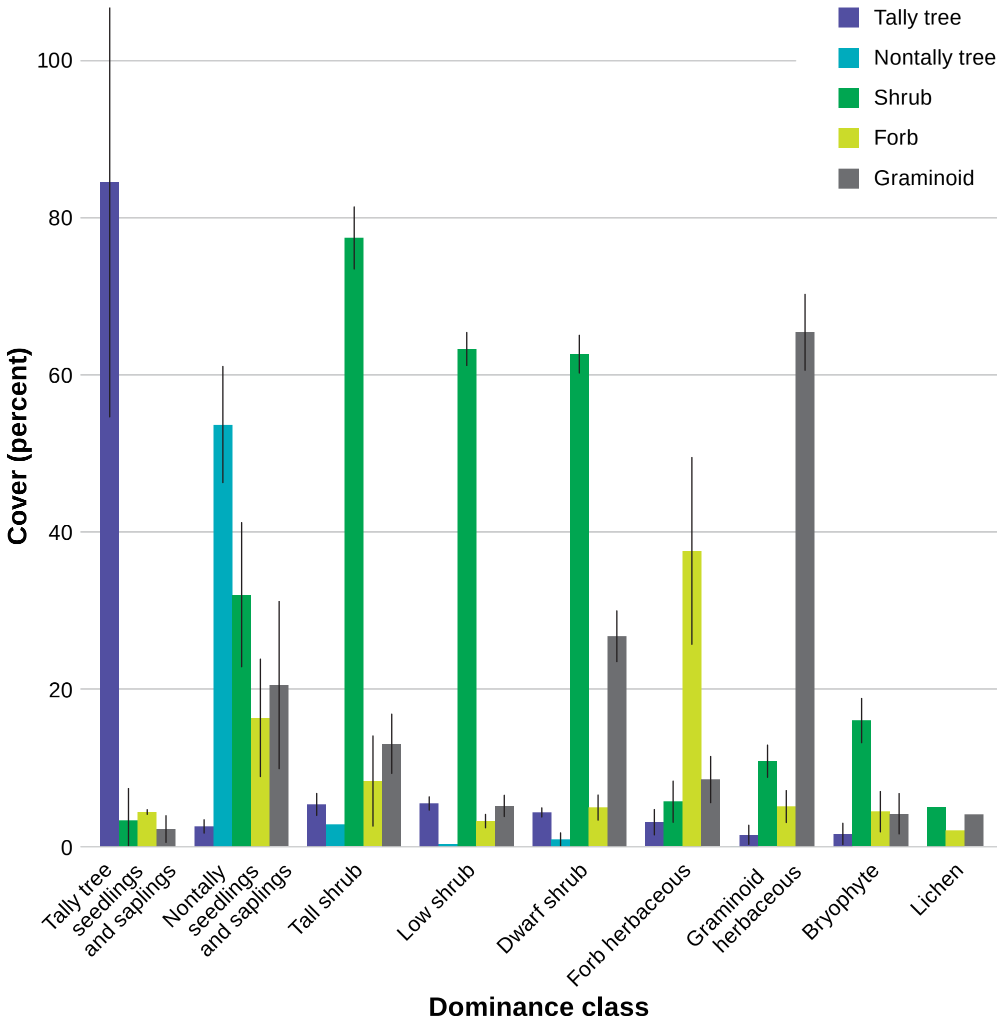


Figure 35—Mean percentage aerial cover of tally trees, nontally trees, shrubs, forbs, and graminoids on conditions assigned to each of the nonforest dominance classes on partially forested and nonforested plots. Error bars are ± 1 standard error. Note that for dominance classes containing a single subplot, no error bars are presented.

each), bryophyte (2 percent), tally tree seedlings and saplings (1 percent), and lichen dominance classes (0.5 percent).

Tally tree seedlings and saplings were overwhelmingly dominant over other growth habits in nonforest conditions assigned to the tally tree seedlings and saplings dominance class. Cover by growth habit in the nontally tree seedlings and saplings dominance class was greatest for nontally trees, but conditions assigned to this dominance class also contained relatively high cover of shrubs, forbs, and graminoids. Shrub cover was highest in all shrub dominance classes, followed by tally tree, graminoid, and forb cover (fig. 35). Vegetation cover in the graminoid herbaceous and forb herbaceous dominance classes was almost entirely composed of graminoids or forbs, respectively. The subplots dominated by lichens or bryophytes had fairly low cover of vascular plants; shrubs dominated the sparse set of vascular plants recorded in these subplots. In contrast, turf moss and nitrogen-fixing feather moss cover in conditions assigned to the bryophyte dominance class was between 10 and 99 percent; cover of nitrogen-fixing and fruticose lichens in the subplot assigned to the lichen dominance class was roughly 25 percent.

Shrubs of low to intermediate height, including resin birch, bog blueberry, and marsh Labrador tea, were the most commonly recorded species on nonforest subplots (fig. 36). Resin birch was also among the species with the greatest mean canopy cover where they were recorded, along with tussock cottongrass, green alder, Bebb willow seedlings and saplings, and bog Labrador tea. The most prevalent species across all nonforest plots were also the most common in both low and dwarf shrub dominance types, although cover was more heavily weighted toward resin birch in the low versus dwarf shrub dominance class. Plots in the tall shrub class were dominated by alder, resin birch, and willow shrubs, along with lower stature bluejoint and bog blueberry.

Tree saplings or seedlings (<5 inches d.b.h.) were recorded at least once in all of the nonforest dominance classes except the single condition assigned to the lichen dominance class. Trees (≥5 inches d.b.h.) were recorded on conditions assigned to all dominance classes except lichen and bryophyte, although cover of these trees was always less than 10 percent. This is unsurprising, as nonforest conditions were

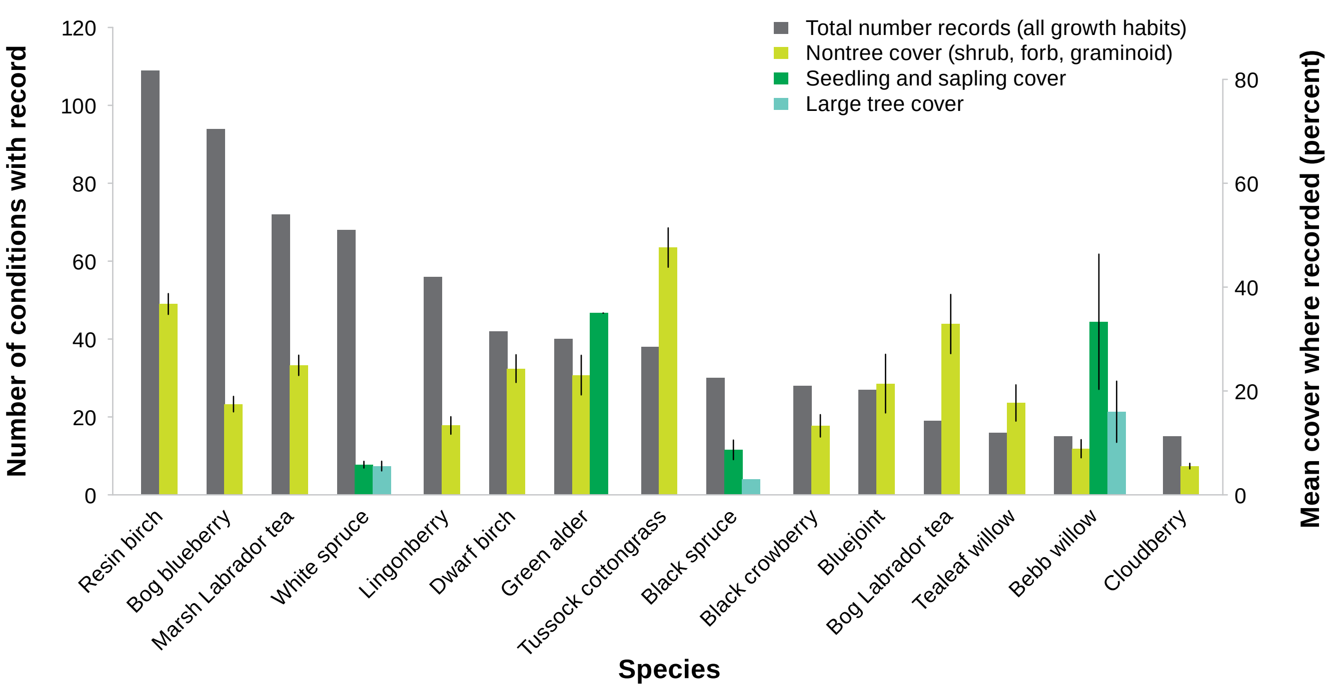


Figure 36—Total number of conditions in which the species was recorded and mean percentage of aerial cover where the species was recorded for the 21 most commonly recorded vascular species on forested plots. No error bars are presented for growth forms of a species recorded only once. Error bars are ± 1 standard error.

either encountered on partially forested plots or plots visited because their forest or nonforest status could not be determined from remote imagery. In conditions assigned to the tally tree seedlings and saplings dominance class, crews recorded seedlings or saplings of white spruce, balsam poplar, Alaska paper birch, and quaking aspen along with white spruce and balsam poplar trees, which together made up the bulk of vascular plant cover in these conditions. White spruce seedlings and Alaska paper birch trees were recorded on conditions assigned to the nontally tree dominance class, although the most commonly recorded tree species in this dominance class was Bebb willow, a nontally species. Conditions assigned to the tall shrub dominance class contained records of seedlings or saplings of Alaska paper birch, white spruce, and black spruce, and trees of Alaska paper birch and white spruce. Low shrub dominance class conditions contained Alaska paper birch, tamarack, black spruce, and white spruce seedlings and white spruce trees. Seedlings or saplings of white and black spruce, balsam poplar, Alaska paper birch, and quaking aspen were recorded on conditions assigned to the dwarf shrub dominance class, as were balsam poplar, black spruce, and white spruce trees. Conditions assigned to the forb herbaceous dominance class contained records of white spruce seedlings or saplings and trees, while those assigned to the graminoid herbaceous dominance class contained records of Alaska paper birch, black spruce, and tamarack seedlings and Alaska paper birch trees. Alaska paper birch seedlings or saplings were also observed on one of the two conditions assigned to the bryophyte dominance class.

Nonforest plots visited by FIA crews may have occurred in transitional zones between forest and nonforest conditions in which tree cover simply did not meet the 10 percent canopy cover threshold necessary for the plot to be categorized as forested. It is also possible that some of the subplots containing tree seedlings, saplings, or large trees are in the process of transitioning from nonforest to forest conditions, possibly as a result of regeneration after a disturbance that favored the early dominance of fast-growing shrubs. Shrubs often recover most quickly after a disturbance event, which may explain why tree seedlings were often recorded in conditions assigned to shrub dominance classes. The presence of trees in some shrub-dominated conditions may also be indicative of either proximity to, or advancement of, tree line. Subplots assigned to the low shrub class in particular tended to occur at relatively high elevation (mean: 2,705 ft; median: 2,803 ft), indicating that these plots may have often been observed at or near tree line and may explain the presence of white spruce, black spruce, tamarack, and Alaska paper birch seedlings and white spruce trees. Conditions assigned to the bryophyte dominance class similarly tended to occur at higher elevations (mean: 2,193 ft; median: 2,043 ft), indicating that this vegetation type may also be associated with proximity to the tree line. Two of the four conditions assigned to the bryophyte dominance class occurred near 3,000 ft elevation; Scouler's willow was common to both. Scouler's willow is a moderately tall shrub or tree (roughly 15 ft on average) that is strongly associated with fire, often occurring in recently burned areas. The presence of other disturbance-associated shrubs (green alder and Bebb willow), each of which occur on one of these conditions, hints that these subplots may have been subject to an upland wildfire or other disturbance in the past.

Citizen Science in the Tanana Unit[1]

Engaging partners is critical to the USDA Forest Service's Forest Inventory and Analysis program (FIA) mission. In 2018, the agency launched the Citizen Science Competitive Funding Program (CitSci Fund) to support collaborative citizen science efforts. Alaska FIA bases field crews in remote interior Alaska communities for months at a time, uniquely positioning the program to participate in citizen science initiatives. FIA field crews can also describe their work to community members and address feedback and stakeholder questions about the data they collect and how it will be used.

The data collection team collaborated with the University of Alaska Fairbanks chapter of the Global Learning and Observations to Benefit the Environment program (GLOBE) to cocreate local forest ecology-related citizen science projects that integrate local knowledge with FIA data. The collaborators successfully proposed their framework to CitiSci Fund, and in 2018, were awarded Forest Service Research and Development national FIA funds to implement a Culturally Responsive Approach With FIA in Interior Alaska.

In partnership with GLOBE, FIA provided support for a second-grade teacher from Tok Elementary School to attend a GLOBE citizen science teacher training workshop in 2018. The workshop focused on techniques for developing a research question based on community-determined needs and educating students about the scientific method. It also highlighted procedures for data collection, data entry, and sharing the results of their investigations. Scientists from FIA and collaborators from the University of Alaska then visited the teacher's second-grade class to facilitate student-led identification of an important scientific question for local stakeholders that could be addressed using data collected by the students with guidance from their teacher.

