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Forests of the Tanana Valley State Forest and Tetlin National Wildlife Refuge, Alaska: Results of the 2014 Pilot Inventory

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Cover photo: Aerial image of boreal forest, bog, and pond areas in the Tanana River Valley taken coincident with the Goddard-LiDAR/Hyperspectral/Thermal LiDAR and multiband remote sensing sampling strips that will improve the accuracy of estimates of forest conditions across interior Alaska. Photo by Bruce Cook, NASA-Goddard Space Flight Center.

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Abstract

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This report highlights key findings from a test ("pilot") of an interior Alaska forest inventory design. The pilot inventoried the forests of the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR) in the Tanana River Valley of interior Alaska, covering 2.5 million ac. The inventory consisted of a systematic grid of 98 field-measured plots integrated with NASA's Goddard-LiDAR/Hyperspectral/Thermal (G-LiHT) imaging system. We summarize and interpret basic resource information such as forest area, ownership, volume, carbon stocks in trees, ground layers, dead wood, and soils; and vegetation community structure and composition. The black spruce forest type covered 49 percent of the forested area. Most of the aboveground live tree biomass was found in Alaska birch and black spruce forest types, but white spruce forest types had the highest mean aboveground live tree biomass per acre. Standing dead tree biomass was 8 percent of the amount in the live tree pool, with the greatest amounts in the white spruce forest type. Soil carbon per acre in the measured layers was highest in black spruce forests and lowest in aspen forests. Biomass of ground layers (i.e., moss and lichen mats) was almost twice as high on black spruce forests than on other forest types. Shrub and grass cover were comparable among units, but forb cover was greater on TVSF than on TNWR. The design and protocols tested during this pilot were refined for the implementation of the large-scale inventory of forests of interior Alaska that started in 2016.

Keywords: Forest Inventory and Analysis, boreal forests, understory vegetation, down woody material, biomass, soil carbon, lichen, moss, carbon pools, LiDAR, remote sensing.

Summary

The boreal forests of interior Alaska cover about 110 million ac and appear to be changing rapidly in response to warming temperatures. The status and trends of these forests are poorly understood owing, in part, to the lack of a comprehensive inventory. In 2014, the U.S. Forest Service's Forest Inventory and Analysis (FIA) program in conjunction with the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center carried out a test ("pilot") of an interior Alaska inventory design. The pilot inventoried the forests of the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR) in the Tanana River Valley of interior Alaska, covering 2.5 million ac. The inventory consisted of a systematic grid of 98 field-measured plots integrated with NASA's Goddard-LiDAR/Hyperspectral/Thermal (G-LiHT) imaging system. The design and protocols tested during this pilot were refined for the implementation of the large-scale inventory of forests of interior Alaska that started in 2016.

Black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.) was the most common forest type, covering 49 ± 5 percent of the forested land area (total ± standard error). Most of the aboveground live tree biomass was found in Alaska birch (*Betula neoalaskana* Sarg.) (18.0 ± 4.4 million tons) and black spruce (13.9 ± 2.7 million tons) forest types on the TVSF. However, white spruce (*P. glauca* Moench Voss) forest types had the highest mean aboveground live tree biomass per acre on both the TVSF (48.8 ± 11.6 tons per acre) and TNWR (46.2 ± 4.8 tons per acre). Black spruce forests on the TNWR had the lowest mean biomass per acre (8.8 ± 2.8 tons per acre). Standing dead tree biomass was 8 percent of the amount in the live tree pool, with the greatest amounts in the white spruce forest type. Birch forests on the TVSF had 48 percent of the biomass of down woody materials (DWM) in the study area despite covering only 24 percent of the forested area. Birch (5.3 ± 1.6 tons per acre) and aspen (*Populus* spp. (5.8 ± 1.5 tons per acre) forests on the TVSF had the highest DWM biomass per acre, while black spruce forests (0.4 ± 0.1 tons per acre) on TVSF lands had the lowest. The majority of the soil carbon (C) in the litter, organic, and the top 1 inch of mineral soil occurred on black spruce (36 percent) and birch (23 percent) forest types across the two inventory units. Soil C per acre in the measured layers was highest in black spruce forests (28 ± 2.6 tons per acre) and lowest in aspen forests (14.9 ± 6.7 tons per acre). Frozen soils were encountered on 14 of the sampled plots, resulting in incomplete measurements and the potential for bias in the statistical estimates. Biomass of ground layers (i.e., moss and lichen mats) was greatest on black spruce forests on the TVSF (10.5 ± 1.3 tons per acre). These forests had almost twice the biomass per acre of any other forest type. Most of the nonvascular ground cover in the inventory unit was in the

form of nitrogen-fixing feather mosses (57 ± 5 percent). Mean cover of tally tree species was greater on TVSF than TNWR (48 ± 2.4 vs. 38 ± 3.6 percent, respectively). Mean shrub and grass cover were comparable among units (overall means of 44 ± 2.5 and 10 ± 1.6 percent for shrubs and grasses, respectively), while forb cover was greater on TVSF than on TNWR (15 ± 2.4 vs. 7.0 ± 1.8, respectively. The most common vascular plant species recorded overall include (in descending order) lingonberry (*Vaccinium vitis-idaea* L.), black spruce, Alaska birch, bog Labrador tea (*Ledum groenlandicum* Oeder), white spruce, green alder (*Alnus viridis* (Chaix) DC.), bog blueberry (*Vaccinium uliginosum* L.), and prickly rose (*Rosa acicularis* Lindl.), all recorded on at least 35 percent of all plots. In terms of all estimated pools (aboveground live tree and standing dead tree, DWM, ground layer, and surface soil) C for the various forest types by inventory unit, soils were the largest pool (47 to 84 percent), live trees for 13 to 47 percent, standing dead trees for 1 to 6 percent, DWMs accounted for 1 to 14 percent, and the ground layer for 0 to 7 percent of the C in all estimated pools.

To increase the precision of the inventory estimates, the relatively sparse field plot sample was augmented with G-LiHT data collected in sample strips across the watershed. Initial analyses are described; work is ongoing to integrate the data into inventory estimation. G-LiHT is an airborne imaging system that simultaneously maps the composition, structure, and function of terrestrial ecosystems using LiDAR, imaging spectroscopy, and thermal imaging. G-LiHT provides high-resolution (~3.28 ft [~1 m]) data that are well suited for studying tree-level ecosystem dynamics, including assessment of forest health and productivity of forest stands and individual trees. In addition, G-LiHT data support local-scale mapping and regional-scale sampling of plant biomass, photosynthesis, and disturbance.

Contents

Introduction[1]

The only place in the United States lacking a comprehensive forest inventory is the 111 million acres of boreal forest in interior Alaska, which is 15 percent of all forested land in the nation.

The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service monitors the status and trends in the forests of the United States. One key region of the United States that has yet to be inventoried is Alaska's interior boreal forests. Remoteness, a limited road network, and lack of infrastructure have prevented the FIA program from conducting an inventory in the region (Barrett and Gray 2011). In 2014, the Pacific Northwest Research Station's FIA (PNW-FIA) program along with the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center carried out a pilot inventory in the Tanana River Valley of interior Alaska. The inventory occurred on the state of Alaska's Tanana Valley State Forest (TVSF) and the U.S. Fish and Wildlife Service's Tetlin National Wildlife Refuge (TNWR). The inventory was a partnership among multiple agencies and organizations including the Alaska Division of Forestry, University of Alaska, U.S. Fish and Wildlife Service, U.S. Geological Survey, and Oregon State University.

A pilot inventory in interior Alaska is timely because the boreal forests of the region contain an estimated 111 million ac of forested lands or roughly 15 percent of the forested land of the United States (Barrett and Gray 2011). Additionally, this region has seen some of the greatest increases in air temperature in North America (Hinzmann et al. 2013, Wolken et al. 2011). Climate change also appears to be driving increases in the frequency and severity of fires in the region (Kasischke and Turetsky 2006, Turetsky et al. 2011) as well as accelerated rates of permafrost degradation (Jorgenson et al. 2001, 2010). Studies suggest that spruce trees are experiencing declines in growth linked to increasing temperatures and longer growing seasons in some areas (Barber et al. 2000, Beck et al. 2011, Juday et al. 2015) while expanding in others (Roland et al. 2013). The region could be experiencing a biome shift toward ecosystems dominated by deciduous tree species, shrubs, and grasses (Beck et al. 2011, Johnstone et al. 2010). Other research indicates that the Alaska boreal forest represents a broad array of ecosystems that are likely to have unique responses to climate change (Chapin et al. 2010, Jorgenson et al. 2013).

Inventory Design

The Tanana River Valley is drained by the Tanana River (fig. 1). In the southern part of the Tanana River Valley, the river is fed by streams from the Alaska Range, and, in the north, it is fed by streams from the Yukon-Tanana uplands. The valley bottom is typically a wide alluvial floodplain. The valley rises to 2,000 ft in its southern and eastern portions (Hanson 2013). Average summer temperatures in the valley are

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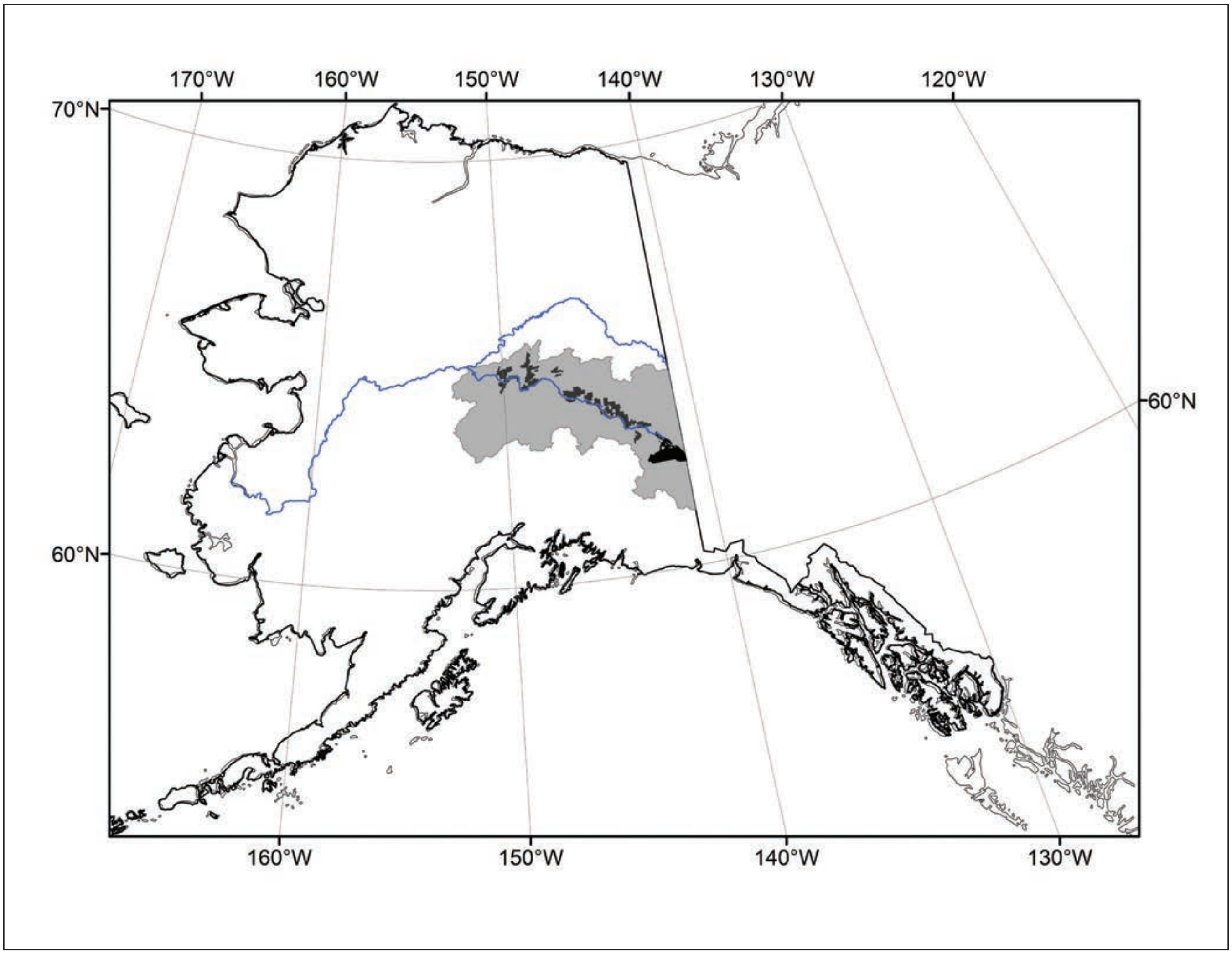

Figure 1—Tanana River basin (in gray) and inventoried lands (in black) within the state of Alaska. The Yukon and Tanana Rivers are shown in blue.

63 °F, and average winter temperatures are -10 °F. The average annual precipitation in the valley is 10.5 inches (Hanson 2013). The TVSF and TNWR land management units are not contiguous, and their positions on the landscape reflect the differences in key management objectives (timber versus wildlife habitat). TVSF lands are most often situated on side hills and active floodplains where productive timber stands occur, with an average elevation of 1,340 ft above sea level (range 250 to 2,900 ft). TNWR, although south of the TVSF, is situated at higher elevations, with an average of 2,200 ft (range 1,770 to 2,860 ft), most commonly on poorly drained lands and lakes within the broad river drainage.

The TVSF covers 1.82 million ac, and the TNWR covers 0.73 million ac. The inventory consisted of a field sample and a remotely sensed sample (fig. 2).

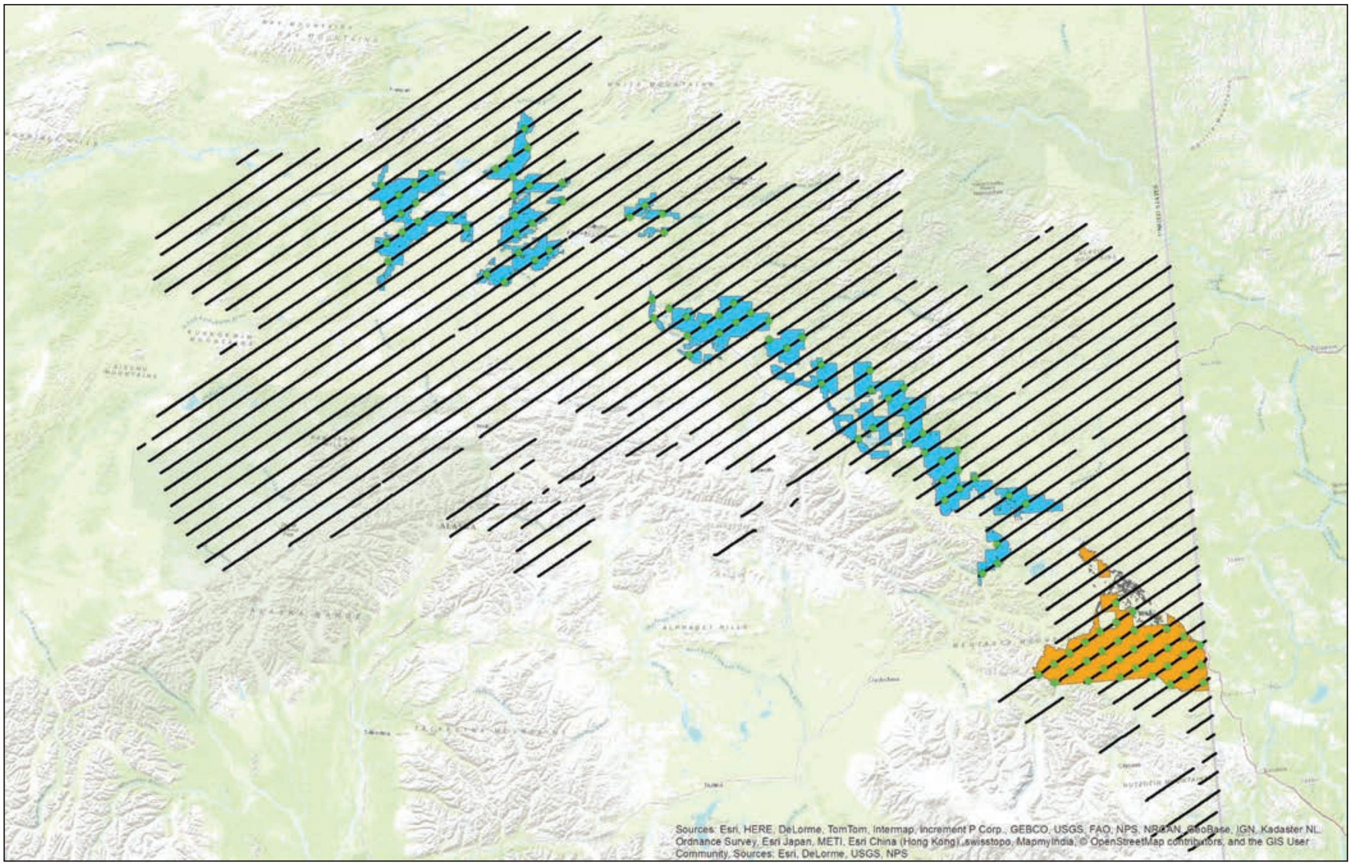

Figure 2—Pilot inventory plot design, showing the approximate location of the plot grid (green dots), the Goddard-LiDAR/Hyperspectral/Thermal imaging system sample strips, the Tetlin National Wildlife Refuge (orange), and the Tanana Valley State Forest (blue).