The forest ecology question chosen by the second-grade class focused on how climatic conditions affect the phenology of berry-producing plants in forests near Tok, Alaska, and what this might mean for subsistence berry availability under future shifts in climatic conditions. This question dovetailed with the University of Alaska Fairbanks' Winterberry citizen science initiative—to investigate how shifting seasons could affect when berries are available to animals and people—and gave students the opportunity to incorporate their data into a statewide database for answering questions about climate change effects on subsistence berry resources. Students collected data on the phenology of berry-producing plants and the quality of berries near Tok from late summer to late fall 2018 and uploaded data to a statewide central repository. Simultaneously, vegetation data collected on FIA plots in the Tanana unit of interior Alaska was queried for occurrence records of berry-producing subsistence species and paired with biotic and abiotic environmental data (dominant vegetation type, topography, and historical climate) to build species distribution models

[1] Authors: Kate Legner and Kathryn Baer, Pacific Northwest Research Station

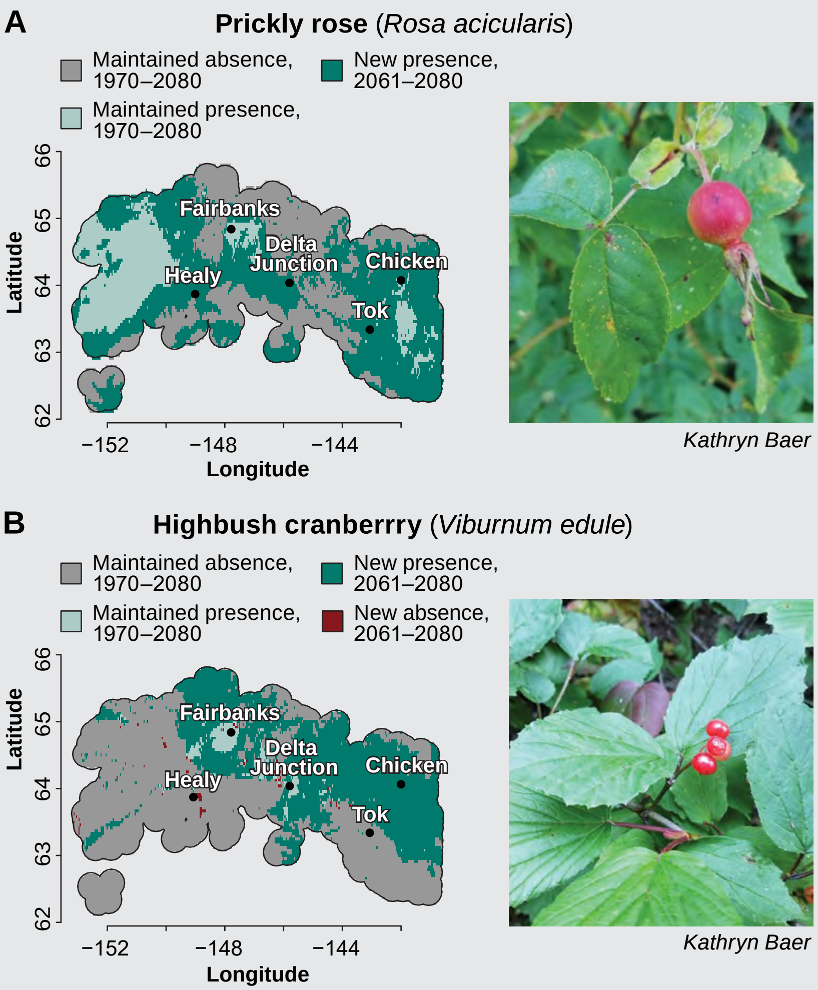


Figure 37—Predicted changes in environmental suitability by 2080 for the presence of (A) prickly rose and (B) highbush cranberry, two common berry-producing forest subsistence species in interior Alaska.

for the region under current and future climate scenarios. For common berry-producing species such as prickly rose (*Rosa acicularis*) and highbush cranberry (*Viburnum edule*) that occur primarily in deciduous or mixed deciduous-coniferous forests, the areas suitable for their presence are predicted to expand under future climate and vegetation scenarios (fig. 37) (Baer, n.d.[2]). However, this may not be the case for berry-producing species that tend to occur in coniferous forests or tundra systems, which may become scarcer under future climate conditions.

In spring 2019, FIA and University of Alaska researchers returned to Tok Elementary School for two events highlighting the citizen science program at the school. The first event was a community engagement open house where the outcome of the citizen science project, including auxiliary research supported by FIA data, was presented to students and other community members. The second event was an overview session with students from the second-grade class who were primarily involved in the citizen science program over the course of the previous school year. Students shared stories of collecting berries for subsistence use, their experiences with data collection, and their interpretation of trends for similar berry phenology data collected across a variety of climatic conditions in communities statewide. Given the information presented on berry phenology and potential shifts in berry distributions, the students were challenged to think of potential solutions to issues that might arise because of climate change, both local and global.

Interior Alaska FIA staff plan to continue collaboration with GLOBE and the University of Alaska throughout the inventory of all interior Alaska. This citizen science initiative allows FIA staff the opportunity to engage with communities in which they work and foster understanding of FIA's mission, and helps to identify ways in which analysis of the collected data may be targeted toward answering questions of particular importance to local stakeholders.

[2] Baer, K.C. [n.d.]. Predicted shifts in subsistence berry distributions under climate change in interior Alaskan forests. Manuscript in preparation. On file with: K. Baer, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 161 E. 1st Avenue, Door 8, Anchorage, AK 99501.

Ground Layer Biomass and Composition[4]

A walk across landscapes of interior Alaska often involves crossing a thick, spongy layer of moss and lichen mats. This important ground layer regulates how quickly water, air, and organic material are exchanged between soil horizons and the aboveground world. Ground layer moss mats hold water like a sponge, releasing it slowly throughout summer growing seasons. Waterlogged ground layers control how much organic material is lost to combustion when wildfires occur, making landscapes more resilient to disturbances. Because large wildfires are increasingly common throughout interior Alaska, this buffering effect is important for limiting the extent and severity of burns (Kasischke et al. 2008). In lowlands, ground layers increase the height of water tables and alter subsurface water chemistry such that lowland plant communities tend to have significantly different composition than nearby uplands. On north-facing upland slopes, ground layer moss mats serve as an insulating blanket that protects permafrost from thawing during hot summer months. As moss-dominated ground layers develop over many years, the slow accumulation of undecomposed moss material generates thick, carbon-rich peat horizons that can extend several meters deep. In recent decades, the combination of wildfires, warming, and drying has begun to challenge the capacity of ground layers to keep carbon sequestered belowground. At the critical soil-air interface occupied by ground layers, community members and natural resource workers alike would like to know the current status and future trends of important ecosystem functions.

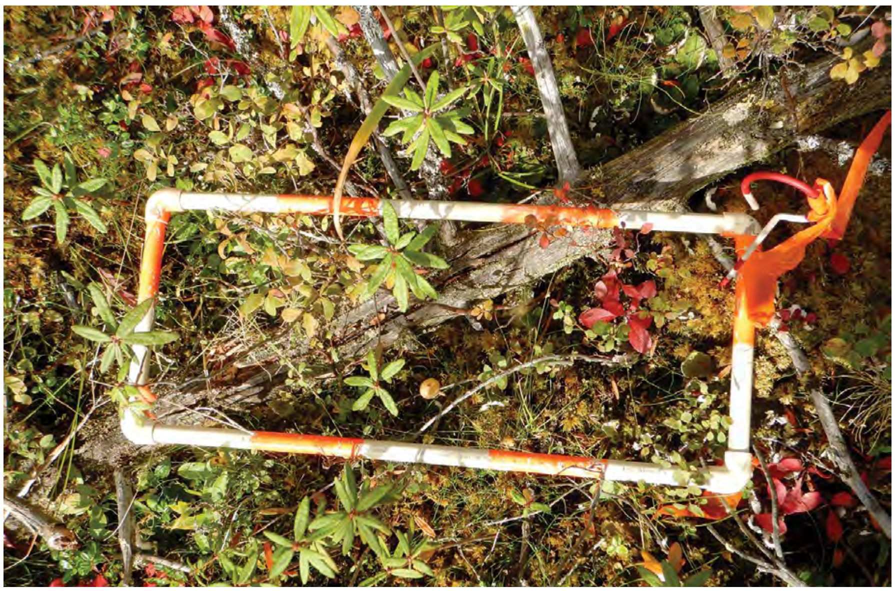

USDA Forest Service

Figure 38—A Daubenmire microquad frame used to quantify ground layer composition and biomass. On each plot, ground layers were recorded at up to 32 locations along eight transects, when feasible (8 microquads and 2 transects per subplot).

Forest Inventory and Analysis crews in interior Alaska measured multiple attributes of ground layers at each plot, including depth and cover of each functional group in the ground layer (fig. 38). Calibration equations were used to

[4]Author: Robert J. Smith, USDA Forest Service Air Resource Management Program.

translate nondestructive field measurements into estimates of cover, volume, dry biomass, total carbon content, and total nitrogen content for each functional group in the ground layer at the plot level (Smith et al. 2015). Important functional groups included peat-forming *Sphagnum* mosses, nitrogen-fixing feather mosses, nitrogen-fixing lichens, and wildlife forage lichens (among others).

Ground layer biomass was greatest in black spruce forest types (mean: 8.4 ± 0.6 tons $acre^{-1}$) and least in balsam poplar forest types (mean: 1.2 ± 0.3 tons $acre^{-1}$; table 6). Ground layer C and nitrogen content were similar in rank among forest types. Among functional groups, the highest biomass occurred in *Sphagnum* peat mosses (6.6 ± 2.0 tons $acre^{-1}$) in lowlands and nitrogen-fixing feather mosses (5.1 ± 1.1 tons $acre^{-1}$) in uplands (table 6). These high-biomass mosses (as well as nitrogen-fixing lichens) were the most frequently encountered across the study area (fig. 39). Other feather mosses and turf mosses had intermediate biomass, followed by the lichen functional groups. Most functional groups had the highest biomass in white spruce and black spruce forest types, except for *Sphagnum* peat mosses and forage lichens (whose biomass peaked in tamarack forest types), nitrogen-fixing foliose lichens (whose biomass peaked in Alaska paper birch forest types), and flat thalloid liverworts (whose biomass peaked in hardwood types).

Despite their small stature, ground layer species have disproportionately large effects on the ecosystem functioning of forest, wetland, and tundra systems in interior Alaska (table 7). In particular, moss mats and lichen carpets store large amounts of carbon and nitrogen that are important for the overall functioning of forested and nonforested lands. The growth and maintenance of moss mats contribute immensely to global carbon sequestration and soil cooling, both of which moderate the release of greenhouse gases. On the other hand, feather mosses can serve as an important fuel source for wildfires in the region by both providing fuel during the fire season and allowing smoldering fires to overwinter and re-emerge in the subsequent season, which may lead to some losses of sequestered carbon in interior Alaska forests. Providing biologically available nitrogen is an important function of nitrogen-fixing lichens, which may be considered as "forest fertilizer" that contributes to tree growth in areas of the Tanana unit where nutrients are otherwise limited. In addition, forage lichens are tightly linked to the welfare of wildlife such as caribou that depend on these species for winter forage. Together, terrestrial mosses and ground layer lichens provide a wealth of ecosystem services in vegetated landscapes of interior Alaska.

Forage lichens are tightly linked to the welfare of wildlife such as caribou that depend on these species for winter forage. Together, terrestrial mosses and ground layer lichens provide a wealth of ecosystem services in vegetated landscapes of interior Alaska.

Table 6—Estimates of ground layer biomass measurements by forest type and functional group for forested lands in the Tanana unit, Alaska, 2014–2018

	Functional group[a]												
Forest type	Crusts, biotic soil crusts	Orange crustose lichens	Forage lichens	Other foliose lichens	Nitrogen-fixing foliose lichens	Nitrogen-fixing fruticose lichens	Other fruticose lichens	Feather (branched) mosses	Nitrogen-fixing feather mosses	Sphagnum peat moss	Turf (upright) mosses	Flat (thalloid) liverworts	Stem-and-leaf liverworts	Total biomass (SE)
								Tons acre^{-1}						
White spruce	0.02	0.02	0.49	0.04	0.17	0.16	0.19	1.30	5.64	5.60	0.96	0.10	0.30	5.90 (0.53)
Black spruce	0.05	0.01	1.04	0.18	0.17	0.23	0.20	1.52	6.23	6.91	1.14	0.10	0.27	8.36 (0.61)
Tamarack	0.00	0.00	3.13	0.00	0.04	0.21	1.07	0.99	2.04	10.73	0.97	0.00	0.31	6.64 (0.78)
Aspen	0.02	0.01	0.23	0.03	0.13	0.09	0.23	0.26	1.97	6.26	1.17	0.34	0.07	1.94 (0.26)
Alaska birch	0.04	0.02	0.28	0.09	0.22	0.13	0.13	0.55	2.77	5.13	1.08	0.42	0.13	2.99 (0.43)
Balsam poplar	0.00	0.00	0.28	0.04	0.09	0.05	0.00	0.27	2.87	0.47	0.19	0.10	0.12	1.15 (0.27)
Nonstocked	0.00	0.00	0.18	0.00	0.15	0.02	0.00	0.31	2.85	5.84	0.46	0.16	0.01	1.86 (0.45)
Total (SE)	0.04 (0.01)	0.02 (0.01)	0.81 (0.30)	0.12 (0.05)	0.17 (0.08)	0.19 (0.08)	0.20 (0.10)	1.17 (0.52)	5.11 (1.05)	6.57 (2.0)	1.07 (0.36)	0.28 (0.09)	0.28 (0.16)	6.28 (0.18)

SE = standard error.

[a] See table 7 for a description of functional groups.

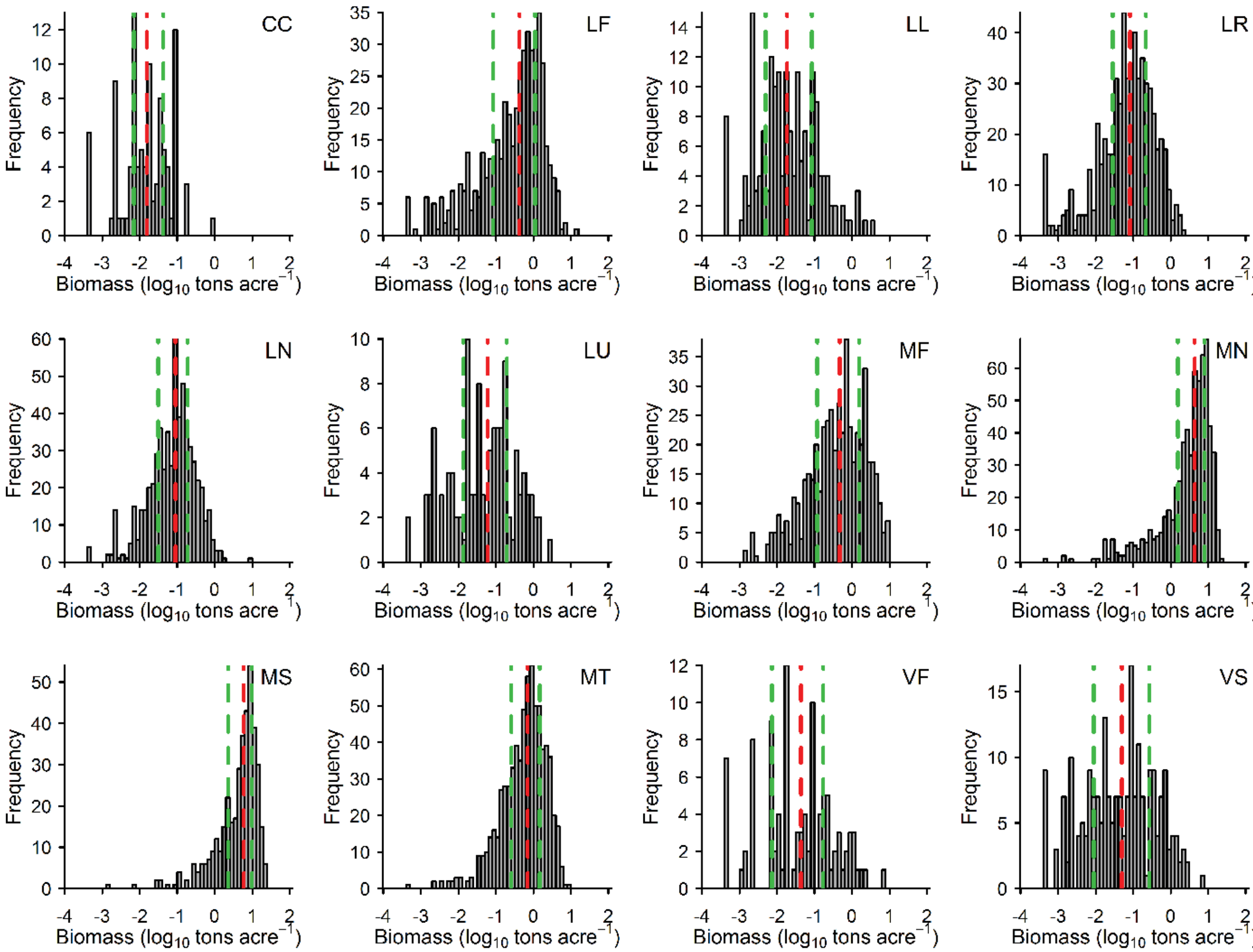


Figure 39—Frequency distributions of biomass for 12 ground layer functional groups in the Tanana unit. Red lines = median value, green lines = 25th and 75th percentiles. Functional group codes: CC = crusts, biotic soil crusts; LF = forage lichens; LL = other foliose lichens; LR = nitrogen-fixing fruticose lichens; LN = nitrogen-fixing foliose lichens; LU = other fruticose lichens; MF = feather mosses; MN = nitrogen-fixing feather mosses; MS = *Sphagnum* peat moss; MT = turf mosses; VF = flat liverworts; VS = stem-and-leaf liverworts. Functional group codes follow the 2018 Forest Inventory and Analysis interior Alaska supplement to the Anchorage Forestry Sciences Laboratory field manual.

Table 7—Description of functional groups and ecosystem function for nonvascular plants surveyed in ground layer cover and biomass measurements

Type	Functional group code[a]	Name	Ecosystem functions
Moss	MS	Sphagnum peat moss	Carbon storage (peat), water regulation, soil cooling
	MN	Nitrogen-fixing feather mosses	Nitrogen-fixation, soil cooling
	MF	Feather (branched) mosses	Rain catching, soil cooling
	MT	Turf (upright) mosses	Soil accrual, bare site colonization
Liverwort	VF	Flat (thalloid) liverworts	Soil and detritus binding
	VS	Stem-and-leaf liverworts	Water infiltration
Macro-lichen	LF	Forage lichens	Wildlife forage
	LN	Nitrogen-fixing foliose lichens	Nitrogen fixation
	LR	Nitrogen-fixing fruticose lichens	Nitrogen fixation
	LL	Other foliose lichens	Invertebrate habitat, nesting materials
	LU	Other fruticose lichens	Bare site colonization, invertebrate habitat
Micro-lichen	CO	Orange crustose lichens	Indicate nutrient over-enrichment
	CC	Crusts, biotic soil crusts	Soil trapping, water influx, disturbance indicator

[a] Functional group codes follow the 2018 Forest Inventory and Analysis interior Alaska supplement to the Anchorage Forestry Sciences Laboratory field manual.

Invasive Plants[5]

Plant invasions can threaten sustainable forestry (Chornesky et al. 2005), alter disturbance regimes (D'Antonio and Vitousek 1992, Pysek et al. 2012), reshape ecosystem processes (D'Antonio and Hobbie 2005, Ehrenfeld 2003, Mack et al. 2000), transform community composition in recipient ecosystems (Mack and D'Antonio 1998), and result in substantial economic costs (Holmes et al. 2009; Pimentel et al. 2000, 2005). Monitoring the location and abundance of invasive species in interior Alaska forests aids in determining which species are capable of invading forested ecosystems, the potential routes of invasion, and the status of nascent invasions. FIA crews recorded the identity and cover of any invasive plant species found on surveyed plots in the Tanana unit; see table A.3 for a list of invasive plant species for which crews were instructed to search each plot.

Six invasive species were observed on 10 subplots across 4 plots in the Tanana unit, indicating that roughly 0.5 percent of surveyed plots contained some evidence of plant invasion. The most common invasive species (each recorded on three subplots across two plots) were bird vetch (*Viccia cracca* ssp. *cracca*) and disc mayweed (*Matricaria discoidea*), although cover of each species was a maximum of 1 percent in all instances. Common dandelion (*Taraxicum officinale*; observed on

[5] Author: Kathryn Baer, Pacific Northwest Research Station.

An Alaska Native Perspective on Collaborating with Forest Inventory and Analysis[1]

Tanana Chiefs Conference (TCC) is a nonprofit tribal service organization based in Fairbanks that serves 42 tribes in interior Alaska. TCC's forestry program provides forest management services to Alaska Native allotments in the region that comprise more than 2,500 parcels of land covering about 250,000 ac. These forest management services include maintaining forest inventory information for allotted land. In an effort to update Native allotment forest inventory data, TCC decided to establish permanent forest inventory plots on allotments to be remeasured periodically on a 10-year cycle—to augment stand-based data that TCC already had on file and to address increased interest in climate change issues and the dynamics of forest growth and mortality in the boreal forest. Funding for this effort was provided by the USDI Bureau of Indian Affairs.

At the time TCC decided to install permanent forest inventory plots, the USDA Forest Service's Forest Inventory and Analysis (FIA) program began establishing FIA plots in interior Alaska, starting with the 2014 Tanana pilot project. In an attempt to explore the possibility of collaborating with FIA on its inventory efforts, TCC was put in touch with FIA's National Inventory and Monitoring Applications Center (NIMAC), which assisted TCC with various inventory design concepts. The result of that consultation was a decision by TCC to adopt FIA's interior Alaska protocols for its own Native allotment inventory project. As a result, TCC received technical assistance and training from the Forest Service and its Alaska state partners, and the FIA program is able to access TCC data as potential auxiliary plots.

TCC has installed 140 plots, with a regionwide goal of 180 plots. Despite the relatively low number of plots, the intensity of the TCC effort is much higher on Alaska Native allotments than across all ownerships on the FIA grid overall, with about 1 Native plot installed per 1,300 ac, compared with the current intensity of 1 plot per 30,000 ac across all of interior Alaska's FIA program. The TCC plots are labor intensive, accessed via boat or ground (not helicopter), with travel logistics playing a major role. All data are stored and managed in TCC's geodatabase system and shared with the FIA program. The TCC and Forest Service collaboration has been very productive. We look forward to maintaining this relationship into the future.

[1]Author: Will Putman, Tanana Chiefs Conference, Fairbanks, Alaska.

one subplot within one plot) and narrowleaf hawksbeard (*Crepis tectorum*; observed on four subplots within one plot) had the greatest canopy cover where they were recorded (up to 3 percent). Common plantain (*Plantago major*) and clover (*Trifolium sp.*) were also recorded; both occurrences were on the same plot and cover of each was a maximum of 1 percent.

Of the four plots on which invasive species were observed, two were within 100 ft of an improved road, one was 1,000 ft to 0.5 mile from the nearest road, and one was 3 to 5 miles from the nearest road. However, note that distance to the nearest road does not include unimproved trails or game trails, which are another potential route of spread for invasive plants. All of the invasive species recorded within 100 ft of the nearest road (clover, common plantain, disc mayweed, and bird vetch) are generally associated with disturbance. Bird vetch was also found on a plot that was more than 1,000 ft from the nearest road. In this instance, a natural dispersal corridor (the Tanana River) or an animal vector may have transported seeds from an existing infestation.

Of greater concern are records of narrowleaf hawksbeard on a plot 3 to 5 miles from the nearest road, supporting previous findings that this species is capable of independently establishing invasions over a wide area via wind or animal dispersal (Najda et al. 1982). Narrowleaf hawksbeard is a known contaminant of alfalfa seed, straw, and ornamental plants in Alaska (Conn et al. 2008, 2010; Nadja et al. 1982). This observation highlights the potential importance of controlling agricultural invasive plants to prevent their spread into forested systems that are both nearby and farther afield.

Timber Products[6]

In addition to conducting forest inventory, the FIA program also reports on statistics tied to the status of the forest products industry for each state. This allows FIA to connect basic information from the forest inventory to local economies that use forest products. The FIA's Timber Products Output program completes surveys of primary wood-using mills in each state to assemble statistics about the local forest products industry. The last survey of Alaska's primary forest producers was based on operating year 2015 and was completed by the University of Montana's Bureau of Business and Economic Research through a joint venture agreement with the FIA program at the USDA Forest Service Pacific Northwest Research Station. Results of the survey are reported by Marcille et al. (2021) and include statistics, such as the volume of Alaska's timber harvest in 2015 by product, ownership, species, and resource area. Also included are statistics describing the

[6]Authors: Glenn Christensen, Pacific Northwest Research Station and Kate Marcille, University of Montana.

flow of timber within the state, across state lines, and exports. The industry's different sectors, capacity, and outputs are included, in addition to statistics on sales, employment, and contribution to the state's economy. This section provides a summary of findings specific to interior Alaska. Timber harvest data are based on operating years and therefore differ from the summary estimates provided by FIA representing an average from a statistical sample of inventory plots. Reported statistics are relevant to the interior region of Alaska, including the Fairbanks North Star Borough, Denali Borough, Yukon-Koyukuk Census Area, and Southeast Fairbanks Census Area.

In 2015, the total volume of timber harvested in the state was 136,371 thousand board feet (MBF) Scribner. Of this volume, 5.8 percent (7,910 MBF Scribner) was estimated to have originated from interior Alaska. In the same 2015 survey, primary processing mills received a statewide timber volume of 31,280 MBF Scribner, 25 percent of which went to interior Alaska mills for processing. A majority of the fuelwood volume (84 percent) received by all Alaska facilities in 2015 went to facilities in the interior of the state. In addition, 39 percent of the house log volume and 11 percent of the sawlog volume were processed by interior Alaska milling facilities. White spruce is the predominant tree species for these products, demonstrating the important role this species plays in the forest products industry of interior Alaska.

Eighty-four percent of the fuelwood volume was received by facilities in interior Alaska.

Statewide, in 2015 Alaska produced 14,969 bone-dry units (BDU) of fuelwood byproducts (firewood, wood pellets, and wood chips). Of this total, 83 percent (12,424 BDU) was produced in interior Alaska. Other products manufactured by interior Alaska facilities in 2015 included 4,752 MBF lumber tally of sawn lumber products, representing 15 percent of the state total lumber production. Additionally, house log manufacturers produced 113 thousand linear feet, representing 35 percent of the state total house log production. Compared to the total lumber production (4,752 MBF lumber tally) from interior Alaska, the area has a lumber production capacity of more than 19,000 MBF lumber tally. From 2011 to 2015, interior Alaska saw a 77 percent drop in house log production capacity. Statewide, there was a 52 percent reduction in the log home sector during the same period. In 2015, house log production capacity in interior Alaska was 200 MBF lumber tally.

The majority of Alaska's forest products industry is located within the heavily forested and more productive coastal region of southeast Alaska. However, despite the economic and logistical challenges highlighted by FIA's survey results, the forest products industry and nontimber forest products fill a unique and important role within the local economy of interior Alaska by supporting the subsistence livelihood of many residents (fig. 40). The FIA program will continue to collect the information needed to assess both the region and the state's forest products industry.

Kate Marcille

Figure 40—Mill operations in interior Alaska are generally small compared with southeast Alaska, but serve an important role for many rural residents in the region. This mill near Tok, Alaska, operated for decades until 2016 when commercial operations ceased.

Conclusions

Interior Alaska is a major component of the nation's forest system that has long been absent from FIA's comprehensive assessments. This report provides a detailed summary of data collected across the first of six inventory units in the vast boreal forest of interior Alaska. The majority of lands in the Tanana unit are managed by the state of Alaska, followed by private landowners, including Alaska Native corporations. The most common forest type in the unit was black spruce—one of the most widespread and iconic species in the circumpolar boreal forest—followed by Alaska paper birch and white spruce. Among the four most common forest types (aspen, Alaska paper birch, black spruce, and white spruce), aboveground biomass was most dense in white spruce and Alaska paper birch, followed by aspen and black spruce. Although timber volume and production were minimal compared with southeast Alaska, fuelwood was the most common product processed by interior Alaska mills, indicating the important role the forest products industry plays in supporting subsistence livelihoods throughout the region. Unique to this inventory was the comprehensive assessment of carbon pools among forest types,

Chris Ferguson

Figure 41—Fireweed (*Chamerion angustifolium*) colors the hillside above a broad floodplain occupied by a mixed conifer and deciduous forest with the Alaska Range in the background—a typical scene in the Tanana Valley.

landowners, and ecosystem components, including substantial belowground carbon storage, which is a defining characteristic of northern soils. Although low in stature and productivity, the upper soil layers (including mineral soil) in black spruce forests contain more than half the unit's total carbon pool. Among all forest types, the belowground carbon pool was estimated to contribute 76 to 90 percent of total ecosystem carbon and was larger than the aboveground live tree carbon pool in coastal Alaska. Completing and summarizing data from the Tanana unit represents a major milestone for the national FIA program. The innovative fusion of inventory and remote sensing data summarized here provide novel insights into the structure and function of a region with local, regional, and global importance. FIA will continue to inventory the broad and remote regions of interior Alaska to help land managers, industry leaders, academic scientists, and the general public to further understand the forest resources and ecosystem services provided by this unique area (fig. 41).

Common and Scientific Plant Names

The following is a list of species most commonly encountered by Forest Inventory and Analysis field crews in the Tanana unit.