A spatially balanced design was used to identify field sample points across all of interior Alaska following standard FIA procedures with a tessellation of hexagons and one sample plot selected per hexagon (Bechtold and Patterson 2005). The Tanana pilot inventory plot locations were identified at one-fourth the intensity (one plot per 24,000 ac) of the standard FIA sample of one plot per 6,000 ac. A total of 104 plot locations were designated. In most cases, helicopters were required to get crews to the plots to take ground measurements (fig. 3). The remote sensing sample consisted of parallel strips of NASA's Goddard-LiDAR/Hyperspectral/Thermal (G-LiHT) imaging system data flown by aircraft; strips were 5.8 mi apart and 800 ft in width and included all preidentified field plot locations in the forested areas of the Tanana basin (mountainous nonforest areas were not flown). Figure 4 shows an example of an output from the G-LiHT data.

Field measurements were taken only at the 98 sample plots where lands qualifying as forest intersected all or part of the FIA plot footprint. Forest land is defined as an area at least 1 ac in size and >120 ft in width that currently has or recently had

Figure 3—Helicopter used to transport field crew to landing zone near a Forest Inventory and Analysis field plot. Mount Denali is in the background.

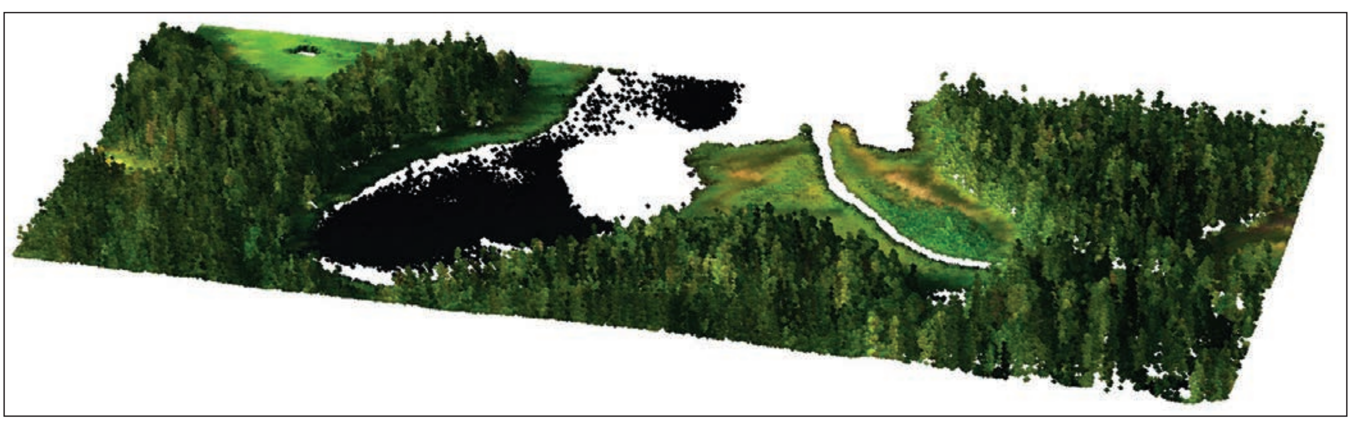

Figure 4—Example of Goddard-LiDAR/Hyperspectral/Thermal imaging system airborne remote sensing data collected in the Tanana Valley.

at least 10 percent cover of tree species and is not being managed for a nonforest land use that would preclude forest succession. FIA-defined tree species are woody perennial plants that commonly have a single well-defined stem exceeding 15 ft in height at maturity over a substantial portion of their range. Forested plots were measured from June through August 2014.

The nationally standardized "core" FIA plot footprint consists of a cluster of four points, with three points evenly spaced 120 ft from plot center (fig. 5). The core protocols consist of classifying land use, ownership, topography, and forest type on fixed 24-ft-radius subplots around each point; thus an individual plot may sample

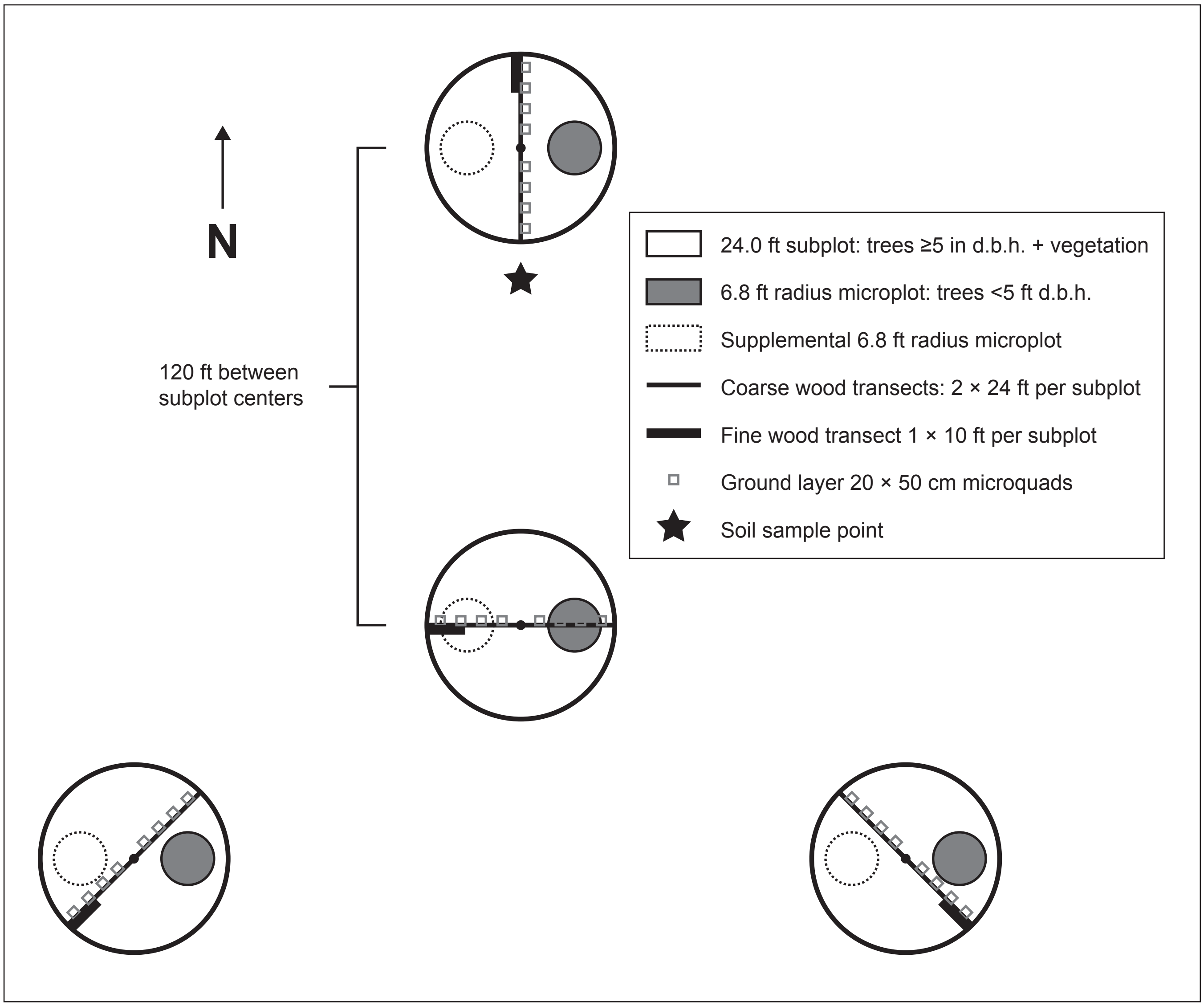

Figure 5—Design of the Forest Inventory and Analysis field plot used in the Tanana pilot study, showing the layout and location of the different measurements within the plot footprint. d.b.h. = diameter at breast height.

Forest Inventory and Analysis

Figure 6—Field crew members measuring tree heights in a recently burned black spruce stand (cones and small branches appear clumped at the tops of the dead trees).

multiple forest or nonforest conditions (Bechtold and Patterson 2005). Trees ≥5 inches diameter at breast height (d.b.h.) are measured on each subplot, and trees 1 to 4.9 inches d.b.h. are measured, and seedlings ≥1-ft tall and <1 inch d.b.h. counted, on 6.8-ft radius microplots offset from each point (fig. 6). Core-optional protocols implemented in the Western States and also in this pilot included measurement of understory vegetation on the subplots and down woody materials (DWM) on transects crossing each subplot. The PNW-FIA program worked with partners and scientists in the region to identify key variables of interest to understand the current state of these boreal ecosystems. In addition to the core and core-optional FIA field protocols, PNW-FIA incorporated additional field protocols based on responses from and interactions with scientists and stakeholders through a series of workshops. Specific changes to the field protocols included the addition of a second microplot on each FIA subplot (USDA FS 2016) to allow for improved sampling of small-diameter trees such as those found in many lowland black spruce (*Picea mariana* (Mill.) Britton, Sterns and Poggenb.) forests common throughout interior Alaska (Van Cleve et al. 1983). Previous work by PNW-FIA in 2007 in interior Alaska identified the need for increased sampling of small-diameter trees (Andersen et al. 2011). As soils in boreal forests can contain up to 85 percent of the total ecosystem carbon (C) (DeLuca and Biosvenue 2012, Malhi et al. 1999, Tarnocai et al. 2009), the PNW-FIA program modified the optional "Phase 3" FIA soil protocol (O'Neill et al. 2005) to improve the sampling of boreal forest soils. Ground layer cover of nonvascular plants can be an important component of ecosystem function and structure in boreal ecosystems (Hollingsworth et al. 2008). PNW-FIA implemented a ground layer protocol to improve the sampling of nonvascular ground cover on field plots using methods that had been tested in the region (Smith et al. 2015). Nonforest conditions on plots that were field visited with measured forest land (e.g., meadows next to forest) were also measured to provide information on transition zones and surrounding vegetation. In addition, collaborators with the U.S. Fish and Wildlife Service measured a full vascular plant census on subplot 1 and sampled insects on the plots in the TNWR.

Stratification and Analyses

Incorporation of remotely sensed data can improve the ability to provide statistically sound insights with a reduced intensity of field plots for some variables of interest (Andersen et al. 2011, Barrett et al. 2009). Population estimates, means, and variances were calculated using standard procedures for poststratification, using remotely sensed information to improve the accuracy of the plot-based estimates (Cochran 1977, Scott et al. 2005). Because the G-LiHT data were not yet fully processed and available for this initial pilot compilation, we used the Landsat-based National Land Classifcation Database (NLCD) to develop our stratification (Homer et al. 2007). Poststratification layers are independent of field data and improve the precision of inventory estimates based on the ability of stratification classes to reflect variation in field attributes; when available, the G-LiHT stratification should markedly improve the precision of inventory estimates. NLCD pixels that intersected the ownership layers for TVSF and TNWR defined the area of the population, and NLCD classes were grouped into strata by ownership and potential forest/nonforest classes. The ratios of the number of pixels within each strata to the known area of sampled lands determined the stratum weights for plots in each class and were used to calculate population means and variances. Ratio estimates (e.g., tons/acre), and their variances were calculated using the ratio of means estimator (Scott et al. 2005).

This initial analysis of the interior pilot data focused on biomass and C attributes and compiled plot data into estimates by landowner (TVSF and TNWR) and forest type. The FIA program defines forest types as “a classification of forest land based upon, and named for, the tree species that forms the plurality of live-tree stocking” (USDA FS 2016). Variance estimates are reported as standard errors (SE) and are shown in the text as ± SE.

Subsequent inventory implementation—

Since conducting the measurements and initial analyses for this pilot study, FIA was funded by Congress to implement a forest inventory for interior Alaska. In partnership with the Alaska Department of Natural Resources, University of Alaska Fairbanks and Anchorage, and local landowners, field work in the Tanana River basin was initiated in 2016 and is planned for completion in 2018. Based on the results of the pilot, as well as logistical and cost considerations, the following changes were made to procedures as envisioned in the pilot:

- Plot density was reduced to one-fifth the national density from one-fourth as implemented in the pilot (to one plot per 30,000 ac)
- The boundaries of the river-basin inventory units were adjusted to avoid splitting large national parks into separate units sampled many years apart. The Tanana unit was adjusted to encompass Denali National Park (originally in three units), while the Copper-Susitna unit was adjusted to encompass Wrangell-St. Elias National Park (originally in two units).
- The second microplot for measuring seedlings and saplings was dropped. Instead, saplings are being measured in a larger area around the core microplot equal to the area of two microplots (radius 9.6 ft). These trees will be readily distinguishable from the national core.
- Soil cores are being collected at three locations on the plot instead of one to improve the precision of estimates of this large C pool, and greater effort will be made to collect mineral soil to a depth of at least 4 inches whenever possible.

Status of Forest Types and Tree Biomass on the TVSF and the TNWR[2]

Interior Alaska is experiencing some of the greatest increases in temperature in North America (Stafford et al. 2000). These changes appear to be contributing to increases in the frequency and severity of fires (Kasischke and Turetsky 2006), declines in growth of white spruce (*Picea glauca* Moench Voss) (Beck et al. 2011), changes in hydrology as permafrost degrades (Jorgenson et al. 2013), and greater occurrence of insect outbreaks (Hansen et al. 2016, Sherriff et al. 2011). The changes occurring in the region highlight the importance of providing a baseline assessment of the current status of the forests in the region. Knowledge of the current status of forests in the region is also important to gain insights into the capacity to use forest resources for timber and energy production (Fresco and Chapin 2009).

Methods

The footprint of 98 plots intersected with lands that met the FIA definition of forest (fig. 7). The FIA plots were used to provide estimates of the area of the forest types and the aboveground biomass of live and standing dead trees in the TVSF and the TNWR. Trees ≥5 inches d.b.h. were measured on each 24-ft-radius subplot, and trees 1 to 4.9 inches d.b.h. were measured on two 6.8-ft-radius microplots per subplot. Tree measurements included d.b.h., height (and height to broken top), species, crown ratio, crown class, and damages. In addition, seedlings (conifers ≥0.5 ft tall or hardwoods ≥1 ft tall, and <1 inch d.b.h.) were counted by species in each microplot. (Smaller trees in many ecosystems are often ephemeral; these size limits are used by FIA nationally to balance field effort with the likelihood of a tree being established and likely to survive in favorable conditions.) The area of each sample size per plot defined the trees-per-acre area expansion for each tree. Aboveground "bone-dry" (oven-dry; 0 percent moisture content) tree biomass was calculated for trees ≥1 inch d.b.h. using equations in Manning et al. (1984) for black spruce, white spruce, and quaking aspen (*Populus tremuloides* Michx.); Singh (1984) for tamarack (*Larix laricina* (Du Roi) K. Koch); Alemdag (1984) for Alaska birch (*Betula neoalaskana* Sarg.); and Standish (1983) for balsam poplar (*P. balsamifera* L. var. *angustifolia* (James) S. Watson). A taper model was used to adjust estimates for broken-top snags and snag decay class used to assign decay-reduction factors from Woodall et al. (2011). Merchantable volume of live trees (cubic foot, for trees ≥5 inches d.b.h., and international board-foot rule, for conifers ≥9 inches d.b.h. and hardwoods ≥11 inches d.b.h.) were calculated with equations from Larson and Winterberger (1988).

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Forest Inventory and Analysis

Figure 7—Aerial photo of mosaic of forest and wetlands in the Tanana River Valley.