Life form	Common name	Scientific name
Trees:	Alaska paper birch, resin birch[a]	*Betula neoalaskana* Sarg.
	Aspen, quaking aspen	*Populus tremuloides* Michx.
	Balsam poplar	*Populus balsamifera* L.
	Bebb willow[b]	*Salix bebbiana* Sarg.
	Black spruce	*Picea mariana* (Mill.) Britton, Sterns & Poggenb.
	Scouler's willow[b]	*Salix scouleriana* Barratt ex Hook.
	Tamarack (larch)	*Larix laricina* (Du Roi) K. Koch
	White spruce	*Picea glauca* (Moench) Voss
Shrubs:	Bebb willow	*Salix bebbiana* Sarg.
	Black crowberry	*Empetrum nigrum* L.
	Bog blueberry	*Vaccinium uliginosum* L.
	Bog Labrador tea	*Ledum groenlandicum* Oeder
	Dwarf birch	*Betula nana* L.
	Grayleaf willow	*Salix glauca* L.
	Lingonberry	*Vaccinium vitis-idaea* L.
	Marsh Labrador tea	*Ledum palustre* ssp. *decumbens* (Aiton) Hultén
	Mountain alder	*Alnus viridis* (Chaix) DC. ssp. *crispa* (Aiton) Turrill
	Prickly rose	*Rosa acicularis* Lindl.
	Resin birch	*Betula glandulosa* Michx.
	Siberian alder	*Alnus viridis* (Chaix) DC. ssp. *fruticosa* (Rupr.) Nyman
	Tealeaf willow	*Salix pulchra* Cham.
	Thinleaf alder	*Alnus incana* (L.) Moench ssp. *tenuifolia* (L.) Moench
Forbs:	Arctic sweet coltsfoot	*Petasites frigidus* (L.) Fr.
	Bunchberry dogwood	*Cornus canadensis* L.
	Dwarf scouringrush	*Equisetum scirpoides* Michx.
	Cloudberry	*Rubus chamaemorus* L.
	False toadflax	*Geocaulon lividum* (Richardson) Fernald
	Field horsetail	*Equisetum arvense* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Purple marshlocks	*Comarum palustre* L.
	Twinflower	*Linnaea borealis* L.
	Tall bluebells	*Mertensia paniculata* (Aiton) G. Don
	Woodland horsetail	*Equisetum sylvaticum* L.

Life form	Common name	Scientific name
Graminoids:	Bigelow's sedge	*Carex bigelowii* Torr. ex Schwein.
	Bluejoint	*Calamagrostis canadensis* (Michx.) P. Beauv.
	Downy ryegrass	*Leymus innovatus* (Beal) Pigl.
	Lapland reedgrass	*Calamagrostis lapponica* (Wahlenb.) Hartm.
	Northern reedgrass	*Calamagrostis stricta* (Timm) Koeler ssp. *inexpansa* (A. Gray) C.W. Greene
	Northern singlespike sedge	*Carex scirpoidea* (Michx.)
	Northland cottonsedge	*Eriophorum brachyantherum* (Trautv. & C.A. Mey.)
	Smallawned sedge	*Carex microchaeta* (C.A. May)
	Tall cottongrass	*Eriophorum angustifolium* Honck.
	Tussock cottongrass	*Eriophorum vaginatum* L.
	Water sedge	*Carex aquatilis* Wahlenb.
	Wideleaf polargrass	*Arctagrostis latifolia* (R. Br.) Griseb.

[a] Common name from USDA Plants. Resin birch is more often used to refer to *B. glandulosa*.

[b] Although not considered a tree by Forest Inventory and Analysis definitions for tally and estimation purposes, the species is included in vegetation summaries.

Tables—Online Supplement

A set of summary data tables accompanies this report as an online supplemental document. The online document is available for download at https://www.fs.fed.us/pnw/pubs/pnw_gtr1005-supplement.pdf. The 91 data tables are listed below for reference.

Forest Area

Table 1—Area of sampled land and water by land status and ownership group

Table 2—Area of forest land by forest type, ownership group, and land status

Table 3—Area of forest land by forest type and stand age class

Table 4—Area of forest land by ownership and land status

Table 5—Area of forest land by forest type and land status

Table 6—Area of forest land by forest type and site productivity class

Table 7—Area of forest land by forest type and stand size class

Table 8—Area of forest land by forest type and ecosection

Table 9—Area of timberland by forest type and stand size class

Number of Trees

Table 10—Number of live trees on forest land by species and diameter class

Table 11—Number of dead trees on forest land by species and diameter class

Table 12—Number of growing stock trees on timberland by species and diameter class

Table 13—Number of live trees on forest land by forest type and ownership group

Table 14—Number of dead trees on forest land by forest type and ownership group

Volume

Aboveground Biomass

Carbon

Down Woody Material

Soil Carbon

Nonforest and Understory Vegetation

Ground Layer

Disturbance

Acknowledgments

The authors would like to thank the tireless efforts of the field crews for collecting high quality data in challenging conditions. In particular, Brendt Mueller played a vital role as the Alaska statewide data collection team leader. The State of Alaska Division of Forestry continues to be an exceptional partner, providing personnel, logistical support, and an outstanding commitment to safety. The USDA Forest Service Forest Inventory and Analysis (FIA) program partnership with the National Aeronautics and Space Administration has delivered novel scientific insights linking ground-based forest inventory with cutting-edge remote and airborne sensing tools at unprecedented scales. We also greatly value the collaboration with other federal and state agencies, local governments and communities, and Alaska Native entities that have made much of FIA's work possible in these remote regions. We thank the Forest Service Pacific Northwest FIA information management team for providing field-operational data collection tools and compiling those data into a high-quality dataset. We are grateful for the soil core analyses provided by the Forest Soils Lab at the University of Alaska Fairbanks and tree core analyses performed at the Environment and Natural Resources Institute, University of Alaska Anchorage. Finally, we sincerely thank the reviewers who provided valuable comments that substantially improved the quality of this report.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.3048	Meters
Miles (mi)	1.609	Kilometers
Acres (ac)	0.405	Hectares
Board feet	0.0024	Cubic meters
Square feet (ft^2)	0.0929	Square meters
Square feet per acre (ft^2/acre)	0.229	Square meters per hectare
Cubic feet (ft^3)	0.0283	Cubic meters
Cubic feet per acre (ft^3/acre)	0.06997	Cubic meters per hectare
Tons per acre	2.242	Megagrams per hectare

U.S. Standard Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	1.61	Miles
Hectares (ha)	2.47	Acre
Kilograms (kg)	2.2046	Pounds
Megagrams (Mg)	1.1023	Tons
Petagrams (Pg)	1.102×10^9	Tons
Megagrams per hectare (Mg/ha)	0.4461	Tons per acre

Literature Cited

Alaska Climate Research Center. 2021. https://akclimate.org. (8 April 2021).

Alemdag, I.S. 1984. Total tree and merchantable stem biomass equations for Ontario hardwoods. Inf. Report PI-X-46. Chalk River, ON: Natural Resources Canada, Canadian Forest Service, Petawawa National Forestry Institute. 54 p.

Andersen, H.-E.; Strunk, J.; Temesgen, H. 2011. Using airborne light detection and ranging as a sampling tool for estimating forest biomass resources in the upper Tanana Valley of interior Alaska. Western Journal of Applied Forestry. 26(4): 157–164. https://doi.org/10.1093/wjaf/26.4.157.

Andersen, H.-E.; Pattison, R.; Gray, A. [et al.]. 2017. Forest resources of interior Alaska and U.S.-affiliated jurisdictions of the insular Caribbean and Pacific. In: Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A., coords. Forest resources of the United States, 2017: a technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97. Washington, DC: U.S. Department of Agriculture, Forest Service: 21–23.

Azuma, D.L.; Dunham, P.A.; Hiserote, B.A.; Veneklase, C.F. 2004. Timber resources statistics for eastern Oregon, 1999. Resour. Bull. PNW-RB-238. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p. https://doi.org/10.2737/PNW-RB-238.

Balshi, M.S.; McGuire, A.D.; Duffy, P. [et al.]. 2009. Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. Global Change Biology. 15(3): 578–600. https://doi.org/10.1111/j.1365-2486.2008.01679.x.

Bechtold, W.A.; Patterson, P.L. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS 80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Beck, P.S.A.; Juday, G.P.; Alix, C. [et al.]. 2011. Changes in forest productivity across Alaska consistent with biome shift. Ecology Letters. 14(4): 373–379. https://doi.org/10.1111/j.1461-0248.2011.01598.x.

Bonan, G.B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science. 320(5882): 1444–1449. https://doi.org/10.1126/science.1155121.

Burrill, E.A.; DiTommaso, A.M.; Turner, J.A.; Pugh, S.A.; Christensen, G.; Perry, C.J.; Conkling, B.L. 2021. FIA database description and user guide for phase 2 (version 9.0.1). https://www.fia.fs.fed.us/library/database-documentation/current/ver90/FIADB User Guide P2_9-0-1_final.pdf. (9 February 2022).

Cahoon, S.M.P.; Kuegler, O.; Christensen, G.A., tech. eds. 2020. Coastal Alaska's forest resources, 2004–2013: ten-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-979. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p. https://doi.org/10.2737/PNW-GTR-979.

Cahoon, S.M.P.; Sullivan, P.F.; Brownlee, A.H. [et al.]. 2018. Contrasting drivers and trends of coniferous and deciduous tree growth in interior Alaska. Ecology. 99(6): 1284–1295. https://doi.org/10.1002/ecy.2223.

Carlson, M.L.; Lapina, I.V.; Shephard, M. [et al.]. 2008. Invasiveness ranking system for non-native plants of Alaska. R10-TP-143. Anchorage, AK: U.S. Department of Agriculture, Forest Service, Alaska Region. 218 p.

Chapin, F.S., III; Matson, P.A.; Mooney, H.A. 2002. Principles of terrestrial ecosystem ecology. New York: Springer. 436 p. Chapter 6. https://doi.org/10.1007/b97397.

Chornesky, E.A.; Bartuska, A.M.; Aplet, G.H. [et al.]. 2005. Science priorities for reducing the threat of invasive species to sustainable forestry. BioScience. 55(4): 335–348. https://doi.org/10.1641/0006-3568(2005)055[0335:SPFRTT]2.0.CO;2.

Cook, B.; Corp, L.; Nelson, R. [et al.]. 2013. NASA Goddard's LiDAR, hyperspectral and thermal (G-LiHT) airborne imager. Remote Sensing. 5(8):4045–4066. https://doi.org/10.3390/rs5084045.

Conn, J.; Stockdale, C.; Morgan. J. 2008. Characterizing pathways of invasive plant spread to Alaska: I. Propagules from container-grown ornamentals. Invasive Plant Science and Management. 1(4): 331–336. https://doi.org/10.1614/IPSM-08-063.1.

Conn, J.; C. Stockdale, C.; Werdin-Pfisterer, N. [et al.]. 2010. Characterizing pathways of invasive plant spread to Alaska: II. Propagules from imported hay and straw. Invasive Plant Science and Management. 3(3): 276–285. https://doi.org/10.1614/IPSM-D-09-00041.1.

D’Antonio, C.M.; Hobbie, S.E. 2005. Plant species effects on ecosystem processes—insights from invasive species. In: Sax, D.F.; Stachowicz, J.J.; Gaines, S.D., eds. Species invasions: insights into ecology, evolution, and biogeography. Sunderland, MA: Sinauer Associates: 65–84. https://doi.org/10.1146/annurev.es.23.110192.000431.

D’Antonio, C.M.; Vitousek, P.M. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics. 23: 63–87. https://doi.org/10.1146/annurev.es.23.110192.000431.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. Northwest Scientist. 33: 43–64.

Ehrenfeld, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 6(6): 503–523. https://doi.org/10.1007/s10021-002-0151-3.

Fahey, T.; Siccama, T.; Driscoll, C. [et al.]. 2005. The biogeochemistry of carbon at Hubbard Brook. Biogeochemistry. 75: 109–176. https://doi.org/10.1007/s10533-004-6321-y.

Flanagan, P.W.; van Cleve, K. 1983. Nutrient cycling in relation to decomposition and organic-matter quality in taiga ecosystems. Canadian Journal of Forest Research. 13(5): 795–817. https://doi.org/10.1139/x83-110.

Genet, G.; He, Y.; Lyu, Z. [et al.]. 2018. The role of driving factors in historical and projected carbon dynamics of upland ecosystems in Alaska. Ecological Applications. 28(1): 5–27. https://doi.org/10.1002/eap.1641.

Gregory, R.A.; Haack, P.M. 1964. Equations and tables for estimating cubic-foot volume of interior Alaska tree species. Res. Note NOR-6. Juneau, AK: U.S. Department of Agriculture, Forest Service, Northern Forest Experiment Station. 21 p. https://doi.org/10.5962/bhl.title.84514.

Haack, P.M. 1963. Volume tables for trees of interior Alaska. Res. Note NOR-5. Juneau, AK: U.S. Department of Agriculture, Forest Service, Northern Forest Experiment Station. 11 p. https://doi.org/10.5962/bhl.title.84513.

Hansen, W.D.; Fitzsimmons, R.; Olnes, J. [et al.]. 2021. An alternative vegetation type proves resilient and persists for decades following forest conversion in the North American boreal biome. Journal of Ecology. 109(1): 85–98. https://doi.org/10.1111/1365-2745.13446.

Hanson, D. 2013. Timber inventory of state forest lands in the Tanana Valley 2013. Anchorage, AK: Alaska Department of Natural Resources, Division of Forestry. 42 p. [plus appendices]. http://forestry.alaska.gov/timber/forestinventories. (26 September 2018).

Harden, J.W.; Koven, C.D.; Ping, C.-L. [et al.]. 2012. Field information links permafrost carbon to physical vulnerabilities of thawing. Geophysical Research Letters. 39(15). 6 p. https://doi.org/10.1029/2012GL051958.

Harmon, M.E.; Fasth, B.G.; Yatskov, M. [et al.]. 2020. Release of coarse woody detritus-related carbon: a synthesis across forest biomes. Carbon Balance and Management. 15(1). 21 p. https://doi.org/10.1186/s13021-019-0136-6.

Hegg, K.M. 1974. Forest statistics for the upper Koyukuk River, Alaska, 1971. Resour. Bull. PNW-RB-54. Portland, OR: U.S. Department Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Research Station. 32 p.

Hegg, K.M. 1975a. Timber resource statistics for the Copper River inventory unit, Alaska, 1968. Resour. Bull. PNW-RB-62. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 68 p.

Hegg, K.M. 1975b. Timber resource statistics for the Fairbanks block, Tanana inventory unit, Alaska, 1970. Resour. Bull. PNW-RB-59. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 45 p.

Hegg, K.M. 1982. Timber resource statistics for the Kantishna block, Tanana inventory unit, Alaska, 1973. Resour. Bull. PNW-RB-95. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 32 p. https://doi.org/10.2737/PNW-RB-95.

Hegg, K.M. 1983. Timber resources statistics for the upper Tanana block, Tanana inventory unit, Alaska, 1974. Resour. Bull. PNW-RB-100. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 34 p. https://doi.org/10.2737/PNW-RB-100.

Hegg, K.M.; Sieverding, H. 1979. Timber resources of the Kuskokwim flood plain and adjacent upland. Resour. Bull. PNW-RB-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 48 p.

Helms, J.A., ed. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p.

Hollingsworth, T.N.; Walker, M.D; Chapin, F.S. III; Parsons, A.L. 2006. Scale-dependent environmental controls over species composition in Alaskan black spruce communities. Canadian Journal of Forest Research. 36: 1781–1796. https://doi.org/10.1139/x06-061.

Holmes, T.P.; Aukema, J.E.; Von Holle, B. [et al.]. 2009. Economic impacts of invasive species in forests: past, present, and future. Annals of the New York Academy of Sciences. 1162(1): 18–38. https://doi.org/10.1111/j.1749-6632.2009.04446.x.

Jackson, R.B.; Lajtha, K.; Crow, S.E. [et al.]. 2017. The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic controls. Annual Review of Ecology, Evolution, and Systematics. 48: 419–445. https://doi.org/10.1146/annurev-ecolsys-112414-054234.

Johnson, E.A. 1992. Fire and vegetation dynamics: studies from the North American boreal forest. Cambridge, UK: Cambridge University Press. 144 p. https://doi.org/10.1017/CBO9780511623516.

Johnson, K.D.; Harden, J.; McGuire, A.D. [et al.]. 2011. Soil carbon distribution in Alaska in relation to soil-forming factors. Geoderma. 167–168: 71–84. https://doi.org/10.1016/j.geoderma.2011.10.006.

Johnstone, J.F.; Hollingsworth, T.N.; Chapin III, F.S. [et al.]. 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. Global Change Biology. 16(4): 1281–1295. https://doi.org/10.1111/j.1365-2486.2009.02051.x.

Kasischke, E.S.; Turetsky, M.R.; Ottmar, R.D. [et al.]. 2008. Evaluation of the composite burn index for assessing fire severity in Alaskan black spruce forests. International Journal of Wildland Fire. 17(4): 515–526. https://doi.org/10.1071/WF08002.

Kasischke, E.S.; Verbyla, D.L.; Rupp, S. [et al.]. 2010. Alaska's changing fire regime—implications for the vulnerability of its boreal forests. Canadian Journal of Forest Research. 40(7): 1313–1324. https://doi.org/10.1139/X10-098.

Koven, C.D.; Ringeval, B.; Friedlingstein, P. [et al.]. 2011. Permafrost carbon-climate feedbacks accelerate global warming. Proceedings of the National Academy of Sciences of the United States of America. 108(36):14769–14774. https://doi.org/10.1073/pnas.1103910108.

Lara, M.J.; Genet, H.; McGuire, A.D. [et al.]. 2016. Thermokarst rates intensify due to climate change and forest fragmentation in an Alaskan boreal forest lowland. Global Change Biology. 22(2): 816–829. https://doi.org/10.1111/gcb.13124.

Mack, M.C.; D'Antonio, C.M. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology & Evolution. 13(5): 195–198. https://doi.org/10.1016/S0169-5347(97)01286-X.

Mack, R.N.; Simberloff, D.; Lonsdale, W.M. [et al.]. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications. 10(3): 689–710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2.

Maher, K.; Little, J.; Champ, P.A. 2013. Insights from a harvest trip model for non-timber forest products in the interior of Alaska. Res. Note RMRS-RN-60. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p. https://doi.org/10.2737/RMRS-RN-60.

Mann, D.H.; Fastie, C.L.; Rowland, E.L.; Bigelow, N.H. 1995. Spruce succession, disturbance, and geomorphology on the Tanana River floodplain, Alaska. Écoscience. 2(2): 184–199. https://doi.org/10.1080/11956860.1995.11682283.

Manning, G.H.; Massie, M.R.C.; Rudd, J. 1984. Metric single-tree weight tables for the Yukon Territory. BC-X- 250. Victoria, BC: Environment Canada, Canadian Forest Service, Pacific Forest Research Centre. 60 p.

Marcille, K.C.; Berg, E.C.; Morgan, T.A. [et al.]. 2021. Alaska's forest products industry and timber harvest, 2015. Resour. Bull. PNW-RB-271. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 45 p. https://www.fs.usda.gov/treesearch/pubs/63556.

McConville, K.; Moisen, G.; Frescino, T. 2020. A tutorial on model-assisted estimation with application to forest inventory. Forests. 11(2). 25 p. https://doi.org/10.3390/f11020244.

McGuire, A.D.; Genet, H.; Lyu, Z. [et al.]. 2018. Assessing historical and projected carbon balance of Alaska: a synthesis of results and policy/management implications. Ecological Applications. 28(6): 1396–1412. https://doi.org/10.1002/eap.1768.

Mead, B.R. 1995. Plant biomass in the Tanana River basin, Alaska. Res. Pap. PNW-RP-477. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 88 p. https://doi.org/10.5962/bhl.title.87994.

Mekonnen, Z.A.; Riley, W.J.; Randerson, J.T. [et al.]. 2019. Expansion of high-latitude deciduous forests driven by interactions between climate warming and fire. Nature Plants. 5: 952–958. https://doi.org/10.1038/s41477-019-0495-8.

Morimoto, M.; Juday, G. 2019. Perspectives on sustainable forest management in interior Alaska boreal forest: recent history and challenges. Forests. 10(6): 484–505. https://doi.org/10.3390/f10060484.

Multi-Resolution Land Characteristics Consortium (MRLC). 2018. National Land Cover Database 2011 (NLCD 2011). https://data.nal.usda.gov/dataset/national-land-cover-database-2011-nlcd-2011. (8 February 2022).

Najda, H.G.; Darwent, A.L.; Hamilton, G. 1982. The biology of Canadian weeds. 54. *Crepistectorum* L. Canadian Journal of Plant Science. 62(2): 473–481. https://doi.org/10.4141/cjps82-067.

Nowacki, G.J.; Spencer, P.; Fleming, M.; Brock, T.; Jorgenson, T. 2002. Unified ecoregions of Alaska: 2001. Open-File Report 2002-297. Reston, VA: U.S. Department of the Interior, Geological Survey. https://doi.org/10.3133/ofr2002297.

Pacific Northwest Forest Inventory and Analysis (PNW-FIA). 2019. Field instructions for the annual inventory of Alaska, 2019. Anchorage, AK: U.S. Department of Agriculture, Forest Service. https://www.fs.usda.gov/pnw/sites/default/files/2019 AFSL FIA Field Manual.pdf. (8 February 2022).

Pastick, N.J.; Duffy, P.; Genet, H. [et al.]. 2017. Historical and projected trends in landscape drivers affecting carbon dynamics in Alaska. Ecological Applications. 27(5): 1383–1402. https://doi.org/10.1002/eap.1538.

Pattison, R.; Andersen, H.-E.; Gray, A. [et al.], tech. coords. 2018. Forests of the Tanana Valley State Forest and Tetlin National Wildlife Refuge, Alaska: results of the 2014 pilot inventory. Gen. Tech. Rep. PNW-GTR-967. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 80 p. https://doi.org/10.2737/PNW-GTR-967.

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience. 50(1): 53–65. https://doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2.

Pimentel, D.; Zuniga, R.; Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. 52(3): 273–288. https://doi.org/10.1016/j.ecolecon.2004.10.002.

Ping, C.L.; Jastrow, J.D.; Jorgenson, M.T. [et al.]. 2015. Permafrost soils and carbon cycling. Soil. 1(1): 147–171. https://doi.org/10.5194/soil-1-147-2015.

PRISM Climate Group. 2014. Oregon State University. https://prism.oregonstate.edu. (12 May 2021).

Pysek, P.; Jarosik, V.; Hulme, P.E. [et al.]. 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Global Change Biology. 18(5): 1725–1737. https://doi.org/10.1111/j.1365-2486.2011.02636.x.

Ringvall, A.H.; Ståhl, G.; Ene, L.T. [et al.]. 2016. A poststratified ratio estimator for model-assisted biomass estimation in sample-based airborne laser scanning surveys. Canadian Journal of Forest Research. 46(11): 1386–1395. https://doi.org/10.1139/cjfr-2016-0158.

Ryan, K.; Chipman, M.L.; Higuera, P.E. [et al.]. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. Proceedings of the National Academy of Sciences of the United States of America. 110 (32): 13055–13060. https://doi.org/10.1073/pnas.1305069110.

Schuur, E.A.G.; Bockheim, J.; Canadell, J.G. [et al.]. 2008. Vulnerability of permafrost carbon to climate change: implications for the global carbon cycle. BioScience. 58(8): 701–714. https://doi.org/10.1641/B580807.

Schuur, E.A.G.; McGuire, A.D.; Schädel, C. [et al.]. 2015. Climate change and the permafrost carbon feedback. Nature. 520: 171–179. https://doi.org/10.1038/nature14338.

Setzer, T.S. 1987. Timber resource statistics for the Porcupine inventory unit of Alaska, 1978. Resour. Bull. PNW-RB-141. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p. https://doi.org/10.2737/PNW-RB-141.

Singh, T. 1984. Biomass equations for six major tree species of the Northwest Territories. Inf. Rep. NOR-X-257. Edmonton, AB: Natural Resources Canada, Canadian Forest Service, Northern Forest Research Centre. 21 p.

Smith, R.J.; Benavides, J.C.; Jovan, S. [et al.]. 2015. A rapid method for landscape assessment of carbon storage and ecosystem function in moss and lichen ground layers. The Bryologist. 118(1): 32–45. https://doi.org/10.1639/0007-2745-118.1.032.

Smith, S.L.; Romanovsky, V.E.; Lewkowicz, A.G. [et al.]. 2010. Thermal state of permafrost in North America: a contribution to the international polar year. Permafrost and Periglacial Processes. 21(2): 117–135. https://doi.org/10.1002/ppp.690.

Strunk, J.; Temesgen, H.; Andersen, H.-E.; Packalen, P. 2014. Prediction of forest attributes with field plots, Landsat, and a sample of lidar strips. Photogrammetric Engineering & Remote Sensing. 80(2): 143–150. https://doi.org/10.14358/PERS.80.2.143-150.

Sullivan, P.F.; Pattison, R.R.; Brownlee, A.H. [et al.]. 2017. Limited evidence of declining growth among moisture-limited black and white spruce in interior Alaska. Scientific Reports. 7: 14 p. https://doi.org/10.1038/s41598-017-15644-7.

Tarnocai, C.; Canadell, J.G.; Schuur, E.A.G. [et al.]. 2009. Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochemical Cycles. 23(2). 11 p. https://doi.org/10.1029/2008GB003327.

Turetsky, M.R.; Mack, M.C.; Hollingsworth, T.N.; Harden, J.W. 2010. The role of mosses in ecosystem succession and function in Alaska's boreal forest. Canadian Journal of Forest Research. 40: 1237–1264. https://doi.org/10.1139/X10-072.

Turetsky, M.R.; Kane, E.S.; Harden, J.W. [et al.]. 2011. Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. Nature Geosciences. 4: 27–31. https://doi.org/10.1038/ngeo1027.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2015a. Forest health conditions in Alaska, 2014: a forest health protection report. R10-PR-36. Anchorage, AK: Alaska Region. 88 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2015b. Forest health conditions in Alaska, 2015: a forest health protection report. R10-PR-38. Anchorage, AK: Alaska Region. 78 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2016. Forest health conditions in Alaska, 2016: a forest health protection report. R10-PR-39. Anchorage, AK: Alaska Region. 74 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2017. Forest health conditions in Alaska, 2017: a forest health protection report. R10-PR-43. Anchorage, AK: Alaska Region. 64 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2018. Forest health conditions in Alaska, 2018: a forest health protection report. R10-PR-44. Anchorage, AK: Alaska Region. 66 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2019. Forest health conditions in Alaska, 2019: a forest health protection report. R10-PR-45. Anchorage, AK: Alaska Region. 68 p.

U.S. Environmental Protection Agency [US EPA]. 2020. EPA greenhouse gas equivalencies calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. (30 June 2020).

van Cleve, K.; Chapin III, F.S.; Dyrness, C.T. [et al.]. 1991. Element cycling in Taiga forests: state-factor control. BioScience. 41(2): 78–88. https://doi.org/10.2307/1311560.

van Everdingen, R., ed. 1998. Multi-language glossary of permafrost and related ground-ice terms. Boulder, CO: National Snow and Ice Data Center. 46 p.

van Hees, W. 2009. Forests of interior Alaska. In: Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A., coords. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington DC: U.S. Department of Agriculture, Forest Service: 92–96. Chapter 8.

van Hees, W.W.S. 1999. Vegetation resources inventory of southwest Alaska: development and application of an innovative, extensive sampling design. Res. Pap. PNW-RP-507. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 51 p. https://doi.org/10.2737/PNW-RP-507.

Viereck, L.A. 1983. The effects of fire in black spruce ecosystems of Alaska and northern Canada. In: Wein, R.W.; MacLean, D.A., eds. The role of fire in northern circumpolar ecosystems. Hoboken, NJ: John Wiley & Sons Ltd.: 201–220. Chapter 11.

Viereck, L.A.; Dyrness, C.T.; Batten, A.R.; Wenzlick, K.J. 1992. The Alaska vegetation classification. Gen. Tech. Rep. PNW-GTR-286. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 p. https://doi.org/10.2737/PNW-GTR-286.

Waddell, K., ed. 2013. PNW-FIADB users manual: a data dictionary and user guide for the PNW-FIADB database. https://www.fs.fed.us/pnw/rma/fia-topics/documentation/documents/PNW_FIADB_P2_Data_Dictionary_Manual_2011.pdf. (9 February 2022).

Wagner, D.; Doak, P. 2013. Long-term impact of a leaf miner outbreak on the performance of quaking aspen. Canadian Journal of Forest Research. 43(6): 563–569. https://doi.org/10.1139/cjfr-2012-0486.

Wagner, D.; Wheeler, J.M.; Burr, S.J. 2020. The leaf miner *Phyllocnistis populiella* negatively impacts water relations in aspen. Tree Physiology. 40(5): 580–590. https://doi.org/10.1093/treephys/tpz109.

Winterberger, K.C. 1983. Timber resource statistics for the Wood-Salcha block, Tanana inventory unit, Alaska, 1975. Resour. Bull. PNW-RB-107. Portland, OR: U.S. Department of Agriculture, Forest Service Pacific Northwest Forest and Range Experiment Station. 34 p. https://doi.org/10.2737/PNW-RB-107.

Yarie, J.; Billings, S. 2002. Carbon balance of the taiga forest within Alaska: present and future. Canadian Journal of Forest Research. 32(5): 757–767. https://doi.org/10.1139/x01-075.

Appendix: Forest Inventory Methods and Design

Two approaches were taken to develop estimates of forest attributes (cover, biomass, volume, carbon, etc.) in interior Alaska. The first approach relied on standard, poststratification methods used nationally by the USDA Forest Service Forest Inventory and Analysis (FIA) program to provide statewide summaries as outlined in Bechtold and Patterson (2005). The second approach used low-altitude airborne flights with high-resolution remote sensing technology developed by National Aeronautics and Space Administration (NASA) Goddard Space Flight Center scientists to capture within and among plot variability in landscape structure. The Goddard LiDAR, hyperspectral, and thermal (G-LiHT) airborne imager technology is a portable imaging system that maps the composition, structure, and function of terrestrial ecosystems. G-LiHT estimates were used to augment the standard FIA estimates and reduce error associated with the lower plot resolution (one plot every 30,000 ac) in interior Alaska. Both methods are described in detail below.