Results

The majority (89 percent) of the total land area of both inventory units (TVSF and TNWR) was forested (table 1). Twenty percent of the land area in TNWR was nonforest, whereas 3 percent of the land area in TVSF was nonforest.

Black spruce (48 percent) and birch (29 percent) forests were the most common forest types across both inventory units.

Black spruce (48 percent) and birch (29 percent) forests were the most common forest types across both inventory units (table 2). On the TVSF, black spruce and birch forests represented 42 and 32 percent of the area, respectively, while on the TNWR they represented 69 and 20 percent of the area, respectively (table 2).

There were 3,861 live trees and 271 standing dead trees measured on the 98 forested plots across the TVSF and TNWR. Six tree species were measured; white spruce had the most aboveground live tree biomass, followed by black spruce and Alaska birch (table 3).

There were an estimated 55.604 (± 5.38) million tons of aboveground live tree biomass on the two inventory units (table 4). The majority (86 percent) of this was found on forests of the TVSF (47.6 ± 5.0 million tons). An estimated 4.3 (± 1.0) million tons of standing dead tree biomass were found on the two inventory units, or 7.7 percent of the live tree biomass. Proportions of dead to live were lowest in the black spruce forest type (2.8 ± 0.6 percent) and substantially higher in the white spruce forest type (11.5 ± 6.1 percent).

Table 1—Estimated area of land cover categories in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR), derived from the Forest Inventory and Analysis field plot weights[a]

Land type	TVSF	SE	TNWR	SE	Total	SE
			Acres			
Forest	1,740,617	34,026	537,052	44,517	2,277,669	56,032
Nonforest	58,872	29,047	145,688	46,727	204,560	55,019
Noncensus water	0	0	0	0	0	0
Census water	0	0	52,833	28,064	52,833	28,064
Total area	1,823,599	44,738	727,043	64,538	2,560,642	78,528

Note: Census water includes bodies of water ≥4.5 ac in size and rivers ≥200 ft wide. SE = standard error.
[a] Estimated area is based on the plot sample and may differ from mapped classifications.

Table 2—Estimates of the area of forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Acres			
Black spruce	732,460	103,208	373,017	58,304	1,105,478	118,537
White spruce	240,778	71,419	56,148	31,017	296,926	77,864
Aspen	82,319	46,142	0	0	82,319	46,142
Birch	555,832	97,770	107,887	46,882	663,718	108,429
Poplar	94,000	48,112	—	—	94,000	48,112
Nonstocked	35,227	30,491	—	—	35,227	30,491
Total area	1,740,617	34,026	537,052	44,517	2,277,669	56,032

Note: Totals may be off because of rounding; data subject to sampling error. SE = standard error. — = estimated at less than 500 ac.

Table 3—Estimated aboveground live tree biomass by species in the Tanana study area, showing totals and per-acre means

Species	Total	SE	Mean	SE
	- - - -*Thousand tons*- - - -		- - - -*Tons per acre*- - - -	
Tamarack	13	10	0.01	0
White spruce	18,350	4,444	8.06	1.95
Black spruce	16,897	2,500	7.42	1.09
Alaska birch	16,605	3,669	7.29	1.61
Quaking aspen	1,764	1,419	0.77	0.62
Balsam poplar	1,974	999	0.87	0.44
All species	55,604	5,378	24.4	2.3

SE = standard error.

Table 4—Estimates of total aboveground tree biomass (thousands of tons) for live and standing dead trees in forests on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Thousand tons			
Live trees:						
Black spruce	13,891	2,652	3,279	1,136	17,170	2,885
White spruce	11,752	4,433	2,592	1,486	14,344	4,676
Aspen	1,811	1,822	—	—	1,811	1,822
Birch	18,009	4,403	2,139	1,339	20,148	4,602
Poplar	2,132	1,097	—	—	2,132	1,097
Nonstocked	—	—	—	—	—	—
Total live	47,594	5,009	8,010	1,957	55,604	5,378
Standing dead trees:						
Black spruce	367	99	115	42	481	107
White spruce	1,559	867	95	78	1,654	871
Aspen	188	174	—	—	188	174
Birch	1,350	358	41	32	1,391	359
Poplar	331	287	—	—	331	287
Nonstocked	256	222	—	—	256	222
Total dead	4,052	948	251	90	4,303	952

SE = standard error. — = no samples fell in this combination of classes.

The forests of the TVSF had higher live tree biomass per acre (27.3 ± 2.8 tons per acre) than those of the TNWR (14.9 ± 3.7), primarily owing to the greater proportions of white spruce forest area on TVSF (fig. 8). On both the TVSF and the TNWR, the greatest tree biomass per acre occurred in white spruce forest types, and the lowest occurred in black spruce forests. White spruce forests had similar biomass per acre for both the TVSF (48.8 ± 11.6 tons per acre) and the TNWR (46.2 ± 4.8 tons per acre), whereas black spruce forests on the TVSF had twice the biomass per acre as TNWR. Nonstocked forest was found on one recently disturbed plot and had the highest standing dead tree biomass per acre (7.3 ± 0 tons per acre). Black spruce forests had the lowest standing dead tree biomass per acre (0.4 ± 0.1 tons per acre).

Similar to the biomass results, merchantable net volume of live trees was substantially higher on TVSF than on TNWR (table 5). Merchantable volumes per acre were much higher in white spruce forests than the other forest types, and were lowest in black spruce for cubic-foot volume. Although cubic-foot volume of black spruce was lower on TNWR than TVSF, the reverse was true for board-foot volume, reflecting a greater density of large trees on that forest type in TNWR than in

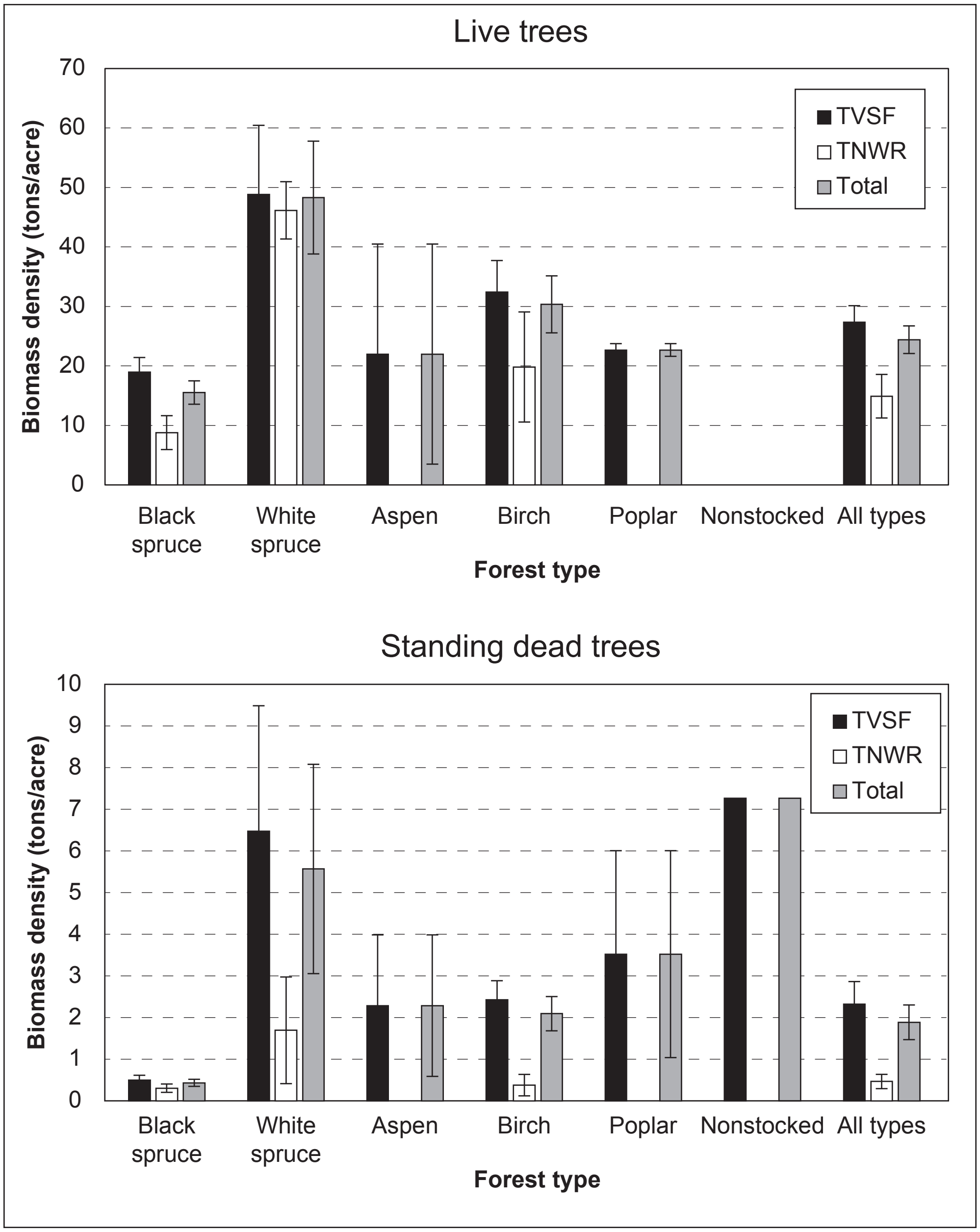

Figure 8—Estimates of aboveground live and standing dead tree biomass per acre (tons per acre) in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR).

Table 5—Estimates of live tree merchantable net volume (cubic and board foot) in forests on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Cubic feet per acre			
Black spruce	183	40	115	61	160	34
White spruce	1,988	518	1,616	277	1,918	424
Aspen	955	845	—	—	955	845
Birch	984	213	146	97	848	188
Poplar	591	68	—	—	591	68
All forest types	743	127	279	105	634	101
			Board feet per acre (international rule)			
Black spruce	148	72	352	332	217	122
White spruce	6,950	2,215	5,831	967	6,738	1,805
Aspen	198	176	—	—	198	176
Birch	2,007	698	178	191	1,709	599
Poplar	1,011	442	—	—	1,011	442
All forest types	1,728	459	890	435	1,531	366

SE = standard error. — = no samples fell in this combination of classes.

TVSF. Hanson (2013) estimated 963 ft^3/ac and 1,885 board feet per acre net volume on state lands in the Tanana Valley, of which 63 percent was TVSF. The lower volume estimates from the FIA inventory may be due to the different land base, or to using different equations in our current compilation system. Older FIA documentation had some of the same equations Hanson (2013) identified for interior Alaska, which we will evaluate before completing the basinwide inventory.

Discussion

There was almost twice the tree biomass per acre on forests of the TVSF as on the TNWR forests.

There was almost twice the tree biomass per acre on forests of the TVSF as on the TNWR forests. Within the TNWR, white spruce forests had more than five times the biomass per acre as black spruce forests (table 4). These results highlight the variability in forests within the region. Forest composition and structure in interior Alaska are strongly determined by physiographic characteristics that influence solar radiation, and soil temperature and moisture (Viereck et al. 1983). Sites with colder soils (e.g., lowlands and north-facing slopes) are commonly dominated by black spruce forests with lower tree biomass, whereas sites with warmer soils (e.g., south-facing uplands) are often dominated by white spruce or deciduous forests (Viereck et al. 1983). The TVSF is characterized primarily by sites supporting more productive forests that are important for their timber resources (Hanson 2013). The TNWR is primarily composed of less productive lowland forests, as indicated by aboveground live tree biomass per acre in black spruce forests at half the amounts found in TVSF. However, areas of more productive forests occur within the TNWR as evidenced by the presence of white spruce forests with high tree biomass per acre (fig. 9). Although black spruce forests had relatively low tree biomass per acre, the collective acreage of these forests highlights their importance to total tree biomass in the region.

Although the values for tree biomass per acre within forest types were generally consistent with the values found in Viereck et al. (1983) (table 6), the values for birch forests in this study were lower. One potential reason for the discrepancy might be that the FIA field sample was a probabilistic sample, whereas Viereck et al. (1983) subjectively sampled forests, which may have resulted in a sample of more productive forests present in the primary study area that was being used.

The FIA forest type classification is a simple grouping based on dominant species and obscures the reality that many forests have multiple dominant tree species, and that many with the same species are significantly different in stature, function, and composition of other species. This topic is explored in more detail later in this report. With additional work and some subjective assessment, it might be possible to group plots to level IV or V classes of Viereck et al. (1992) or other classifications that users might find useful.


Forest Inventory and Analysis

Figure 9—Dense ground layer of forage lichens and mosses in patchy mosaic of a mixed black and white spruce forest.

Table 6—Tree biomass for different forest types near Fairbanks, Alaska

Forest type	Number of stands	Range		Mean	SE
		Tons per acre			
Black spruce	4	7.07	49.00	22.72	9.40
White spruce	4	27.44	109.64	77.81	19.09
Aspen	2	20.76	78.02	49.39	28.63
Birch	3	41.00	65.63	49.77	7.95
Poplar	3	18.14	80.42	53.96	18.58

SE = standard error.
Source: Viereck et al. 1983.

Although this study represents a preliminary estimate for a subset of the landscape, it demonstrates the variation present in forest composition and density and the effect that can have on landscape- and regional-level estimates of live and dead tree biomass. We expect the mean biomass densities for forest land to change as we complete the Tanana River basin and move on to other areas of interior Alaska. Live tree growth is being estimated from increment cores and will be reported in future publications. Mortality rates will be difficult to estimate with much precision until these plots are up for remeasurement, hopefully in 10 to 12 years.

Characterizing Forest Vegetation of the Tanana Valley[3]

Introduction

Knowledge of the existing distribution and abundance of plant species and how they are organized into plant community types is important for monitoring the successional changes of natural ecosystems in response to both discrete and chronic disturbances. Many recent studies in Alaska have documented large-scale changes in vegetation cover linked to changes in climatic conditions. Shrubs are expanding into both arctic (e.g., Berner et al. 2015, Tape et al. 2006) and alpine tundra (Dial et al. 2007, 2016), hardwoods replace spruce in some areas (Johnstone et al. 2010), and white spruce forests are expanding in others (Roland et al. 2013). Our understanding of successional pathways is evolving as increasing fire frequency and permafrost degradation re-order community structure (Johnstone et al. 2008, Jorgenson et al. 2013). At the same time, new pest outbreaks are being observed that could further influence shifts in vegetation composition (Nossov et al. 2011, USDA FS 2015). These changes can affect biomass accumulation and

[3] Author: Bethany Schulz.

greenhouse gas emissions (Rupp 2011), which are commonly used to assess rates of climate change. In the past, national assessments of greenhouse gas emissions have excluded most of Alaska outside of southeast coastal forests owing to lack of data and the minimal amount of managed forested lands, and the long-held idea that the boreal region was a C sink.

Forest vegetation in interior Alaska is less species-rich in vascular plants than in other biomes, with a limited number of overstory tree species and fewer FIA forest types. However, plant species organize into many unique assemblages, depending on site characteristics. Characterizing forest plant communities beyond forest types determined by tree stocking can sharpen our focus/understanding of the consequences of the changes we may detect in future measurements, potentially influenced by changes in climate and disturbance regimes.

Vegetation data collected on the ground are relatively scarce in Alaska and are usually collected within a limited spatial extent owing to the logistical challenges of travel in interior Alaska. For example, sampling strategies are often limited to a land management unit (Roland et al. 2013) or along the limited road system (Hollingsworth et al. 2006, Malone et al. 2009). The FIA 2014 pilot project in interior Alaska provides a systematic sample of 71 plots within the TVSF and 27 plots on the TNWR. This relatively small sample size allows us to begin to explore the current structure and species distributions. Given rapid changes occurring and expected to occur in interior Alaska, documenting vegetation conditions now is essential for monitoring vegetation change over time. Using data generated from FIA's Vegetation Profile (VEG profile) protocol along with standard inventory data, the vegetation in the different forest communities sampled are characterized.

Methods

Standard national FIA core data elements, as described in the introduction, were collected on 98 plots and distributed systematically across the TVSF and the TNWR in interior Alaska. In addition, the FIA Core-Optional VEG Profile level of detail 3 protocol was implemented on all plots (USDA FS 2014c). Both forest and nonforest conditions were sampled if accessible. Data were collected on each subplot.