Poststratification Methods

The standard estimates in interior Alaska rely on two phases of data collection and analysis. In phase 1, the area in the inventory unit is interpreted from remotely sensed imagery, classifying land into broad, relatively homogenous groups called strata. In phase 2, field plots are measured for a variety of indicators that describe forest composition, structure, and the physical geography of the landscape. In interior Alaska, phase 2 plots are spaced approximately every 30,000 ac on a hexagonal grid across the state.

Phase 1

The purpose of phase 1 is to reduce the variance associated with estimates of various forest attributes. For phase 1 interpretation of the Tanana unit, FIA used the National Land Cover Database 2011 (MRLC 2018) to stratify the land by forest (≥10 percent tree canopy cover), nonforest (<10 percent tree canopy cover), and water. Grid cells in each class were further subdivided into categories, including an elevation grouping from digital elevation models, broad ownership information from a variety of sources, and climate data representing a spatial model of 1981–2010 average annual precipitation (PRISM Climate Group 2018). The resulting strata were evaluated for each estimation unit and collapsed as necessary to ensure that at least 10 plots were present in each stratum. Stratified estimation was applied by assigning each plot to one of these collapsed strata and calculating the area of each collapsed stratum in each estimation unit. Stratification is applied to various forest attributes such as biomass, volume, and carbon to extrapolate values collected at the plot scale to their prevalence at the landscape scale. Estimates from stratified data are usually more precise than those derived from unstratified data.

Because of the statistical methods used, classification errors in the phase 1 data may cause imprecision but do not create bias in the estimators used. More information on sample design and estimators is available in Bechtold and Patterson (2005).

Phase 2 data collection and analysis—

Phase 2 plots are a systematic sample with a random component selected from the entire area within the inventory unit, including both land and water. Plots are visited in the field if an aerial photo indicates that they might contain forest. The plot installed at each phase 2 location is a cluster of four subplots whose centers are spaced 120 ft apart (fig. A.1). Subplot 1 is in the center of the plot, with subplots 2

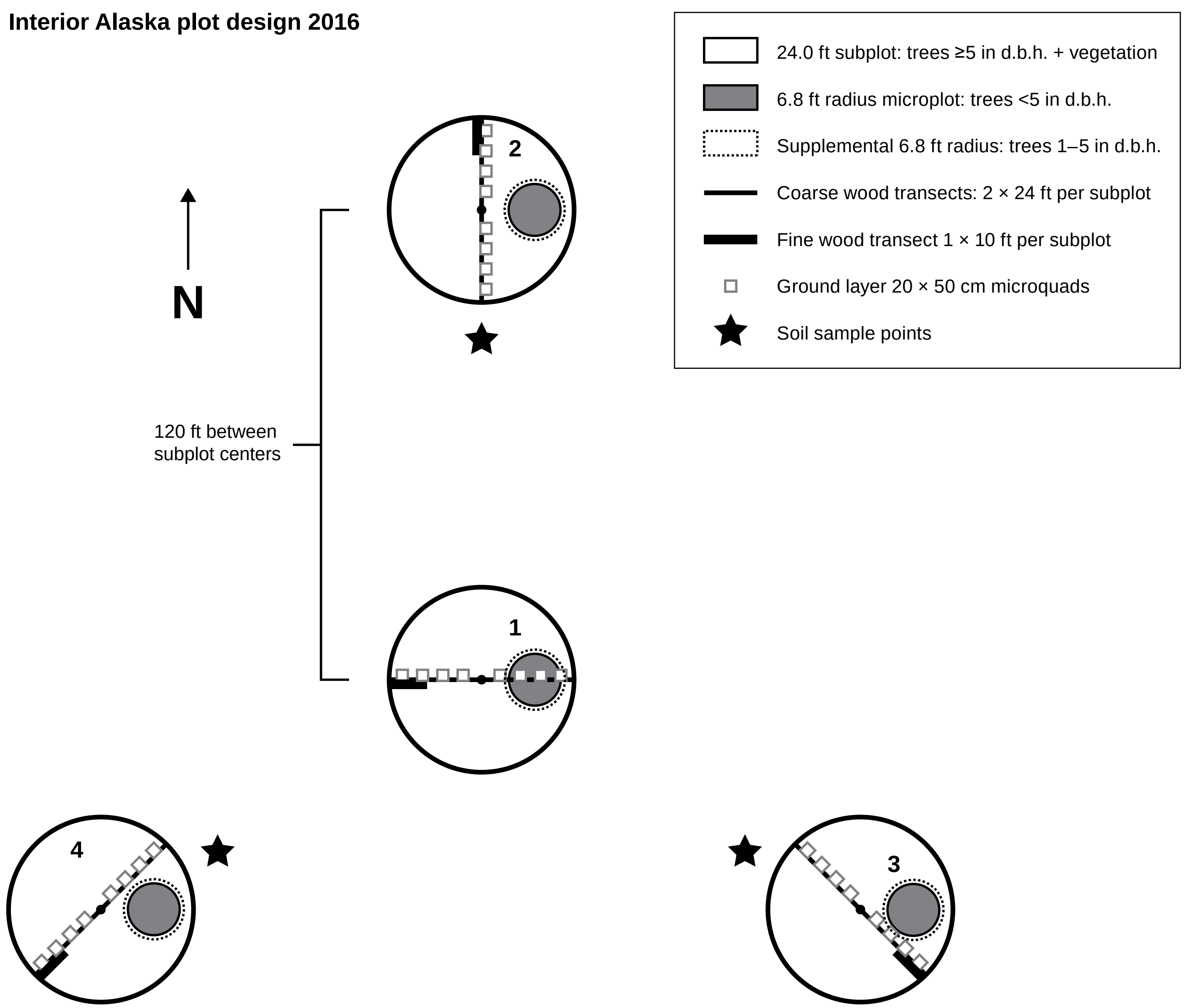


Figure A.1—Interior Alaska Forest Inventory and Analysis plot design used from 2016 to present. Figure shows the layout and location of the four subplots and different measurements collected within the plot footprint; d.b.h. = diameter at breast height.

through 4 uniformly distributed radially around it. Each point serves as the center of a 1/24-acre circular subplot used to sample all trees at least 5 inches in diameter at breast height (d.b.h.). A 1/150-acre microplot, with its center located 12 ft to the east of each subplot center, is used to sample trees 1.0 to 4.9 inches d.b.h., as well as seedlings (trees less than 1.0 inch d.b.h.).

Field crews delineate areas that are relatively homogenous using (1) reserved status, (2) owner group, (3) forest type, (4) stand size class, (5) regeneration status, and (6) tree density; these areas are described as condition classes. The process of delineating these condition classes on a fixed-radius plot is called mapping. All measured trees are assigned to the mapped condition class in which they are located. On phase 2 plots, crews assess physical characteristics such as slope, aspect, and elevation; stand characteristics such as age, size class, forest type, disturbance, site productivity, and regeneration status; and tree characteristics such as tree species, diameter, height, and vertical crown dimensions. They also collect general descriptive information, such as proximity to roads and the geographic position of the plot in the larger landscape.

The FIA program measured 690 forested or partially forested phase 2 plots and 33 nonforest plots in the Tanana unit between 2014 and 2018. Estimates of tree biomass and other forest attributes were derived from tree measurements and classifications collected at each plot. Volume for individual tally trees were computed using published allometric equations for each of the major species in Alaska (table A.1).

Table A.1—Sources used to generate biomass, volume, and site index from field-collected data

Species	Biomass	Volume and site index
Aspen	Manning et al. (1984)	Haack (1963)
Balsam poplar	Singh (1984)	Haack (1963)
Alaska paper birch	Alemdag (1984)	Haack (1963)
Black spruce	Manning et al. (1984)	Gregory and Haack (1964)
Tamarack	Singh et al. (1984)	Gregory and Haack (1964)
White spruce	Manning et al. (1984)	Gregory and Haack (1964)

Core, core-optional, and regional variables—
Almost all of the FIA variables collected in Alaska are identical to those collected by FIA elsewhere in the United States; these are referred to as national "core" or "core optional" variables. Core optional, as the name suggests, are variables that are optional for any state but, if collected, must be collected using the standard national method. A small number of other variables are unique to the PNW-FIA program. These are "regional" variables and include the species and cover of any

invasive plants found on the plot, soil cores, and ground cover. The database and documentation of variables used in this report are available online (Burrill et al. 2021, Waddell 2013). Field manuals can also be useful for understanding how variables were collected (PNW-FIA 2019).

Site index, volume, and biomass estimates—
Site index is used to measure the potential productivity of forest land and to distinguish timberland from forest land. Application to individual trees differed depending on the height class and diameter class of the tree and type of volume (cubic foot, Scribner board foot, or international board foot) estimated. Biomass calculations for tree species in interior Alaska are derived from the sources listed in table A.1.

Access denied, hazardous, or inaccessible plots—
Although every effort was made to visit all field plots that were either entirely or partially forested, some plots were not sampled for a variety of reasons, including a landowner denying permission to access the plot location ("denied access"), hazardous plot conditions, or inaccessibility of the plot. In Alaska, it is common for plots to be temporarily inaccessible owing to the presence of snow or for extreme topography to make plots hazardous or impossible to reach. These kinds of missing data can introduce bias into the estimates if the nonsampled plots tend to be different from the entire population. The poststratification approach outlined in Bechtold and Patterson (2005) removes nonsampled plots from the analysis. Estimates are adjusted for plots that are partially nonsampled by increasing the estimates based on the sampled proportion of the plot by the nonsampled proportion within each stratum. To reduce the possible bias introduced by nonsampled plots, the phase 1 data are used to group plots similar in climate, vegetation, and ownership strata. The proportion of denied-access, hazardous, or inaccessible plots is significantly smaller for nonforest plots than for forested plots as field crews rarely visit nonforested plots (however, see "Forest Understory and Nonforest Vegetation Methods" in this appendix).

Aligning pilot and production data—
Following the 2014 pilot project, several key changes to the field methods were made to enhance FIA inference in interior Alaska's boreal forest. First, the 2014 pilot project inventoried 99 plots on a standard FIA grid of one plot per 6,000 ac, whereas the remainder of the inventory would reduce the resolution to one plot per 30,000 ac (one-fifth intensity) because of logistical constraints. Hence, only plots from the 2014 pilot that fell within the reduced resolution were used in subsequent estimation procedures. Second, in the 2014 pilot, saplings (1–4.9 inches d.b.h.) were inventoried on two microplots, each with a radius of 6.8 ft. However, after

consultation with station researchers, analysts, information management personnel, and data collection leadership, the protocol was changed in 2016 to eliminate one microplot, but increase the radius of the other microplot to 9.6 ft to accommodate the greater proportion of small-diameter trees and reduce trampling by field crews. In order to align small-diameter trees between pilot and production inventories, saplings sampled in the 2014 pilot from the second microplot were assigned a new horizontal distance from microplot center of 9.6 ft, and assigned to a single microplot. This essentially “moved” saplings from the second microplot into a single sampling unit, the new larger microplot. The original distance was retained in the NOTES column for future remeasurement purposes. In addition, the single, larger microplot required a new trees per acre value for saplings. Thus, for trees collected on microplots in interior Alaska, the trees per acre value is 37.612789:

Radius of microplot = 9.6 ft
Area of microplot = $\pi \times 9.62 = 289.5$ ft^2
Acres in a microplot = 289.5 / 43560 (ft^2 per acre) = 0.006647
Acres in a plot (4 microplots per plot) = $4 \times 0.006647 = 0.026587$
Trees per acre = 1/0.026587 = 37.612789

This value was assigned to all saplings collected, including those “moved” from the second microplot in 2014.

Soil core collection also differed between the 2014 pilot and the remainder of the inventory. In 2014, field crews identified six different layers in each soil core (where present): litter and live moss, dead moss, root-dominated duff, upper humified duff, lower humified duff, and mineral soil. From 2016 onward, these layers were collapsed to include litter, live moss and lichen, identifiable plant parts, unidentifiable plant parts, and mineral soil. Thus, the 2014 data were aligned with the 2016 layers such that lower humic and upper humic layers were combined to form the unidentifiable plant parts layer; dead moss and root-dominated duff were combined to form the identifiable plant parts layer. Litter was collected differently between the two inventories and was impossible to reconcile. Therefore, estimates of litter attributes are limited to 2016–2018 measurement years.

Data processing—

The data used for this report are stored in the FIA National Information Management System (NIMS). The system provides a means to input, edit, process, manage, and distribute FIA data—NIMS includes a process for data loading, a national set of edit checks to ensure data consistency, an error correction process, approved equations and algorithms, code to compile and compute calculated attributes, a table report generator, and routines to populate the presentation database. In addition, NIMS applies numerous algorithms and equations to calculate stocking, forest type, stand size, volume, and biomass, and generates estimates and associated statistics based on the combined phase 1 and phase 2 information. Additional FIA statistical design and estimation techniques are further reviewed in Bechtold and Patterson (2005).

Statistical estimates—

Throughout this report we published the standard error (SE) for most of our estimates. These standard errors account for the fact that we measured only a small sample of the forest (thereby producing a sample-based estimate) and not the entire forest (which is the population parameter of interest). Because of small sample sizes or high variability within the population, some estimates can be very imprecise. The reader is encouraged to take the SE into account when drawing any inference. One way to consider this type of uncertainty is to construct confidence intervals. Customarily, 66 or 95 percent confidence intervals are used. A 95 percent confidence interval means that one can be 95 percent confident that the interval contains the true population parameter of interest. It is relatively easy to construct approximate 66 or 95 percent confidence intervals by multiplying the SE by 1 (for 66 percent confidence intervals) or 1.96 (for 95 percent confidence intervals) and subtracting and adding this to the estimate itself.

The reader may want to assess whether two estimates are significantly different from each other. The statistically correct way to address this is to estimate the SE of the difference of two estimates and either construct a confidence interval or use the equivalent z-test. However, this requires the original inventory data. It is often reasonable to assume that two estimates are nearly uncorrelated. For example, plots usually belong to only one landowner. The correlation between estimates for different owners will be very small. If both estimates are assumed to be nearly uncorrelated, the standard error of the difference can be estimated by

$$SE_{Difference} = \sqrt{SE^2_{\text{Estimate 1}} + SE^2_{\text{Estimate 2}}}.$$

Using the SE of the difference, a confidence interval of the difference can be constructed with this method. However, if two estimates are based on data that occur on the same plot at the same time, the above equation should not be used. All estimates, including means, totals, and their associated SEs are based on the poststratification methods described in detail by Bechtold and Patterson (2005).