Structure was measured as canopy cover of growth habits by height layer (see the tabulation below). Growth habits include graminoids (grass-like plants), forbs, shrubs, tally species trees, and nontally tree species. Tally tree species are those that are tracked and measured with core FIA tree measurements. The tally list is short for Alaska, and only six species are found in interior Alaska: black spruce, white spruce, Alaska birch, balsam poplar, trembling aspen, and tamarack. Other species encountered as trees are recorded as nontally trees.

Layer number	Range
1	Ground level (0 to 2 ft)
2	Greater than 2 to 6 ft
3	Greater than 6 to 16 ft
4	Greater than 16 ft

Species information was collected for the four most abundant vascular plant species per growth habit, if the species was present with at least 3 percent canopy cover on a subplot. Abundance was recorded as a percentage of the area of a subplot with canopy cover. The growth habits for species data are as described for structure, except for trees, which are recorded as small trees (distinct main stem but less than 5 inches d.b.h.) or large trees (at least 5 inches d.b.h.), regardless of tally tree status. These data were summarized by averaging subplot cover measurements by plot (and condition for those plots with more than one condition class), and determining the percentage of plots where species were recorded for various domains. Estimates of forest structure and species cover were produced following standard FIA compilations (Bechtold and Patterson 2005).

In addition, a full census of all vascular plants on subplot 1 was implemented on the plots within the TNWR by the U.S. Fish and Wildlife Service (which also conducted insect surveys). Here, all species were recorded with an ocular estimate of percentage canopy cover, with no minimum cover limitation.

Results and Discussion

Standard FIA forest types are based on the existing tree species stocking. Forest type is one of several variables that define a forested "condition;" other biologically defined variables include stand size class and tree density. Although the official definition refers to the "plurality" of tree species, all FIA forest types in Alaska refer to one tree species only. Because plot centers are systematically selected, there are many plots where several conditions or forest types occur on a single plot. For the interior Alaska pilot, nonforest conditions on forested plots were included in measurements; 15 of 26 subplots with nonforest conditions have VEG Profile data.

Of the 98 sampled plots, 73 were intact (fully forested in a single condition), 11 were fully forested but with multiple conditions, and 14 plots included some nonforest land cover class (table 1). The black spruce forest type was the most common, with 38 intact plots, and occurred on 7 plots with multiple conditions and 8 plots with some nonforest conditions. Alaska birch was the second most common with 20 intact plots; white spruce was third with 8 intact plots. All the nonforest land cover classes sampled were natural vegetation types, with shrubland being most common. Full descriptions of forested conditions sampled and distribution between the two land managers are included in table 7.

Structure—

Average cover by growth habit and layer varied by forest type and land manager (fig. 10). Note that all aspen and balsam poplar stands are within the TVSF, and that the white spruce forests on TNWR are represented by mixed-condition plots and some plots with nonforest conditions. Tree cover in black spruce stands on TVSF was greatest in layer 3, while tree cover in TNWR was greatest in layer 2. White spruce stands had similar profiles for both management areas, but with grass and forbs providing more cover in TVSF. The tally tree species cover tends to be highest in birch and balsam poplar stands. Aspen and balsam poplar stands occurred only in TVSF. Balsam poplar had the highest average cover of tally trees in layer 4 of all forest types, but these estimates are based on very small sample sizes. Nontally tree cover was minimal and is not shown to simplify the figures.

Shrubs were common in all types but varied by height. Low shrubs in layer 1 dominate in most forest types, with average canopy cover from greater than 25 to over 40 percent. In some stands, these low shrubs provide continuous ground fuels that play an important role in fire behavior. Tall shrubs (layers 3 and 4) are prominent in birch, white spruce, and balsam poplar forest stands. Tall shrubs often provide browse for wildlife species and contribute more to total biomass than other components of understory vegetation. Grass can compete with trees in regeneration harvest units; it was present in all types, with the highest values found in birch forest types on TVSF. Forbs were most abundant in balsam poplar stands.

Tall shrubs (layers 3 and 4) are prominent in birch, white spruce, and balsam poplar forest stands.

Vascular plant species—

Two methods were used to collect species records: (1) the core FIA VEG Profile and (2) a full census on subplot 1 conducted by TNWR. In total, 79 genera, 145 species, 11 subspecies, and seven varieties were recorded; 47 genera, 94 species, and 7 subspecies were recorded with the VEG Profile; and 68 genera, 115 species, 10 subspecies, and 7 varieties from the full census. There were 32 genera, 45 species, 3 subspecies, and 7 varieties recorded unique to the full census. Over the same TNWR plots where the full census was conducted, only 34 genera, 54 species, and 6 subspecies were recorded over the 105 subplots with the VEG Profile method. Scientific and common names, recorded growth habits, wetland indicator status, and with constancy (percentage of plots where recorded) by owner and survey method are shown in appendix 1. Note that the genus *Carex* is represented

Table 7—Number of plots by forested condition and percentage of plots with records of large (LT) and small (SD) trees by species

Condition and forest type description	Plot count			Tree species: Black spruce		Alaska birch		White spruce		Quaking aspen		Balsam poplar		Tamarack
	Total	TVSF	TNWR	LT	SD	LT	SD	LT	SD	LT	SD	LT	SD	SD
	- - - - Number - - - -			*Percentage of plots where recorded*										
Single condition:														
Black spruce	38	25	13	47	100	21	50	21	0	8	8	0	0	8
Alaska birch	20	17	3	20	45	80	90	55	60	5	25	5	5	0
White spruce	8	8	0	0	0	75	50	100	88	25	25	13	0	0
Aspen	3	3	0	0	33	33	67	67	67	67	67	0	0	0
Balsam poplar	3	3	0	0	0	0	0	33	67	0	0	100	100	0
Nonstocked	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Multiple condition:														
Black spruce/Alaska birch	4	4	0	75	100	100	100	50	100	0	0	0	0	0
Black spruce/multiage	3	0	3	33	100	0	100	67	100	0	0	0	0	0
White spruce/multiage	2	1	1	0	0	0	0	100	100	0	0	50	0	0
Alaska birch/multiage	1	1	0	0	0	100	100	100	100	0	0	0	0	0
White spruce/Alaska birch	1	0	1	0	100	100	100	100	100	0	0	0	0	0
Some nonforest:														
Black spruce/shrubland	3	2	1	33	100	0	33	0	0	0	0	0	0	33
Black spruce/mixed vegetation	2	1	1	50	100	50	0	50	100	0	50	0	0	0
White spruce/shrubland	2	2	0	0	0	100	50	100	50	0	0	0	0	0
Black spruce/shrubland/mixed vegetation	1	1	0	100	100	100	0	100	100	0	0	0	0	0
Black spruce/nonvascular	1	0	1	100	100	0	100	0	0	0	0	0	0	0
White spruce/mixed vegetation	1	1	0	100	100	0	100	100	100	0	0	0	0	0
Alaska birch/shrubland	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Alaska birch/nonvascular	1	0	1	0	100	0	100	0	0	0	0	0	0	0
Alaska birch/mixed vegetation	1	1	0	100	100	0	100	100	0	0	0	0	0	0
White spruce/nonvascular	1	0	1	100	0	0	0	0	100	0	0	0	0	0

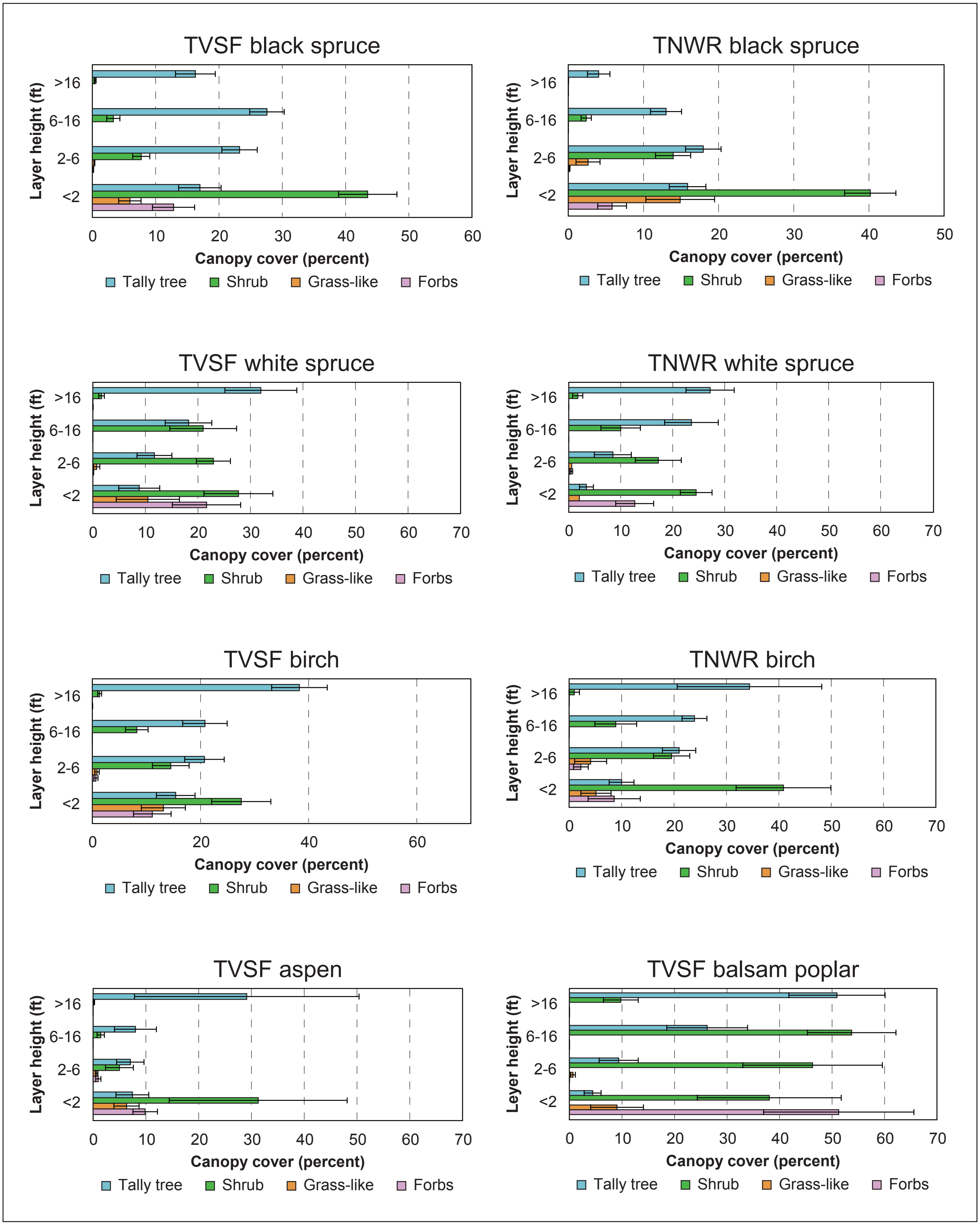

Figure 10—Average cover by growth habit by layer for five predominant forest types in the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR).

by 20 species. There are also 17 species of *Salix* (8 of which can attain small tree size), and 6 species of *Equisetum*. No introduced or invasive species were recorded in either effort. There is one record of the common dandelion (*Taraxacum officinale* ssp. *ceratophorum* (Ledeb.) Schinz ex Thell.), but this subspecies is native to Alaska.

Combining both methods of species surveys, in total 26 obligate wetland species (those species almost always occurring in wetlands) were recorded on 20 plots. Fourteen obligate wetland species were recorded on 11 plots using the Veg Profile method, and another 12 obligate species were recorded using the full census method plots. On TVSF, five plots had obligate wetland species; three were single-condition black spruce, one was black spruce with shrubland, and another was black spruce with shrubland and mixed vegetation. On TNWR, 12 plots were single-condition black spruce, 1 was black spruce with nonvascular vegetation, and 2 were white spruce—one with shrublands and another with nonvascular vegetation. Finding obligate wetland species within black spruce vegetation types is not unusual, considering that black spruce can be found in a variety of landscape positions. Wetland species occurring within a white spruce forest type is a bit unusual, as it is generally understood that white spruce is found on drier, more productive sites. This could indicate the presence of thermokarst formation—areas where ice wedges have melted out, often producing small ponds of standing water surrounded by slightly elevated lands now draining and drying out (Jorgenson et al. 2001). As we continue work in interior Alaska, it would be beneficial to note potential signs of thermokarst formation.

Most abundant species—

Tree and shrub species dominated the most commonly recorded abundant species for each forest type using the core FIA VEG Profile (table 8), and most forest types had several top species in common. The hardwood types with only a few sample plots had a few unique species that are included in table 8, but most species are ubiquitous across most forest types. The most abundant species plus any fruit-bearing species by land manager are shown in tables 9 and 10.

Tree species distributions are displayed by size across forest conditions in table 1. The VEG Profile data allow for a different perspective of regeneration than the sapling and seeding counts on microplots; abundance is recorded as canopy cover over the entire subplot area. Large trees were 5 inches or greater in diameter, and small trees were less than 5 inches in diameter (USDA FS 2014b). Black spruce and birch forest types are tied for number of other tree species found on single-condition plots, but white spruce and birch trees are found on more forest types and condition combinations than black spruce trees (table 7). Fifty percent of black

Table 8—Most common abundant species and percentage of plots where recorded overall and by forest type

	Forest type						
Species common name	All plots (n = 98)	Black spruce (n = 38)	Alaska birch (n = 20)	White spruce (n = 8)	Balsam poplar (n = 3)	Aspen (n = 3)	Other (n = 25)
	Percentage of plots where recorded						
Lingonberry	72 [1]	84 [3]	65 [4]	38	0	33	88
Black spruce	68 [2]	100 [1]	45	0	0	33	76
Alaska birch	67 [3]	53 [4]	100 [1]	88 [2]	0	67 [2]	68
Bog Labrador tea	62 [4]	87 [2]	55 [5]	0	0	33	64
White spruce	58 [5]	34	70 [3]	100 [1]	67 [2]	67 [2]	72
Green alder	53 [6]	40	75 [2]	63 [3]	0	67 [2]	60
Bog blueberry	38 [7]	53 [4]	25	0	0	33	44
Prickly rose	36 [8]	8	70 [3]	88 [2]	67 [2]	33	32
Bluejoint	28 [9]	13	40	38	67 [2]	67 [2]	28
Dwarf birch	24 [10]	42 [5]	5	0	0	0	24
Field horsetail	16	11	20	63 [3]	67 [2]	33	16
Quaking aspen	16	11	30	25	0	100 [1]	4
Fireweed	12	3	25	13	33	67 [2]	8
Thinleaf alder	8	0	5	38	100 [1]	0	4
Balsam poplar	6	0	5	13	100 [1]	0	4
Redosier dogwood	2	0	0	0	67 [2]	0	0

Note: Superscripts indicate the rank of the five most common species within each forest type; n = number of plots.

spruce plots had small Alaska birch trees present with at least 3 percent cover. Co-occurrence of spruce and birch on many plots reflects how FIA forest types do not identify mixed stands.

Nontally tree species were recorded as either large or small trees on seven plots and included green alder (*Alnus viridis* (Chaix) DC.), Bebb willow (*Salix bebbiana* Sarg.), and Scouler's willow (*S. scouleriana* Barratt ex Hook.). The seven plots included three white spruce, three birch, and one black spruce forest type.

Other alder and willow species were commonly recorded as shrubs and provided cover in the mid layers of most other conditions sampled. An alder species was recorded on 58 of 98 plots, and on 30 of those plots, the average subplot cover was greater than 15 percent. Green alder was the most commonly recorded species. Alder species are important pioneer species on many sites. They provide nitrogen fixation via symbiotic bacterial nodules, and litter production leads to higher C incorporation into soil, producing sites suitable for other plant species. Soils beneath alders are known to be higher in C and nitrogen than adjacent spruce or mixed-forest stands (Mitchell 1968). Thin-leaf alder *Alnus incana* (L.)

Table 9—Most commonly recorded species, plus fruit-bearing species in Tanana Valley State Forest (TVSF), with constancy and average cover where present

Common name	Constancy	Average cover	SE
		Percent	
Alaska birch	69	22	3.1
Lingonberry	67.6	13	2.2
White spruce	63.4	17	2.8
Black spruce	59.2	39	3.5
Bog Labrador tea	57.7	21	3.5
Prickly rose	42.3	15	3.8
Bluejoint reed grass	35.2	16	3.7
Mountain alder	26.8	12	2.4
Bog blueberry	25.4	10	2.4
Field horsetail	23.9	27	6.6
Cloudberry	14.1	4	1.2
High bush cranberry	12.7	11	6.4
Black crowberry	11.3	6	1.6
American red raspberry	4.2	2	0.4
Red currant	2.8	2	0.5

SE = standard error.