G-LiHT and Model-Assisted Estimation Methods

In addition to the standard poststratified estimates described previously, poststratified ratio estimators under a two-stage design were used to incorporate the additional measurements provided by the high-resolution NASA G-LiHT airborne remote sensing collection over the Tanana unit. The G-LiHT data were collected as a systematic sample of light detection and ranging (LiDAR) strips (i.e., single swaths approximately 1,148 ft [350 m] wide) covering virtually all of the forested

FIA plots in the Tanana unit. The LiDAR strips are oriented in a SW-NE direction and extend across the entire unit. The FIA plots and G-LiHT acquisition can be seen as a two-stage (cluster) sampling design, where the G-LiHT swaths (strips) are clusters (first stage) and the FIA plots represent subsampling within the clusters (second stage). The efficiency of the estimation from this two-stage design can be further improved through poststratification and by accounting for the length of the strips. The resulting estimator is a poststratified ratio estimator for model-assisted estimation in a two-stage design (Andersen et al. 2011, Ringvall et al. 2016, Strunk et al. 2014). Following Ringvall et al. (2016), if y_k represent a forest attribute (possibly for a specific domain, such as forest type) summarized at the kth FIA plot, x_k represents a vector of G-LiHT derived metrics extracted from the footprint of the kth FIA plot (average LiDAR-derived canopy height, hyperspectral based forest type classification), and a linear regression model is developed relating the inventory attribute to LiDAR metrics:

$$y_k = \beta \boldsymbol{x_k} + \varepsilon \text{ where } \varepsilon \sim N(0, \sigma^2).$$

FIA plots are distributed about 6.5 miles (10.5 km) apart along each G-LiHT strip (1,109 total FIA plots), and remote sensing (RS) plots (with the same spatial configuration and size as a FIA plot) were distributed at 656 ft (200 m) intervals along the center of each G-LiHT strip (fig. 3) (73,509 total RS plots). The population of strips is denoted as M, and the sampled strips m. At each of these RS plots, the regression model is used to predict the inventory parameter. In addition, if the population is poststratified into H strata where the number of remote sensing plots within each stratum (N_h) is assumed to be known without error, the model-assisted regression estimate for inventory attribute y_k in strip i and stratum h is:

$$\hat{t}_{irh} = \sum_{k=1}^{N_{ih}} \hat{y}_{kh} + \frac{N_{ih}}{n_{ih}} \sum_{k=1}^{n_{ih}} y_{kh} - \hat{y}_{kh}.$$

In cases where a RS plot is missing (mountainous areas, low clouds, etc.), the value for the RS plot measurement (LiDAR or forest type classification) was imputed as the mean LiDAR height or most commonly occurring forest type class within the stratum. The ratio-to-size estimator at the stratum level is then:

$$\hat{t}_{Rh} = N_h \frac{\sum_{i=1}^{m} \hat{t}_{ih}}{\sum_{i=1}^{m} N_{ih}}$$

and the poststratified ratio estimator is given by:

$$\hat{t}_{PS} = \sum_{h=1}^{L} N_h \frac{\sum_{i=1}^{m} \hat{t}_{ih}}{\sum_{i=1}^{m} N_{ih}}.$$

The variance estimator of the poststratified ratio estimator $\hat{V}(\hat{t}_{PS})$ takes into account (1) the variance of the model-assisted estimator within strips, (2) variance between strips, and (3) the dependency between stratum-level estimates within strips. The following variance estimator can be applied in cases where only a small portion of the strips may cover individual strata (Ringvall et al. 2016):

$$\hat{V}(\hat{t}_{PS}) = \sum_{h=1}^{H} \hat{V}(\hat{t}_{Rh}) + \sum_{h=1}^{H} \sum_{g \neq h} \frac{N_h}{\hat{N}_h} \frac{N_g}{\hat{N}_g} M^2 \left(\frac{1}{m} - \frac{1}{M}\right) \times \frac{\sum_{i=1}^{m} \left(\hat{t}_{irh} - \hat{R}_h N_{ih}\right) \left(\hat{t}_{irg} - \hat{R}_g N_{ig}\right)}{m-1}$$

where

$\hat{V}(\hat{t}_{Rh}) = \left(\frac{\bar{N}_h}{\hat{\bar{N}}_h}\right) \left(M_h{}^2 \left(\frac{1}{m_h} - \frac{1}{M_h}\right) s_{rh}^2\right) + \left(\frac{M_h}{m_h}\right)^2 \left(\frac{m}{M}\right) \sum_{S_I} \hat{V}(\hat{t}_{irh})$, the second component of $\hat{V}(\hat{t}_{PS})$ accounts for the dependency between stratum-level estimates within strips, M_h is the total number of strips with any RS plots in stratum h, and m_h is the number of sampled strips containing RS plots in stratum h, $\bar{N}_h = N_h / M_h$, $\hat{\bar{N}}_h = \hat{N}_h / \hat{M}_h$, and $\hat{M}_h = \left(\frac{M}{m} m_h\right)$. Between strip variability is given by:

$$s_{rh}^2 = \frac{1}{m_h - 1} \sum_{i=1}^{m_h} \left(\hat{t}_{irh} - \hat{R}_h N_{ih}\right)^2,$$

where $\hat{R}_h = \frac{\sum_{S_I} \hat{t}_{irh}}{\sum_{S_I} N_{ih}}$, and within strip variability given by:

$\hat{V}(\hat{t}_{irh}) = N_{ih}^2 \left(\frac{1}{n_{ih}} - \frac{1}{N_{ih}}\right) s_{\hat{e}_h}^2$, where $s_{\hat{e}_h}^2 = \frac{1}{n_h - 1} \sum_{k=1}^{n_h} (e_{kh} - \bar{e}_h)^2$, with $\bar{e}_h = \frac{1}{n_h} \sum_{k=1}^{n_h} e_{kh}$ and $e_{kh} = y_{kh} - \hat{y}_{kh}$. Note that Ringvall et al. (2016) calculate the within strip residual variance as:

$$s_{\hat{e}_{ih}}^2 = \frac{1}{n_{ih} - 1} \sum_{k=1}^{n_{ih}} (e_{kh} - \bar{e}_{ih})^2,$$

with $\bar{e}_{ih} = \frac{1}{n_{ih}} \sum_{k=1}^{n_{ih}} e_{kh}$ and $e_{kh} = y_{kh} - \hat{y}_{kh}$. However, with very small strip- and stratum-level plot sample sizes (n_{ih}), $s_{\hat{e}_{ih}}^2$ is likely highly variable or even impossible to calculate. It is assumed that the stratum-level residual variance calculated across all strips ($s_{\hat{e}_h}^2$) will be more stable and, if anything, will be a conservative estimate because residuals within strips are likely to be spatially autocorrelated). Since the estimator $\hat{t}_{PS}$ is an estimate over the population of RS plots, an estimate over the entire area is obtained by dividing by N and multiplying by the total area A, i.e., $\hat{t}_{PS,A} = \hat{t}_{PS} \left(\frac{A}{N}\right)$, with corresponding variance estimator $\hat{V}(\hat{t}_{PS,A}) = \hat{V}(\hat{t}_{PS}) \left(\frac{A}{N}\right)^2$. Note that this variance estimator assumes that the G-LiHT strips, RS, and FIA plot subsamples are collected as a simple random sample in both stages. In actuality, just as the FIA data are a systematic sample (regular grid); the G-LiHT strips, RS plots and FIA plot subsample are also a systematic sample (regular interval between plots/strips). This likely leads to an overestimation of variance, although it should be noted that small samples at the strip level can also lead to unstable variances (Ringvall et al. 2016). Further research on optimal stratification within this two-stage design, as well as optimal use of hyperspectral based forest type classification within a model-assisted inferential framework is needed and ongoing.

Forest Understory and Nonforest Vegetation Methods

The core optional FIA phase 2 vegetation profile (VEG) includes an overall description of vascular vegetation structure (cover by growth habit by height layer) and captures the percentage of canopy cover of the most abundant species by growth habit (up to four species per growth habit, if the species is present with at least 3 percent canopy cover) for each condition encountered on each subplot, with a height layer assigned to designate where the majority of foliage occurs (PNW-FIA 2019). In Alaska, the Pacific Northwest Research Station Resource Monitoring and Assessment program collects these data on all standard inventory plots and also includes all field-visited nonforest plots with at least 10 percent vascular plant cover.

Estimates of average percentage of cover and standard errors for tally and nontally trees, shrubs, forbs, and graminoids on forest lands were calculated following the standard ratio of means method (Bechtold and Patterson 2005). The most commonly recorded species on forested lands were determined by counting the number of records of each species within forested conditions on subplots assigned to a particular forest type. Species with the greatest number of records were considered the most commonly recorded species for that forest type. Estimates of average percentage of cover of a species within each forest type were calculated using the standard ratio of means method. Standard errors of these means were calculated by dividing the standard deviation of cover estimates for each species on each condition and subplot within a particular forest type by the square root of the number of records of the species within conditions assigned to the forest type.

Table A.2—Nonforest dominance classes in the Tanana unit, Alaska, 2014–2016

Dominance class[a]	Description
Tally tree seedlings and saplings	Tally tree seedlings and/or saplings cover ≥25 percent
Nontally tree seedlings and saplings	Nontally tree seedlings and/or saplings cover ≥25 percent
Tall shrub	Shrub cover ≥25 percent; at least 25 percent shrub cover >6 ft, or majority shrub cover >6 ft
Low shrub	Shrub cover ≥25 percent; at least 25 percent shrub cover 2.1–6 ft, or majority shrub cover 2.1–6 ft
Dwarf shrub	Shrub cover ≥25 percent; at least 25 percent shrub cover <2 ft, or majority shrub cover <2 ft
Forb herbaceous	Vascular plant cover ≥25 percent; majority of herbaceous cover is forbs
Graminoid herbaceous	Vascular plant cover ≥25 percent; majority of herbaceous cover is graminoids
Bryophyte	Vascular plant cover <25 percent; bryophyte cover ≥25 percent
Lichen	Vascular plant cover <25 percent; lichen cover ≥25 percent

Note: For the purposes of this report, nonforest conditions are divided into dominance classes based upon level II and level III described in the Alaska vegetation classification.

[a] Adapted from Viereck et al. 1992.

To summarize vegetation on nonforest conditions, vegetation data for each nonforest condition were first assigned a dominance class. Dominance classes roughly followed those of the Alaska vegetation classification, although they differed somewhat due to limitations associated with FIA vegetation data (Viereck et al. 1992) (table A.2). Methods for determining the most common species in nonforest dominance classes and the mean and standard deviation of each species' cover were identical to those used for determining these values on forested conditions.

Invasive Plants

FIA began surveying for invasive species in 2005 in coastal Alaska, and national core optional methods were officially established in 2011. Alaska's current list of targeted species is included in table A.3 and is based on the most common known invasive plants in Alaska that may be present in forests. Most have been ranked for invasiveness using a system developed for natural areas of Alaska, based on ecological impacts, biological attributes, distribution, and control measures associated with each species (Carlson et al. 2008). There is no minimal cover limitation, so any listed species can be recorded if present in any amount. Collections of known or suspected invasive plants are encouraged, especially in remote areas greater than one-half mile from an improved road.

Table A.3—Scientific and common names of invasive plants surveyed for in the Tanana unit, Alaska, 2014–2018

Scientific name	Common name	Alaska invasive ranking
Ailanthus altissima	tree of heaven[a]	NA
Albizia julibrissin	silktree[a]	NA
Alliaria petiolata	garlic mustard	70
Bromus inermis	smooth brome	62
Bromus tectorum	cheatgrass	78
Campanula rapunculoides	rampion bellflower	64
Capsella bursa-pastoris	shepherd's purse	40
Caragana arborescens	Siberian peashrub	74
Centaurea stoebe ssp. *micranthos*	spotted knapweed	86
Cirsium arvense	Canada thistle	76
Cirsium vulgare	bull thistle	61
Crepis tectorum	narrowleaf hawksbeard	56
Cytisus scoparius	Scotch broom	69
Dactylis glomerata	orchardgrass	53
Elymus repens	quackgrass	59
Galeopsis	hempnettle	50
Heracleum mantegazziuanum	giant hogweed	81
Hesperis matronalis	dames rocket	41
Hieracium aurantiacum	orange hawkweed	79

Table A.3—Scientific and common names of invasive plants surveyed for in the Tanana unit, Alaska, 2014–2018 (continued)

Scientific name	Common name	Alaska invasive ranking
Hieracium pilosella	mouseear hawkweed	63
Hieracium caespitosum	meadow hawkweed	79
Hieracium umbellatum	narrowleaf hawkweed	51
Hypochaeris radicata	hairy cat's ear	NA
Impatiens glandulifera	ornamental jewelweed	82
Lappula squarrosa	European stickseed	44
Leucanthemum vulgare	oxeye daisy	61
Linaria vulgaris	butter and eggs	69
Lolium	ryegrass	41–52
Lythrum salicaria	purple loosestrife	84
Lythrum virgatum	spike loosestrife	84
Matricaria discoidea	disc mayweed	32
Melia azedarach	Chinaberry tree[a]	NA
Medicago	alfalfa	48–64
Melilotus officinalis	yellow sweetclover	69
Melaleuca quinquenervia	punktree[a]	NA
Phalaris arundinacea	reed canarygrass	83
Paulownia tomentosa	princess tree[a]	NA
Phleum pratense	timothy	54
Plantago major	common plantain	44
Polygonum aviculare	prostrate knotweed	45
Polygonum × *bohemicum*	Bohemian knotweed	87
Polygonum convolvulus var. *convolvulus*	black bindweed	50
Polygonum cuspidatum	Japanese knotweed	87
Polygonum sachalinense	giant knotweed	87
Prunus padus	European bird cherry	74
Ranunculus repens	creeping buttercup	72
Rubus armeniacus	Himalayan blackberry	77
Senecio jacobaea	stinking willie	63
Senecio vulgaris	old-man-in-the-Spring	36
Sonchus arvensis	field sowthistle	73
Stellaria media	common chickweed	54
Taraxacum officinale	common dandelion	58
Tanacetum vulgare	common tansy	60
Tragopogon dubius	yellow salsify	50
Trifolium	clover	50–59
Triadica sebifera	Chinese tallow[a]	NA
Tripleurospermum perforatum	scentless false mayweed	48
Ulmus pumila	Siberian elm[a]	NA
Vicia cracca ssp. *Cracca*	bird vetch	73

NA = not applicable.

[a] Species from national list; unlikely to occur in Alaska.