Table 10—Most commonly recorded species, plus fruit-bearing species in Tetlin National Wildlife Refuge (TNWR), with constancy and average cover where present

Common name	Constancy	Average cover	SE
		Percent	
Black spruce	92.6	24	3
Lingonberry	85.2	8	1.1
Bog Labrador tea	77.8	24	3.4
Bog blueberry	70.4	8	1.3
Alaska birch	63	19	6.7
Grayleaf willow	51.9	4	0.9
Dwarf birch	44.4	11	2.5
White spruce	44.4	15	5.1
Mountain alder	40.7	16	4.3
Black crowberry	33.3	8	2.2
Prickly rose	22.2	4	2.1
Cloudberry	7.4	2	0.8

SE = standard error.

Moench ssp. *tenuifolia* (Nutt.) Breitung has been subject to die-back in recent years, especially in dense stands that form along riverbanks (Nossov et al. 2011, USDA FS 2015).

There were 54 plots with one to three species of willow, and 32 plots with one of the seven willow species that may be encountered either as shrubs or trees (app. 1) (USDA NRCS 2015, Viereck and Little 2007). Grayleaf willow was recorded most often. Willows are important browse species, with feltleaf (*Salix alaxensis* (Andersonn) Coville, Bebb (*S. bebbiana* Sarg.), and grayleaf all being important for moose browse. Bebb willow is the most common species forming "diamond willow:" stems with diamond-shaped patterns along their trunks that can be carved into walking sticks or furniture (fig. 11). Formations are formed by several species of fungi that attack branches at the junction with the main stem (Viereck and Little 2007)


Matthew O'Driscoll

Figure 11—Carved Bebb's willow stems displaying "diamond willow" scar formations.

Tall alder and willow shrubs represent an underaccounted source of biomass; allometric equations based on cover and height alone do not exist. Although common in lands classified as forests, they also cover vast landscapes as the tall shrub vegetation cover. Tall shrubland cover type represent a measureable portion of the landscape: 6 percent of interior/Cook inlet—19,065,193 ac (tall shrub) and an additional 316,209 ac (low or tall shrub) (Boggs et al. 2014).

Common low shrubs include the important berry species valued as traditional food sources, lingonberry, (*Vaccinium vitis-idaea* L.), and bog blueberry, (*V. uliginosum* L.) (Hupp et al. 2015) as well as species that create continuous fuels for wildfire such as bog Labrador tea (*Ledum groenlandicum* Nutt.) and dwarf birch, (*Betula nana* L.) (fig. 12). Bog Labrador tea and lingonberry make up the majority of shrub cover in layer 1 in black spruce forest types (mean canopy cover 21.4 (SE 3.0) and 10.8 (SE 2.1), respectively). Prickly rose (*Rosa acicularis* Lindl.) produce rose hips, important for human use and forage for bird species (Viereck and Little 2007).

Common low shrubs include the important berry species valued as traditional food sources, lingonberry, (*Vaccinium vitis-idaea* L.), and bog blueberry.

Sarah Ellison

Figure 12—Detail of vegetation on a boreal forest floor showing forage lichen and lingonberry.

Only a few herbaceous species appear in tables 8 through 10; bluejoint grass (*Calamagrostis canadensis* (Michx.) P. Beauv.) and field horsetail (*Equisetum arvense* L.). Both can indicate rich, wet soils. Although many forb and grass species were recorded (65 forb species and 34 grass-like species), they may be more commonly present with percentage canopy cover lower than 3 percent.

Overall, TVSF is more diverse, with a wider range of elevations, forest types, and lower constancies for most common species recorded. Although berry species may be more dispersed on TVSF, one might find bigger patches there. If you are looking for new berry picking spots, you may have better success on the TNWR.

Crosswalk to the Alaska Vegetation Classification—
The Alaska Vegetation Classification (Viereck et al. 1992) is widely referenced by land managers and resource specialists and is often used to interpret vegetation mapping efforts in Alaska (Boggs et al. 2001, 2014; Cella et al. 2008). This classification is broadly hierarchical. Level I describes the major vegetation cover: forest, scrub, and herbaceous. At Level II, forests are defined as needle-leaved, broadleaved, and mixed. Needle-leaved and broadleaved designations indicate that conifer or deciduous tree species make up 75 percent or more of the tree cover. In mixed forests, there is no clear dominance of either needle-leaved or broadleaved species. Level III is defined by canopy closure; closed forests have canopy cover of 60 percent or more, open forests have between 25 and 60 percent canopy closure, and woodlands have less than 25, but at least 10 percent cover. Scrub vegetation classes (dominated by shrubs) include dwarf tree scrub, tall scrub, low scrub, and dwarf scrub. The dwarf tree scrub class is defined as vegetation having 10 percent or more cover of a tree species that will not exceed the height of 10 ft at maturity, and tall scrub is vegetation at least 5 ft tall, with 25 percent or more cover in tall shrubs. Herbaceous vegetation types are dominated by nonwoody vegetation and are divided into graminoid, forbs, bryoid (mosses and lichens), and aquatic vegetation. These are further divided by moisture classes; dry, mesic, and wet. Level IV of the Alaska Vegetation Classification begins to specify the dominant vegetation species, which can be difficult to distinguish from remotely sensed data over large geographic areas.

Using VEG Profile data together with tree data collected, each subplot or condition can be classified to at least Level III, and often beyond. I examined the Veg Profile subplot species records and classified each to Level III of the Alaska Vegetation Classification, often referring to Veg Profile Structure, Plot, Condition and Tree data to verify or adjust the Level III class. For each subplot or condition assessed, the FIA forest type assigned was noted. Hardwood stands less than 20 years old and conifer stands less than 30 years old were not included to avoid misplacement into Level I scrub types (10 complete and 2 partial plots). Table 11 demonstrates the wide variety of structure and composition that each of the five FIA forest types can represent, with both the FIA black spruce and birch forest types each keying out to nine different Alaska Vegetation Classification Level III classes. Summarizing the results of inventory by FIA forest types can lose sight of the complex relationships among site qualities, past and ongoing disturbances, and species composition and structure. As forest inventory continues in interior Alaska, there may be reason to further define the FIA forest types in this region.

Table 11—Number of plots of each Forest Inventory and Analysis (FIA) forest type where at least one subplot or condition represents a Level III type of the Alaska Vegetation Classification

			Level III		
Level I	**Level II**	**FIA forest type**	**Closed (1)**	**Open (2)**	**Woodland (3)**
I (forest)				*Number of plots*	
	A (needle-leaf)	Black spruce	9	33	14
		White spruce	4	9	4
		Birch	2	2	0
		Balsam poplar	0	1	0
	B (broadleaf)	Birch	12	7	1
		Aspen	1	0	0
		Balsam poplar	1	3	0
	C (mixed)	Black spruce	0	8	4
		White spruce	2	4	1
		Birch	6	10	0
		Balsam poplar	1	0	0
II (scrub)					
	A (dwarf tree)	Black spruce	2	9	6
		Nonstocked	0	0	2
	B (tall scrub)	White spruce	0	1	0
		Nonstocked	1	0	0
	C (low scrub)	Black spruce	0	1	0
		White spruce	0	1	0
		Birch	0	1	0
		Nonstocked	1	2	0
III (herbaceous)			Dry (1)	Mesic (2)	Wet (3)
	A (graminoid)	Nonstocked	0	0	2
	B (forb)	Nonstocked	0	0	1

Summary—

Vegetation data collected on the ground are relatively scarce in Alaska, but is essential to aid the interpretation of the remotely sensed data that managers have come to depend on with increasing frequency. One goal of vegetation data analysis is to understand how existing vegetation communities may change in the future. Shifts in species composition can be a signal of changes in moisture availability or drainage that are not evident at the soil surface. Changes in vegetation structure often trigger further change to communities by altering waterflow, nutrient cycling, and capture of solar radiation (Jorgenson et al. 2013, Sturm et al. 2001). Although the interior Alaska pilot was a first-time visit, some novel plant communities sampled could indicate sites undergoing transitions.

The VEG Profile provides important information about the arrangement of vascular plants in the forest stands sampled. Structure characterization is important for fire behavior modeling and wildlife habitat assessments. Data on the distribution of large and small trees reveal the presence of multiple other tree species on most plots assigned to a single-species forest type, suggesting that alternative successional pathways are possible under particular disturbance regimes, including climate change (Johnstone et al. 2010, Mann et al. 2012, Rupp 2011). Although VEG Profile captures the presence of large shrubs and nontally trees with cover and height layer, the only allometric equations for calculating biomass of large shrubs are based on stem diameters (Chojnacky and Milton 2008). Stem diameter measures for large woody shrubs and nontally tree species should be considered in the future for inclusion into biomass estimations (e.g., Bond-Lamberty et al. 2002, Mack et al. 2008). In addition, adding a full census of vascular plant species on at least one subplot per plot would capture important rare or indicator species that can occur with minimal abundance and provide a measure of species richness across the vast landscapes of interior Alaska.

Although vegetation data allow us to describe forested areas with more detail and inference than tree data alone, we can go further by fully integrating the full suite of data variables collected. Standard plot and condition information collected on FIA plots, along with the special interior Alaska protocols (ground layer and soils), go a long way toward elucidating the types of changes that may be occurring. Combining tree, Veg Profile, soils, and ground layers provides the means to classify vegetation types further, incorporating landscape and topographic positions, which is helpful when overall species diversity is limited.

Patterns of DWM on the 2014 Tanana Pilot Inventory[4]

Introduction

Down woody materials are an important component of forest ecosystem structure and function. Down woody materials influence nutrient cycling, contribute to wildlife habitat and forest fires, and can contain a substantial proportion of terrestrial ecosystem biomass (Harmon et al. 1986, Woodall 2010). Relative to other forests types, the role of DWM in boreal forests is poorly understood (Pan et al. 2011, Pedlar et al. 2002). Recent natural disturbances in boreal forests of Siberia and Canada have led to an estimated 27 percent increase in the total deadwood (standing dead and DWM) in these forests (Pan et al. 2011). As boreal forest ecosystems of interior Alaska are experiencing some of the greatest increases in temperature globally (Arctic Climate Impact Assessment 2005) with associated declines in spruce productivity (Beck et al. 2011) and increases in fire frequency and severity (Kasischke and Turetsky 2006, Turetsky et al. 2011), it is important to understand the current status of these systems both to provide insights into the role of fire and to serve as a baseline for monitoring trends.

Methods

As part of the 2014 Tanana pilot inventory, we carried out standard DWM sampling protocols (USDA FS 2014a). Down woody materials were sampled on accessible forest conditions on all field plots (i.e., portions of plots that were forested and where access was not hazardous). Sampling occurred by using the line-intercept method along transects located through the center of each of the subplots (fig. 5). Each transect is segmented to tally coarse woody debris (CWD) and fine woody debris (FWD). Coarse woody debris includes downed, dead tree and shrub boles, large limbs, and other woody pieces that are ≥3 inches diameter, ≥6 inches in length, and severed from their original source of growth. Coarse woody debris also consists of dead tally tree species or single-stemmed woodland species trees that are leaning more than 45° from vertical. Fine woody debris consists of downed, dead branches, twigs, and small tree or shrub boles <3 inches in diameter that are not attached to a living or standing dead source. Fine woody debris is tallied on 6- to 10-ft transects depending on the size of pieces. These FWD transects occur along the 24-ft CWD transects (fig. 5). The attributes collected on each piece intersecting the transect differ based on whether the pieces are CWD or FWD. For each CWD piece, transect diameter,

[4] Authors: Robert Pattison, Andrew Gray, and Hans-Erik Andersen.

species, and decay class were recorded. Decay class is a classification of the level of decay based on shape, presence of bark or branches, and wood density. Decay class 1 refers to pieces with little decay, while decay class 5 refers to pieces that have advanced decay.

Field data were compiled into estimates of DWM biomass using estimators based on transect diameter, transect length, and species detailed in Woodall and Monleon (2008). These estimators generate a volume for CWD pieces and convert these volumes into per-unit-area estimates. Volume estimates are then converted to biomass by accounting for species-specific wood density and decay class (Woodall and Monleon 2008). The estimates of the DWM content by forest type and owner for the Tanana pilot inventory unit were derived using the poststratified plot weights described in the "Introduction" ("Stratification and Analyses" section).

Results

Birch forests on the TVSF had an estimated 4,122 (± 1,080) thousand tons of biomass in DWM or 48 percent of the total DWM biomass in the two inventory units (fig. 13). About 72 percent of that biomass was in CWD. The next highest DWM biomass values occurred on white spruce forests on TVSF, which had an estimated 1,244 (± 453) thousand tons of biomass or 14 percent of the total DWM biomass in the two inventory units. For these forests, CWD made up 79 percent of the total DWM biomass. Within each forest type and landowner category, the percentage of DWM in CWD and fine woody materials (FWM) varied. Black spruce forests on TVSF and birch forests on TNWR had the lowest proportion of total DWM in CWD (33 to 39 percent). The remaining forest types had 50 to 79 percent of the total DWM in CWM (fig. 13). Birch forests on TVSF had the most CWD and FWD stocks (tables 12 and 13).

Aspen forest types had the highest DWM biomass per acre, while black spruce forest types had the lowest (fig. 14). Birch forest DWM biomass per acre showed high variability between TVSF and TNWR with birch forests on TVSF having 2.8 times more DWM biomass per acre than on TNWR. The CWD consisted of a range of decay classes (fig. 15) for each forest type.

On a per-acre basis, aspen and birch forest types had the highest CWD biomass, while black spruce had more than an order of magnitude less (table 14). Interestingly, birch forest types on TNWR lands had five times less CWD than on TVSF lands, but this trend was not apparent for FWD (table 15). Deciduous forest types had the highest FWD on a per-area basis (table 15).

On a per-acre basis, aspen and birch forest types had the highest CWD biomass, while black spruce had more than an order of magnitude less.

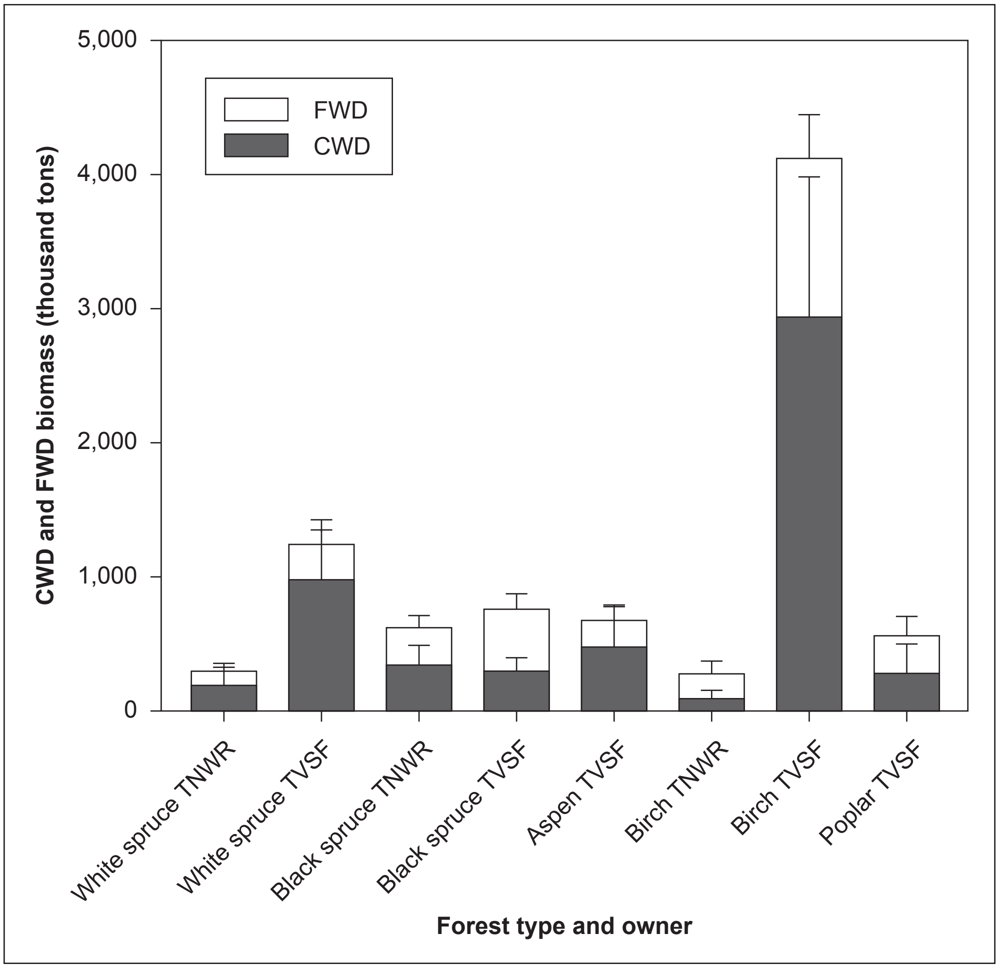

Figure 13—Downed woody material biomass on an area basis for each of the forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Error bars represent the standard error of the estimates. Estimates are for coarse woody debris (CWD) and fine woody debris (FWD).

Table 12—Estimated total coarse woody debris (CWD) biomass stocks in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

	TVSF		TNWR		Total	
Forest type	CWD biomass	SE	CWD biomass	SE	CWD biomass	SE
			Thousand tons			
Black spruce	298.4	100.5	344.6	141.4	643.0	173.5
White spruce	981.7	440.9	194.9	131.1	1,176.5	460.0
Aspen	480.2	297.0	—	—	480.2	297.0
Birch	2,950.3	1,030.2	94.7	58.5	3,045.1	1,031.8
Poplar	278.7	220.0	—	—	278.7	220.0
Nonstocked	7.4	6.4	—	—	7.4	6.4
Total biomass	4,996.7	1,074.2	634.2	181.5	5,630.9	1,089.4

SE = standard error. — = no samples fell in this combination of classes.

Table 13—Estimated total fine woody debris (FWD) biomass stocks in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

	TVSF		TNWR		Total	
Forest type	FWD biomass	SE	FWD biomass	SE	FWD biomass	SE
			Thousand tons			
Black spruce	460.9	116.8	276.0	95.0	736.8	150.5
White spruce	261.9	104.5	104.8	57.5	366.7	119.3
Aspen	196.3	114.8	—	—	196.3	114.8
Birch	1,171.3	326.4	185.9	93.6	1,357.2	339.6
Poplar	280.5	145.8	—	—	280.5	145.8
Nonstocked	54.1	46.8	—	—	54.1	46.8
Total biomass	2,425.0	303.4	566.6	123.5	2,991.6	327.6

SE = standard error. — = no samples fell in this combination of classes.

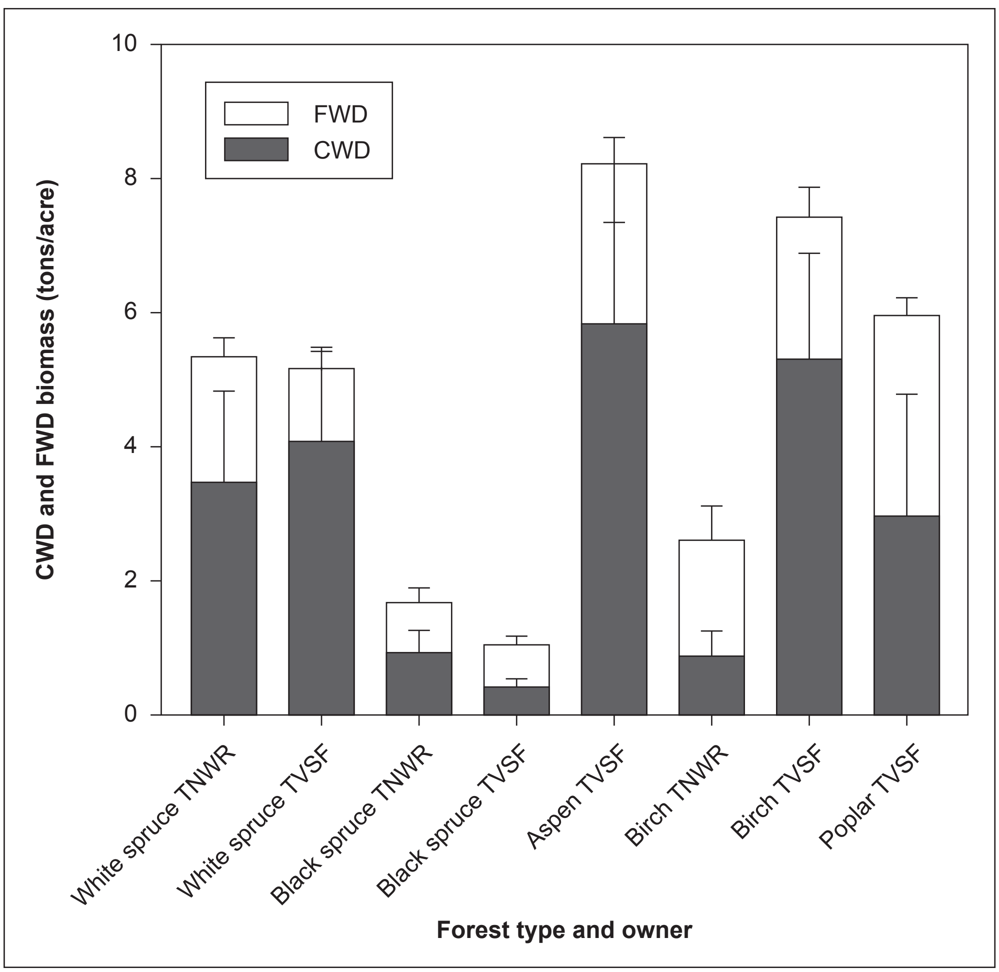

Figure 14—Estimated density (tons/acre) of biomass in down woody material (DWM) for each of the forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Error bars represent + 1 standard error of the estimated totals for coarse woody debris (CWD) and fine woody debris (FWD) in each category.

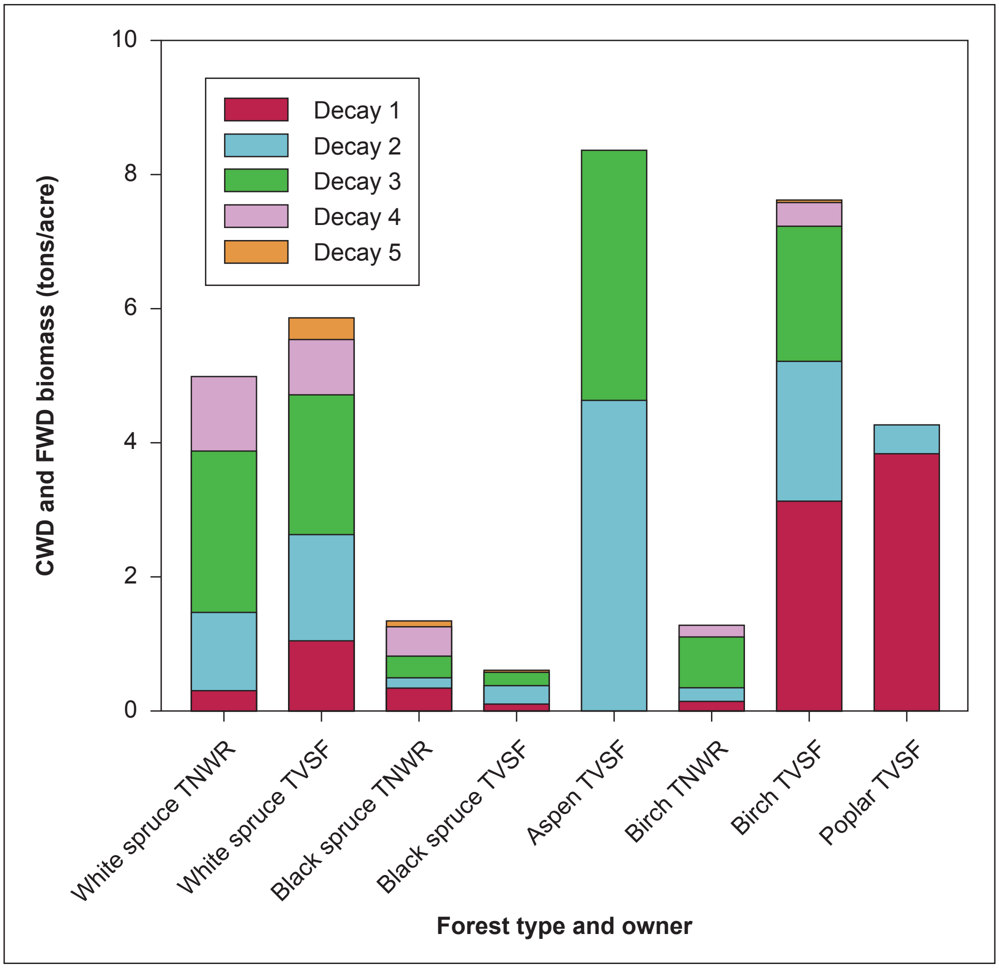

Figure 15—Composition of coarse woody debris (CWD) and fine woody debris (FWD) biomass by decay class for each of the forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Decay class 1 refers to the least decayed, and decay class 5 refers to the most advanced decayed pieces.

Table 14—Estimated coarse woody debris (CWD) biomass (tons per acre) in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

	TVSF		TNWR		Total	
Forest type	CWD biomass	SE	CWD biomass	SE	CWD biomass	SE
			Tons per acre			
Black spruce	0.4	0.1	0.9	0.3	0.6	0.1
White spruce	4.1	1.3	3.5	1.3	4.0	1.1
Aspen	5.8	1.5	—	—	5.8	1.5
Birch	5.3	1.6	0.9	0.4	4.6	1.3
Poplar	3.0	1.8	—	—	3.0	1.8
Nonstocked	0.2	0.0	—	—	0.2	0.0
All forest	2.9	0.6	1.2	0.3	2.5	0.5

SE = standard error. — = no samples fell in this combination of classes.

Table 15—Estimated fine woody debris (FWD) biomass in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

	TVSF		TNWR		Total	
Forest type	**FWD biomass**	**SE**	**FWD biomass**	**SE**	**FWD biomass**	**SE**
			Tons per acre			
Black spruce	0.6	0.1	0.7	0.2	0.7	0.1
White spruce	1.1	0.3	1.9	0.3	1.2	0.3
Aspen	2.4	0.4	—	—	2.4	0.4
Birch	2.1	0.4	1.7	0.5	2.0	0.4
Poplar	3.0	0.3	—	—	3.0	0.3
Nonstocked	1.5	0.0	—	—	1.5	0.0
All forest	1.4	0.2	1.1	0.2	1.3	0.1

SE = standard error. — = no samples fell in this combination of classes.

Discussion

There was an eightfold variation in DWM per unit area across the various forest types and ownerships. With the exception of birch forests on the TNWR, the highest values occurred on deciduous forests. Birch forests on the TVSF had 48 percent of the DWM of the total in the two inventory units with 71 percent of that DWM on these forests consisting of CWD. The 2.8-fold difference in birch DWM on state and TNWR lands indicates key functional differences may occur within forest types. These differences may be attributable in part to differences in tree biomass as birch forests on TVSF lands (32.4 tons per acre) had 1.6 times more tree biomass than birch forest on TNWR lands (20.0 tons per acre) (fig. 16). Differences among forest types may also be attributed to tree longevity and inherent mortality rates, where aspen and birch forests tend to be the least long lived of the interior species (fig. 17). Greater DWM biomass per acre in black spruce forests on TNWR lands compared to TVSF, despite the lower live-tree biomass, may reflect slower wood decomposition on wetter sites owing to anaerobic conditions in water-logged wood when temperatures are conducive to microbial activity. The greater amounts of fine wood could result in more extreme fire behavior in hardwood stands than conifer stands, but height to tree crown base and abundance of understory vegetation is also important to predicting fire behavior.

Differences among forest types in the amount of down wood material were related to aboveground biomass as well as species' inherent mortality rates.

The values of DWM biomass in this study are similar to other studies of boreal forest with similar forest types. For example, DeLuca and Biosvenue (2012 and references therein) found CWD values ranging from 2.6 to 8.0 (tons of biomass acre-1). These values are similar to those found in this study (fig. 14).

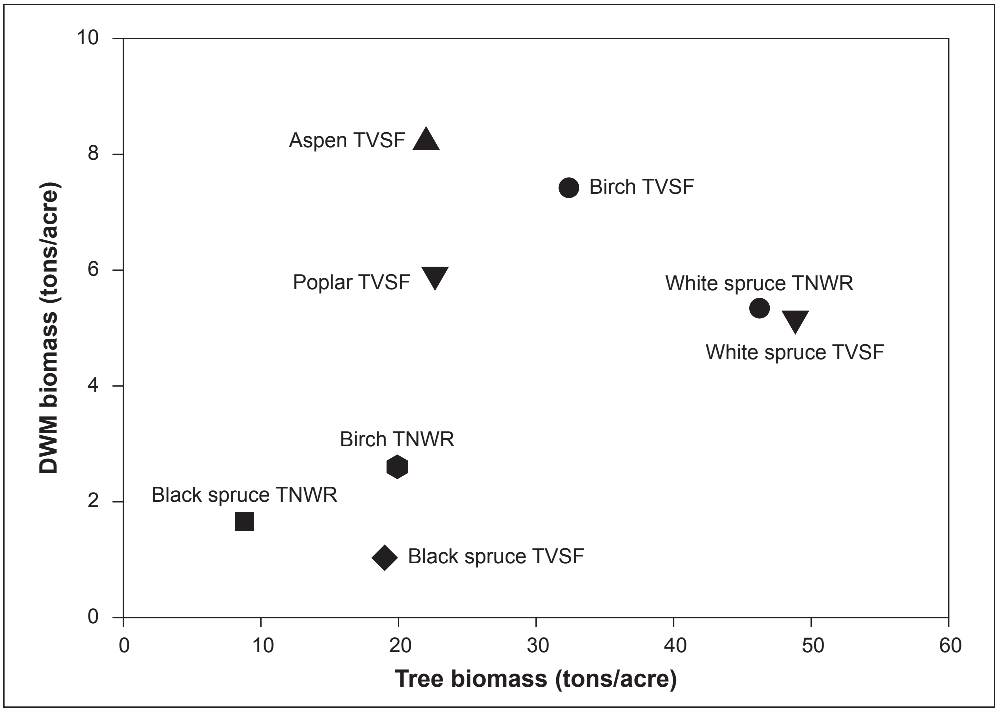

Figure 16—Relationship between aboveground live tree biomass and down woody material (DWM) biomass on the forest types and ownerships on the Tanana pilot inventory. Categories include black spruce, white spruce, birch, aspen, and poplar in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR).

Sarah Ellison

Figure 17—Field crew member laying out a Forest Inventory and Analysis plot in an aspen forest.

Soil Carbon Content in the 2014 Tanana Pilot Inventory[5]

Introduction

Boreal ecosystems account for about 50 percent of the world's forest ecosystem C stocks (Malhi et al. 1999). The majority of the C in these ecosystems often occurs in soils (DeLuca and Biosvenue 2012, Malhi et al. 1999, Tarnocai et al. 2009). In addition to their C storage capacity, boreal forest soils are important components of ecosystem productivity owing to their role in nutrient cycling and the limitations frozen soils place on tree growth. As boreal forests are experiencing some of the greatest increases in temperature globally (Arctic Climate Impact Assessment 2005, Trenberth et al. 2007) with concurrent increases in fire severity and frequency that can consume soil C (Kasischke and Turetsky 2006, Turetsky et al. 2011), it is important that inventory and monitoring efforts in the boreal regions sample soils.

Methods

The FIA program measured soils in the early 2000s on a 1/16th sample of the standard field plots (i.e., one plot per 96,000 ac). The soil sampling protocol for the 2014 Tanana pilot inventory occurred on all plots and was based on standard FIA soils sampling protocols (O'Neill et al. 2005) but also integrated additional boreal forest-specific sampling methods developed by scientists from the U.S. Geological Survey (USGS) (USDA FS 2014b). One of the key differences between standard FIA protocols and those used in the Tanana pilot inventory was the use of an electric drill and a metal corer (Nadler and Wein 1998) that improved the ability to sample the thicker organic layers common in many boreal forest soils (fig. 18). Also, because of the thickness of organic soil layers in boreal Alaska, the target depth for mineral soil samples was 4 inches instead of 8 inches.

The soil sampling methods are outlined in the Tanana pilot inventory manual (USDA FS 2014b). Some details of these methods include the following: sampling soils at a location 30 ft south of subplot 2; use of a 12-inch circular frame to sample litter and live moss; and measuring depth of the active (unfrozen) soil layer at the time of sampling. Fourteen percent of forested plots were sampled in June, 60 percent in July, and 26 percent in August.