Glossary

abiotic—Pertaining to nonliving environmental attributes, such as temperature, moisture, and wind.

aspect—Compass direction that a slope faces.

basal area—The cross-sectional area of a tree's trunk.

biodiversity—Variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequencies.

biomass—The aboveground weight of wood and bark in live trees 1 inch diameter at breast height (d.b.h.) and larger from the ground to the tip of the tree, excluding all foliage. The weight of wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch in diameter at the point of occurrence on sapling-size trees is included in the measure, but on poletimber- and sawtimber-sized trees, this material is excluded. Biomass is typically expressed as green or oven-dry weight in tons.

board foot—A volume measure of lumber 1-ft wide, 1-ft long, and 1-inch thick (12 inches × 12 inches × 1 inch = 144 cubic inches).

bole—Trunk or main stem of a tree.

bone-dry units (BDU)—The amount of wood residue that weighs 2,400 lb (1,088 kg) at 0 percent moisture content. One BDU equals approximately 9.49 yd^3 or 96 ft^3 of solid wood.

carbon mass—The estimated weight of carbon stored within wood tissues. On average, carbon mass values are about half of biomass values for trees and are summarized as thousand tons or mean tons per acre.

carbon sequestration—Incorporation of carbon dioxide into permanent plant tissues.

coarse woody debris—Down dead tree and shrub boles, large limbs, and other woody pieces that are severed from their original source of growth. Coarse woody material also includes dead trees that are supported by roots, severed from roots, or uprooted, and leaning >45 degrees from vertical. Also sometimes called coarse woody material or down woody material.

damage—Damage to trees caused by biotic agents such as insects, diseases, and animals or abiotic agents such as weather, fire, or mechanical equipment.

diameter at breast height (d.b.h.)—The diameter of a tree stem, located at 4.5 ft above the ground ("breast height") on the uphill side of a tree. The point of diameter measurement may vary on abnormally formed trees.

disturbance—Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Helms 1998).

ecological region (ecoregion)—A top-level scale in a hierarchical classification of ecological units subdivided on the basis of global, continental, and regional climatic regimes and broad physiography. Ecological regions are further subdivided into domains, divisions, and provinces. The next level down in the hierarchy, subregion, is divided into ecological sections (ecosections) and subsections.

ecological section (ecosection)—A level in a hierarchical classification of ecological units for a geographic area delineated on the basis of similar climate, geomorphic processes, stratigraphy, geologic origin, topography, and drainage systems.

ecosystem—A spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries. An ecosystem can be of any size: a log, a pond, a field, a forest, or the Earth's biosphere (Helms 1998).

elevation—Height above a fixed reference point, often the mean sea level.

federal land—An ownership class of public lands owned or managed by the U.S. government.

fire regime—The characteristic frequency, extent, intensity, severity, and seasonality of fires within an ecosystem (Helms 1998).

fixed-radius plot—A circular sampled area with a specified radius in which all trees of a given size, shrubs, and other items, are tallied.

forb—A broad-leaved herbaceous plant, as distinguished from grasses, shrubs, and trees.

forest land—Land that is currently or formerly (within 30 years) at least 10 percent stocked by trees of any size and not currently developed for nonforest use. Forests must be at least 1 ac in size with a minimum width of 120 ft. A modified definition was adopted in 2012 that defines forest as at least 10 percent canopy cover (instead of stocking), which was used to define forest land for the purposes of the Tanana Unit inventory.

forest type—A classification of forest land based on and named for the tree species that forms the plurality of non-overtopped live-tree stocking.

forest type group—A combination of forest types that share closely associated species or site requirements.

graminoid—Grasses (family Gramineae or Poaceae) and grass-like plants such as sedges (family Cyperaceae) and rushes (family Juncaceae).

greenhouse gas—A gas, such as carbon dioxide or methane, which contributes to potential climate change.

growing-stock—All live trees 5 inches diameter at breast height or larger that are considered merchantable in terms of saw-log length, and grade; excludes rough and rotten cull trees.

hardwood—Tree species belonging to the botanical subdivision Angiospermae, class Dicotyledonous, usually broad-leaved and deciduous.

house log— Roundwood timber used to construct log homes. Products manufactured from house logs can be sawn, scribed by hand, notched or milled by lathe to meet customer construction needs. House log timber is often dead (by choice, because "green" logs usually require drying before they can be used for construction) and of lower value than sawlogs.

identifiable plant parts—A layer that includes dead mosses and materials that are identifiable to botanical origins. Has mainly fine and very fine roots, with varying amounts and sizes of old plant biomass (old roots, moss pieces, etc.).

invasive plant—Plants that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health.

lichen—An organism consisting of a fungus and an alga or cyanobacterium living in symbiotic association. Lichens look like masses of small, leafy, tufted or crust like plants.

litter—Undecomposed or only partially decomposed organic material that can be readily identified (e.g., plant leaves, twigs, etc.)

live moss/lichen—Moss or lichen that is green or obviously alive.

live trees—All living trees, including all size classes, all tree classes, and both commercial and noncommercial species for tree species listed in the FIA field manual (PNW-FIA 2019).

lumber tally—The volume of sawn products, usually expressed in board feet.

mean annual increment (MAI) at culmination—A measure of the productivity of forest land expressed as the average increase in cubic feet of wood volume per acre per year. For a given species and site index, the mean is based on the age at which the MAI culminates for fully stocked natural stands. The MAI is based on the site index of the plot.

mesic—Describes sites or habitats characterized by intermediate moisture conditions, i.e., neither decidedly wet nor dry.

MBF—A thousand board feet of wood in logs or lumber.

mineral soil—A soil consisting predominantly of products derived from the weathering of rocks (e.g., sands, silts, and clays).

model—(1) An abstract representation of objects and events from the real world for the purpose of simulating a process, predicting an outcome, or characterizing a phenomenon. (2) Geographic information system (GIS) data representative of reality (e.g., spatial data models), including the arc-node, georelational model, rasters or grids, polygon, and triangular irregular networks (Helms 1998).

mortality—The death of trees from natural causes, or subsequent to incidents such as storms, wildfire, or insect and disease epidemics (Helms 1998).

net volume—Gross volume less deductions for sound and rotten defects. Growing-stock net volume is gross volume (in cubic feet) less deductions for rot and missing bole sections on poletimber and sawtimber growing-stock trees. Sawtimber net volume is gross volume (in board feet) less deductions for rot, sweep, crook, missing bole sections, and other defects that affect the use of sawtimber trees for lumber (Azuma et al. 2004).

noncensus water—Lakes, reservoirs, ponds, and similar bodies of water that are 1 to 4.5 ac in size; and rivers, streams, canals, etc., that are 30 to 200 ft wide.

noncorporate forest land—Private forest land owned or managed by non-governmental conservation or natural resource organizations; unincorporated partnerships, associations, or clubs; individuals or families; or American Indians.

nonforest land—Land that does not support, or has never supported, forests, and lands formerly forested where use for timber management is precluded by development for other uses. Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining rights-of-way, power line clearings of any width, census and noncensus water. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120-ft wide, and clearings, etc. must be more than 1 ac in size, to qualify as nonforest land.

nonstocked areas—Timberland that is less than 10 percent stocked with live trees. Recent clearcuts scheduled for planting are classified as nonstocked areas (Azuma et al. 2004).

nontimber forest products (NTFP)—Species harvested from forests for reasons other than production of timber commodities. Vascular plants, lichens, and fungi are the primary organisms included in NTFPs.

organic soil—This is the layer of soil that begins with the live moss or liter layer at the ground surface and extends to the mineral soil (also known as the organic [O] layer).

other private forest lands—Lands in private ownership and not reported separately. These may include coal companies, land trusts, and other corporate private landowners.

overstory—That portion of the trees, in a forest of more than one story, forming the uppermost canopy layer.

owner class—A variable that classifies land into categories of ownership. Current ownership classes are listed in the FIA field manual.

owner group—A variable that combines owner classes into the following groups: Forest Service, other federal agency, state and local government, and private. Differing categories of owner group on a plot require different conditions.

ownership—A legal entity having an ownership interest in land, regardless of the number of people involved. An ownership may be an individual; a combination of persons; a legal entity such as corporation, partnership, club, or trust; or a public agency. An ownership has control of a parcel or group of parcels of land.

permafrost—Ground (soil or rock and included ice or organic material) that remains at or below 0 °C for at least 2 consecutive years.

primary processing facility (mill)—Forest products manufacturing facility that processes logs (unmanufactured round-wood timber) into primary wood products, such as lumber or veneer, and facilities, such as biomass power and particle-board plants that use low-value woody biomass removed from harvest sites or wood fiber residuals generated by timber-processing facilities.

productive forest land—Forest land that is producing or capable of producing in excess of 20 cubic ft per ac per year of wood at culmination of mean annual increment without regard to reserved status.

regeneration (artificial and natural)—The established progeny from a parent plant, seedlings or saplings existing in a stand, or the act of renewing tree cover by establishing young trees naturally or artificially. May be artificial (direct seeding or planting) or natural (natural seeding, coppice, or root suckers) (adapted from Helms 1998).

remote sensing—Capture of information about the Earth from a distant vantage point. The term is often associated with satellite imagery but also applies to aerial photography, airborne digital sensors, ground-based detectors, and other devices.

reserved forest land—Land permanently reserved from management for the production of wood products by statute. Examples include national wilderness areas, national parks and monuments, and state parks.

ring width index—A measure of annual tree ring width that has been standardized for tree age.

riparian—Related to, living in, or associated with a wetland, such as the bank of a river, stream, or lake edge, or tidewater. The riparian biotic community significantly influences and is influenced by the neighboring body of water (Helms 1998).

sampling error—Difference between a population value and a sample estimate that is attributable to the sample, as distinct from errors due to bias in estimation, errors in observation, etc. Sampling error is measured as the standard error of the sample estimate (Helms 1998).

sapling—A live tree 1 to 4.9 inches in diameter.

sawlog—A log meeting minimum standards of diameter, length, and defect for manufacture into lumber or plywood. The definition includes logs with a minimum diameter outside bark for softwoods of 7 inches (9 inches for hardwoods) (Azuma et al. 2004).

sawn lumber products—Wood product manufactured from logs by means of a powered saw, such as a bandsaw or circular saw.

sawtimber trees—Live softwood trees of commercial species at least 9 inches in diameter at breast height (d.b.h) and live hardwood trees of commercial species at least 11 inches in d.b.h. At least 25 percent of the board foot volume in a sawtimber tree must be free from defect. Softwood trees must contain at least one 12-foot saw log with a top diameter of not less than 7 inches outside bark; hardwood trees must contain at least one 8-foot saw log with a top diameter of not less than 9 inches outside bark (Azuma et al. 2004).

Scribner rule—The common board foot log rule used to determine sawtimber volume. Scribner volume is estimated in terms of 32-ft logs for softwoods and 16-ft logs for hardwoods.

seedlings—Live trees <1 inch diameter at breast height and at least 6 inches in height (softwoods) or 12 inches in height (hardwoods).

shrub—Perennial, multi-stemmed woody plant, usually less than 13 to 16 ft in height, although under certain environmental conditions shrubs may be single-stemmed or taller than 16 ft.

slope—Measure of change in surface value over distance, expressed in degrees or as a percentage (Helms 1998).

snag—Standing dead tree ≥5 inches diameter at breast height and ≥4.5 ft in length, with a lean of <45 degrees. Dead trees leaning more than 45 degrees are considered to be down woody material. Standing dead material shorter than 4.5 ft are considered stumps.

stand age—Average age of the live dominant and codominant trees in the predominant stand size class.

stand size class—A classification of stands based on tree size. Large-diameter stands have the majority of trees at least 11 inches diameter at breast height (d.b.h.) for hardwoods and 9 inches d.b.h. for softwoods; medium-diameter stands have the majority of trees at least 5 inches d.b.h. but not as large as large-diameter trees; and small-diameter stands have the majority of trees less than 5 inches d.b.h.

state land—An ownership class of public lands owned or managed by states or lands leased by states for more than 50 years.

stocked or nonstocked—In the Forest Inventory and Analysis program, a minimum stocking value of 10 percent live trees is required for accessible forest land.

stocking—(1) At the tree level, the density value assigned to a sampled tree (usually in terms of numbers of trees or basal area per acre), expressed as a percentage of the total tree density required to fully use the growth potential of the land. (2) At the stand level, the sum of the stocking values of all trees sampled (Bechtold and Patterson 2005).

stratification—A statistical tool used to reduce the variance of the attributes of interest by partitioning the population into homogenous strata (Bechtold and Patterson 2005).

succession—The gradual supplanting of one community of plants by another (Helms 1998).

sustainability (sustainable)—The capacity of forests, ranging from stands to ecoregions, to maintain their health, productivity, diversity, and overall integrity in the long run, in the context of human activity and use (Helms 1998).

terrestrial—Of or relating to the Earth or its inhabitants; of or relating to land as distinct from air or water.

thermokarst—The process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice (van Everdingen 1998).

timberland—Forest land that is producing or capable of producing >20 ft^3 per ac per year of wood at culmination of mean annual increment. Timberland excludes reserved forest lands.

transect—A narrow sample strip or a measured line laid out through vegetation chosen for study (Helms 1998).

tree—A woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown with a minimum height of 15 ft at maturity. Any plant on the tree list in the current Forest Inventory and Analysis field manual is measured as a tree.

understory—All forest vegetation growing under an overstory (Helms 1998).

unidentifiable plant parts—a layer type of the organic soil typically below the identifiable plant parts layer that is dominated by amorphous material. It may also contain small, decomposed plant parts and live roots.

unproductive forest land—Forest land that is not capable of producing in excess of 20 ft^3 per ac per year of wood at culmination of mean annual increment without regard to reserved status.

unreserved forest land—Forest land that is not withdrawn from harvest by statute or administrative regulation. Includes forest lands that are not capable of producing in excess of 20 ft^3 per ac per year of industrial wood in natural stands.

vascular plant—A plant possessing a well-developed system of conducting tissue to transport water, mineral salts, and sugars.

wilderness—(1) According to the Wilderness Act of 1964, "a wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." (2) A roadless land legally classified as a component area of the National Wilderness Preservation System and managed to protect its qualities of naturalness, solitude, and opportunity for primitive recreation. Wilderness areas are usually of sufficient size to make maintenance in such a state feasible (Helms 1998).

wildfire—Any uncontained fire, other than prescribed fire, occurring on wildland. Synonym: wildland fire (Adapted from Helms 1998).

Pacific Northwest Research Station

Website	https://www.fs.usda.gov/pnw
Telephone	(503) 808-2100
Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	sm.fs.pnw_pnwpubs@usda.gov
Mailing address	Publications Distribution Pacific Northwest Research Station USDA Forest Service 1220 SW 3rd Avenue Portland, OR 97204

Federal Recycling Program
Printed on Recycled Paper

Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Ave., Suite 1400
Portland, OR 97204