Soil cores were separated into five layers and their thicknesses measured: dead moss (recognizable plant matter with few roots), root-dominated duff (mainly fine and very fine roots with old plant matter), upper humified duff

[5] Authors: Robert Pattison, Andrew Gray, Hans-Erik Andersen, and Kristen Manies.

Forest Inventory and Analysis

Figure 18—Soil core after extraction showing the live moss layer on the right and mineral soil on the left.

(dark amorphous material with unrecognizable plant parts), lower humified duff (when present, a sticky amorphous layer without distinct plant fibers), and mineral soil (grittier and denser than organic layers, with no distinct plant parts). Samples were analyzed for oven-dried weights and C content among other properties. Sample bulk density was calculated based on oven-dried weight and sample volume as determined from the sample's length and the diameter of the corer. These values were then converted into C in pounds per acre. Mineral soil samples varied between 1 and 4 inches in thickness. To provide a standardized measure of C content of mineral soil, the C concentration of the mineral soil was calculated for a 1-inch depth. Total soil C for a plot was determined as the sum of the litter and live moss, dead moss, root-dominated duff, upper and lower humified duff layers, and 1-inch of mineral soil. In addition to total soil C, separate analyses were generated for each of the five layers. Estimates of soil C by forest type and ownership were generated using the poststratified plot weights described in the introduction and the double-sampling equations described in Scott et al. (2005).

Results

There were an estimated 56,728 (± 4,224) thousand tons of soil C on the TVSF and TNWR (table 16). The majority (75 percent) of this was found on the forests of the TVSF (42,310 ± 4,065 thousand tons) (fig. 19).

Total measured soil C per acre was relatively similar across forest types for both inventory units (table 17). Deciduous forest types tended to have lower soil C per acre than evergreen forest types (table 17).

The organic layer contained the greatest proportion (65 to 81 percent) of measured soil C across all forest types on both TVSF and TNWR lands (figs. 19 and 20). Birch forests on TNWR had the lowest (65 percent) proportion of measured soil C in the organic layer, while white spruce on TNWR and poplar on TVSF had the highest (81 percent). Mineral soil (1 inch) contained between 8 and

Soil carbon (C) per acre was relatively similar across forest types for both inventory units. Deciduous forest types tended to have lower soil C per acre than evergreen forest types.

Table 16— Estimated soil carbon stocks for all soil layers in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Thousand tons			
Black spruce	20,455	2,810	10,502	1,044	30,969	2,863
White spruce	5,894	2,019	1,671	250	7,474	2,177
Aspen	1,224	548	—	—	1,224	548
Birch	13,232	1,436	2,445	293	15,662	1,440
Poplar	2,069	730	—	—	2,069	730
Nonstocked	433	—	—	—	433	—
Total carbon	42,310	4,065	14,432	1,125	56,728	4,224

SE = standard error. — = no samples fell in this combination of classes.

Table 17—Estimated total soil carbon (litter, live moss, organic layer and 1 inch of mineral soil) per acre on forest types in the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Tons per acre			
Black spruce	27.9	3.8	28.2	2.8	28.0	2.6
White spruce	24.5	8.4	29.8	4.4	25.2	7.3
Aspen	14.9	6.7	—	—	14.9	6.7
Birch	23.8	2.6	22.7	2.7	23.6	2.2
Poplar	22.0	7.8	—	—	22.0	7.8
Nonstocked	12.3	0	—	—	12.3	0
All forest	24.3	2.3	26.9	2.1	24.9	1.9

SE = standard error. — = no samples fell in this combination of classes.

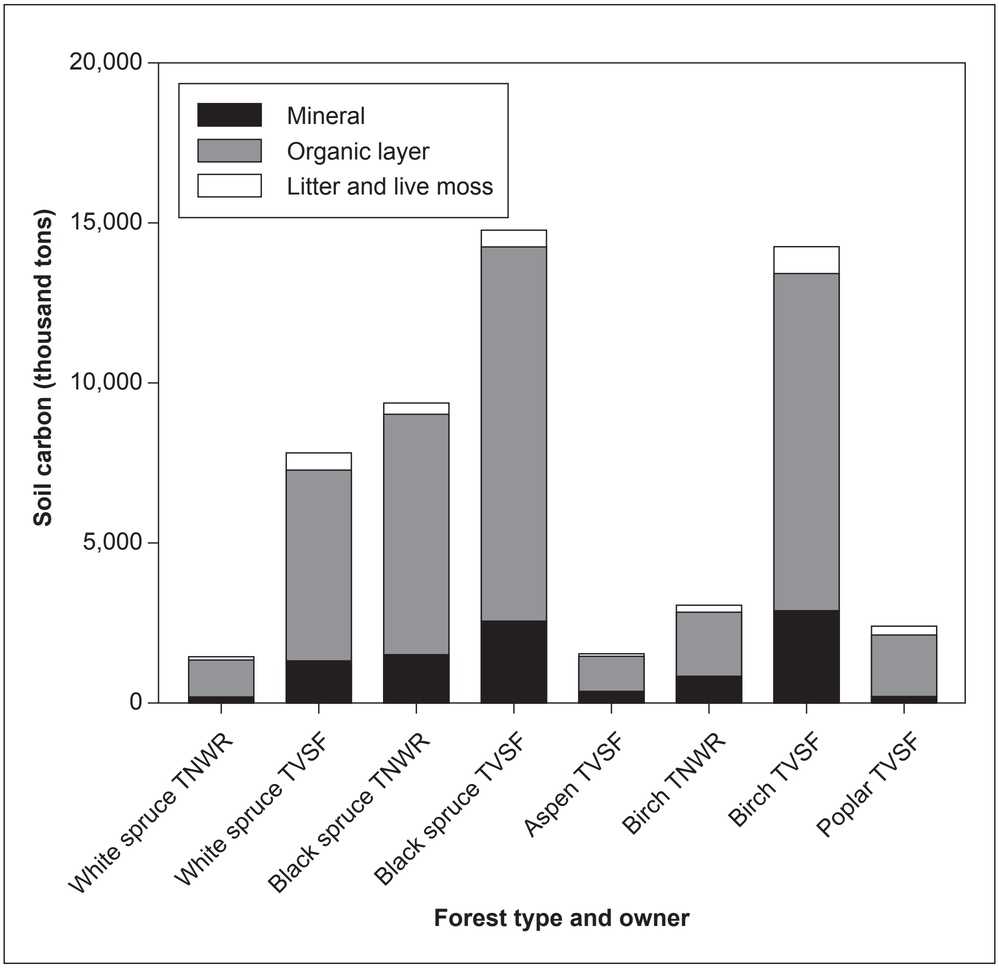

Figure 19—Soil carbon (litter and live moss, organic layer, and 1 inch of mineral soil) for the different forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR).

26 percent of measured soil C, with the lowest percentages occurring in balsam poplar forests and the highest occurring in birch forests on TNWR. Litter and live moss accounted for 4 to 11 percent of the measured soil C for all the forest types on both inventory units.

There was a large variation in the contribution of the various layers within the organic layer to the total organic layer content (figs. 21 and 22). Dead moss accounted for 0 to 21 percent of the organic layer. Birch forests on the TNWR and balsam poplar forests on the TVSF had no dead moss, while black spruce forests on the TVSF had 21 percent of the organic layer C made up of dead moss.

Root-dominated duff was found on all forest types and accounted for 9 percent of the aspen forest organic layer and 100 percent of the balsam poplar forest

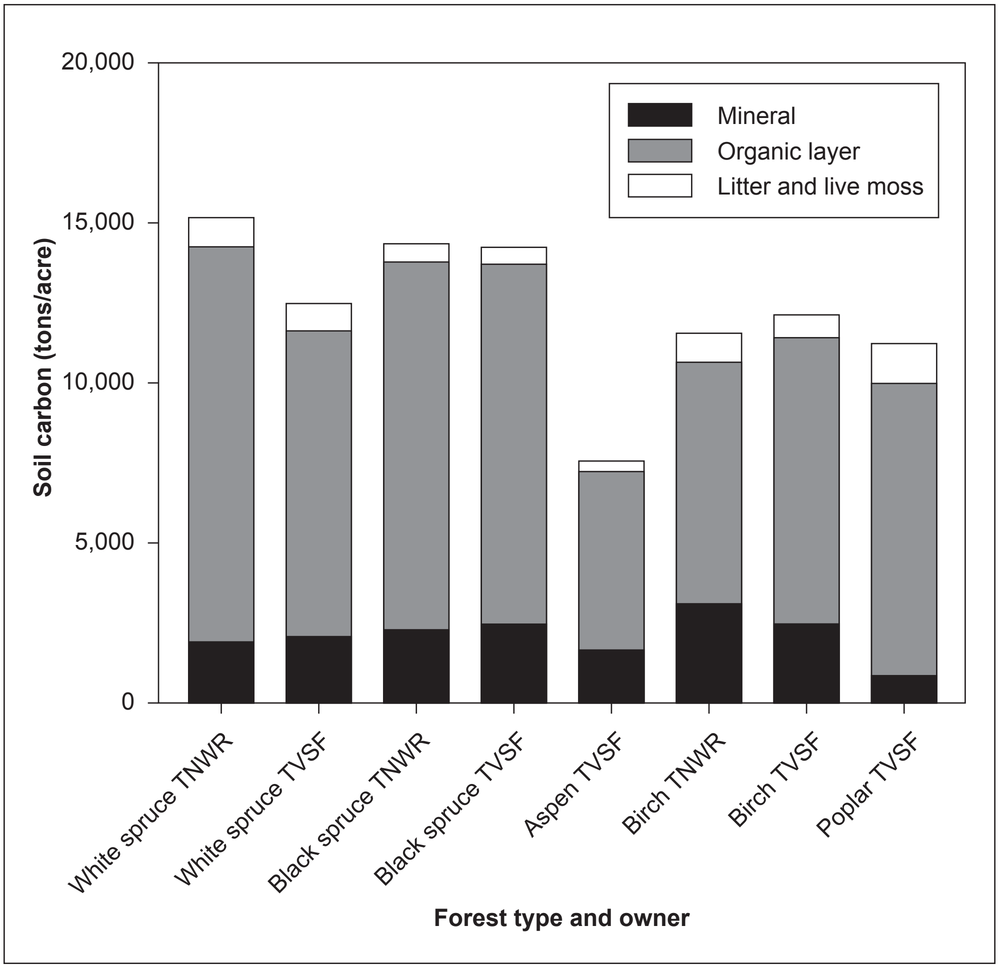

Figure 20—Distribution of soil carbon between litter and live moss, organic and mineral (1 inch) soil layers on a per-acre basis for forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR).

organic layer on the TVSF. The upper humified duff layer was not present on balsam poplar forests but accounted for 17 to 35 percent of the other forest types on the TVSF and TNWR. The lower humified duff layer was not present on white spruce and birch forests on the TNWR, nor balsam poplar forests of the TVSF. However, this layer accounted for 50 percent of the organic layer of the aspen forests on the TVSF.

Thaw depths were deepest in the balsam poplar and aspen forest types and shallowest in black spruce forests (fig. 23). Within a forest type, there did not appear to be differences in thaw depths between the TVSF and TNWR.

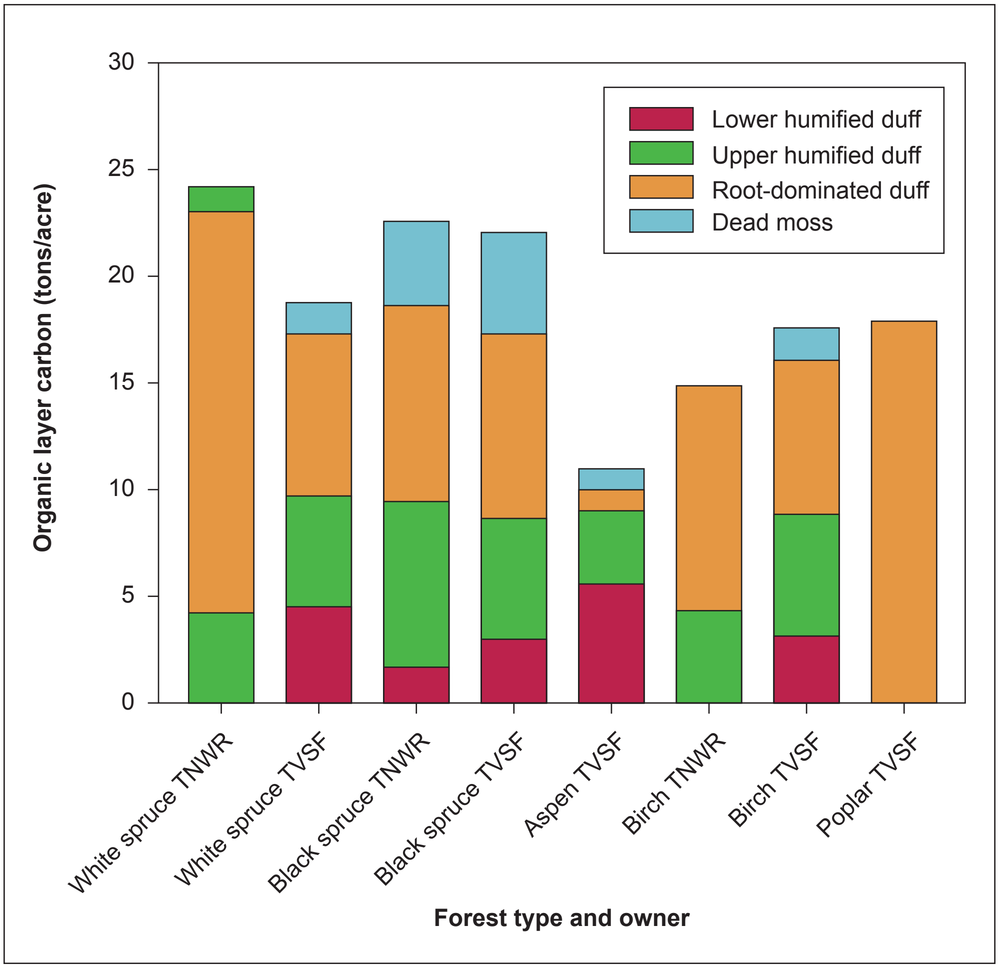

Figure 21—Distribution of soil carbon within the organic layer per acre for forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). The layers within the organic layer include dead moss, root-dominated duff, upper humified duff, and lower humified duff.

Discussion

Across the Tanana pilot inventory unit, most of the total soil C occurred in black spruce and birch forests on TVSF lands (table 16). The total soil C per acre was relatively similar between forest types and ownerships (table 17). White spruce forests on the TNWR had the highest total soil C per acre, and aspen forests on TVSF had the lowest values (table 17). The majority of C in the soils estimated in this study was found in the organic layer (figs. 19 and 20). However, it is likely that substantial amounts of mineral soil C were present at depths greater than the 1 inch estimated here. For soils in the Bonanza Creek Experimental Forest, the C in the upper 1 inch represents 4 to 18 percent of the C down to 39 inches (1 m) in floodplain forests, and 12 percent to 19 percent in upland forests.[6] Those

[6] Yarie, J. 2017. Personal communication. Soil scientist, University of Alaska Fairbanks. Fairbanks, AK 99775.

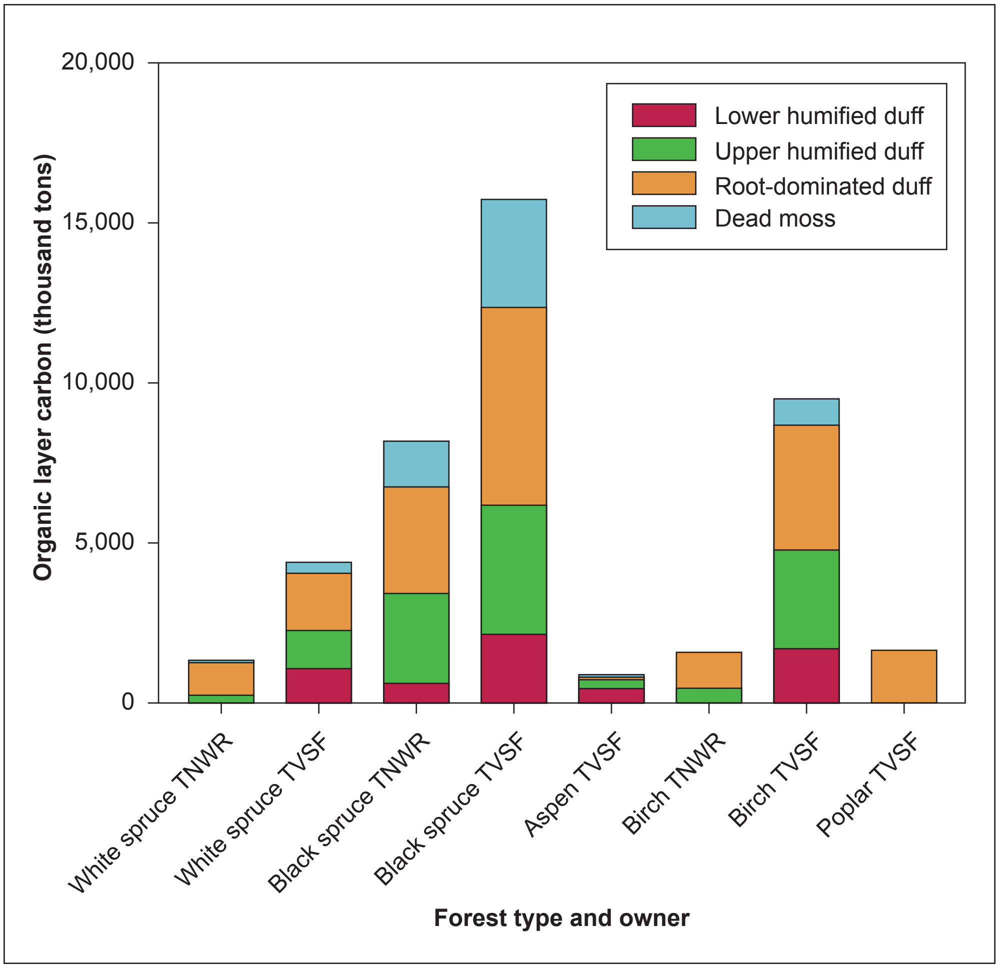

Figure 22—Estimates of organic layer carbon (dead moss, root-dominated duff, upper humified duff, and lower humified duff) content for the different forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR).

estimates do not include any black spruce stands, which likely have an even lower proportion of C in the top 1 inch. Using 15 percent as a rough guide with the FIA sample would suggest that mineral soils down to 39 inches (1 m) have as much or up to twice as much C as the organic layer. Although there was a high amount of variability as to which of the organic layers contributed the most to organic layer C content, in general, the root-dominated duff layer tended to contain most of the C in the organic layer C content.

The values in this study are similar to those in other studies in the region (Hollingsworth et al. 2008, Kane and Vogel 2009, Ping et al. 2010). Hollingsworth et al. (2008) found that the C content of the organic layer of black spruce forests ranged from 15 to 24 tons per acre, while Kane and Vogel (2009) found values that ranged from 17 to 33 tons per acre. In an inventory of 52 sites in interior Alaska dominated by black spruce across a range of topographic positions from well drained to poorly drained, Ping et al. (2010) found that organic layer contained 24 to 1,156

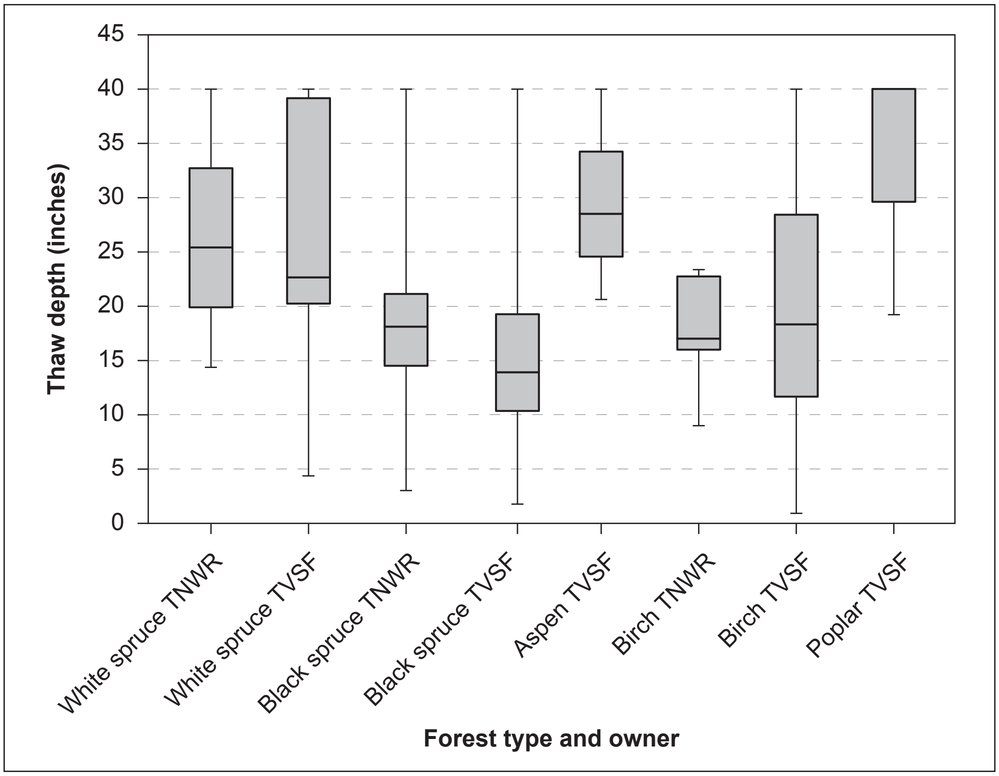

Figure 23—Box and whisker plots of thaw depth for the forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Each box shows the upper and lower quartile, the central bar shows the median, the whiskers show the minimum and maximum values. Depths were measured to a maximum value of 40 inches.

tons per acre. Their work sampled soils down to 39 inches, and found that organic layer had 13 to 100 percent of the total C within the top 39 inches of soils in this wide range of sites.

The total soil C was weakly but positively related to stand age for the black spruce forest types ($r^2 = 0.14$, $P = 0.0303$) but not for other forest types in this study. Kane and Vogel (2009) found a similar trend for black spruce forests in the Tanana Valley region. As mentioned above, TVSF lands are considered to be more productive upland ecosystems, whereas TNWR is characterized as less productive, low-lying ecosystems. In spite of these general differences, we did not find clear differences in soil C characteristics between these two landowner groups. When examined on a per-acre basis, black and white spruce and birch forest types had similar soil C content on both ownerships. One potential reason might be that a simple characterization of forest types based on the predominant tree canopy species may fail to recognize the diversity of conditions where black spruce can be abundant (Viereck and Johnston 1990). Consequently, additional effort should be made to refine black spruce forest types based on additional features (Hollingsworth et al. 2008). Incorporating vegetative and ground cover data could help in this regard (see "Characterizing Forest Vegetation of the Tanana Valley" section) and may lead to more refined insights into understanding soil C as it relates to aboveground composition.

Thaw depths were greatest in the balsam poplar and aspen forest types (fig. 23). This finding was consistent with previous work suggesting that these forest types typically occur on sites where soils thaw more rapidly in the early growing season and where there is little to no permafrost (Jorgenson et al. 2010).

Soils in boreal regions are typically sampled later in the season than our field season—e.g., September and October (Hollingsworth et al. 2008)—to capture the maximum thaw depth of soils and limit the occurrence of frozen layers. However, visiting all plots within a short window late in the season is logistically unfeasible for a broad-scale multiresource inventory. One of the primary concerns in undertaking the Tanana pilot inventory was that soils in some low-lying poorly drained forests such as those dominated by black spruce might be frozen above the mineral layer as the soil corer is unable to sample frozen soils. This concern was warranted for some forest types. For example, 14 of the 95 plots where soils were collected had frozen layers above mineral soil. Of these plots, 13 occurred on black spruce forest types (TNWR n = 2, TVSF n = 11), and one occurred on birch forest types (TVSF). Two of the 14 plots had soils frozen very near the surface (dead moss layer). Overall, 38 percent of the black spruce forests plots on the TVSF did not have the entire organic layer sampled. Our inventory procedures assume that nonsampled information is "missing at random"; i.e., that the mean of the values that were measured is the same as the mean of the nonsampled areas and the population as a whole. The presence of frozen soils therefore leads to lower precision of total soil C estimates for black spruce forest types on TVSF in particular, where frozen soils were most frequently encountered. Soils frozen above the mineral layer were encountered on plots sampled throughout the growing season (fig. 24). Most of these plots had thaw depths of less than 15 inches at the time of measurement. This result is consistent with Ping et al. (2010), who found that organic layer thickness for a range of black spruce forests was relatively shallow, ranging from 1 to 15 inches for 51 of their 52 field sites. The remaining site had the entirety of the 39-inches-depth sample consisting of organic layer. As mentioned above, Ping et al. (2010) found that the organic layer contained between 13 and 95 percent of the total soil C down to 39 inches for the 51 plots (mean = 51 percent, SE = 19 percent). Collectively, these results suggest that organic layers are relatively shallow and contain a substantial proportion of the soil C.

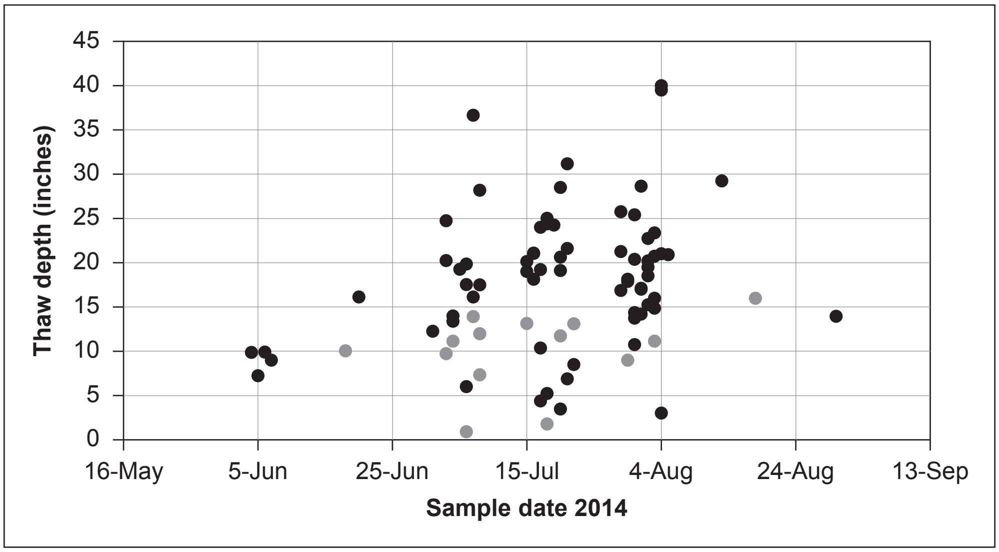

Figure 24—Relationship between thaw depth and sample date for plots. Thaw depth is the average of four measurements at the soil sample site. Light grey symbols (n = 14) represent plots where mineral soil was not reached owing to the presence of frozen soil.

Carbon Storage and Other Functions of Moss and Lichen Mats in the Tanana River Valley of Alaska[7]

Introduction

How much C is stored in the ground layer of boreal forests? In northern areas, moss and lichen mats are key players in C cycling because they are often the main interface between soils and the atmosphere (fig. 25). Moss mats in boreal forests account for 20 percent of understory net C uptake and the majority of understory nitrogen fixation (Hasselquist et al. 2016, Lindo et al. 2013). The C storage capacity of ground layers is potentially huge: moss-dominated peatlands currently store roughly 33 percent of the world's terrestrial C (Yu 2012).

Despite this massive potential, ground layer nutrient cycling is now shifting in response to global changes. Specific challenges include increasing area in fires and the expansion of tall shrub vegetation, both of which reduce ground layers. Ground layer carbon losses are rising as arctic and boreal wildfires combust more material than at any point in the last several thousand years (Hu et al. 2015, Kelly et al. 2013, Turetsky et al. 2015). Of particular concern are declines of forage lichens on which caribou and other wildlife depend, and whose decline will have socioeconomic impacts on hunting, tourism, and subsistence practices (Joly et al. 2009). Knowing how these changes might interact with carbon cycling at the soil-atmosphere interface (fig. 25) requires us to understand carbon pool status and trends using emerging forest inventory methods.

[7] Authors: Robert J. Smith, Sarah Jovan, Andrew Gray, and Bruce McCune.

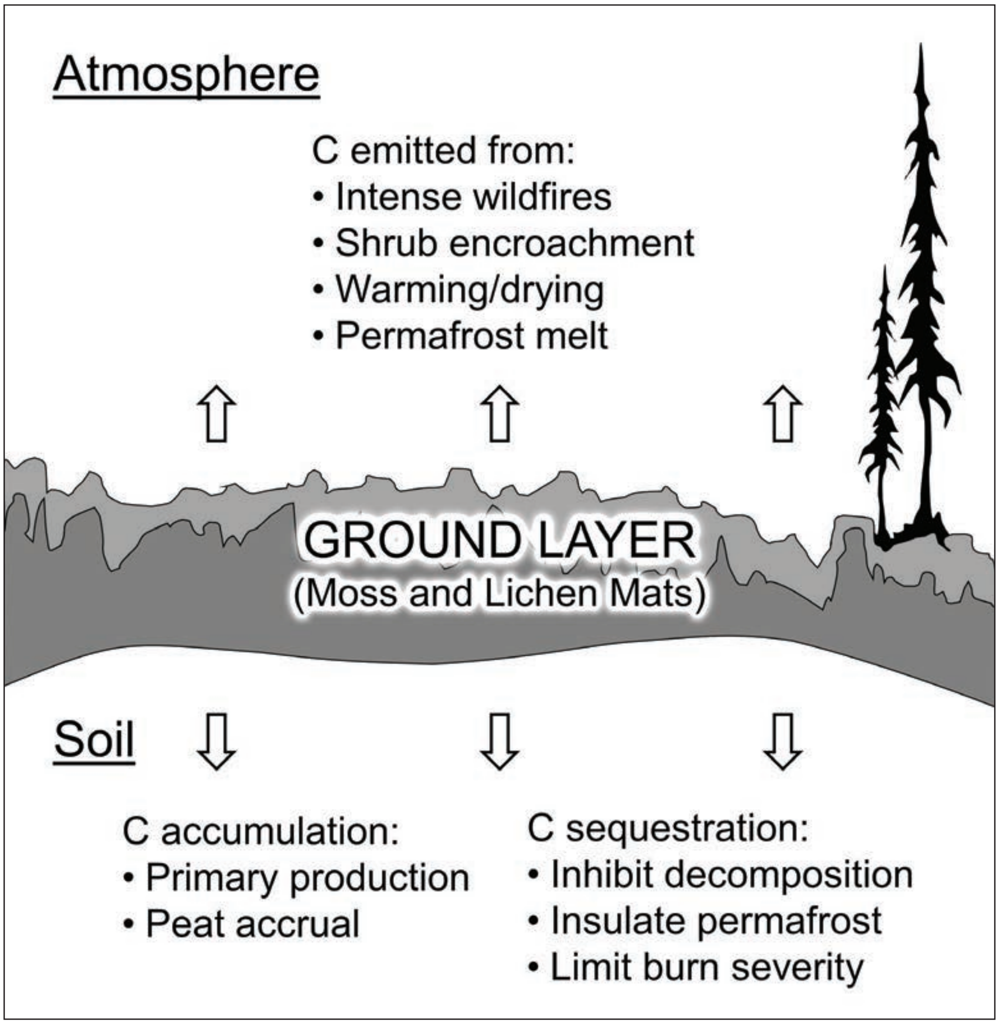

Figure 25—Conceptual carbon (C) balance in moss and lichen mats at the soil-atmosphere interface. In addition to regulating C, ground layers have many other functions (see table 18).

Methods

Carbon and nitrogen pools in boreal ground layers—

We evaluated ground layer attributes at 96 sites in the study area using the FIA Ground Layer Indicator (Smith et al. 2015). This indicator converts field-measured depth and cover of ground-dwelling mosses and lichens into a plot-level estimate of biomass, carbon, and nitrogen for each functional group (fig. 26). Moss and lichen species were grouped into functional groups that were relatively easy to identify after a few hours' training and that corresponded with important nutrient and habitat functions (fig. 27). A further benefit of this method is the ability to assess ecosystem functions of ground layers (e.g., wildlife forage, biological nitrogen-fixation, many others). The Ground Layer Indicator is rapid (about 1 to 2 hours survey time) and complements existing FIA protocols.

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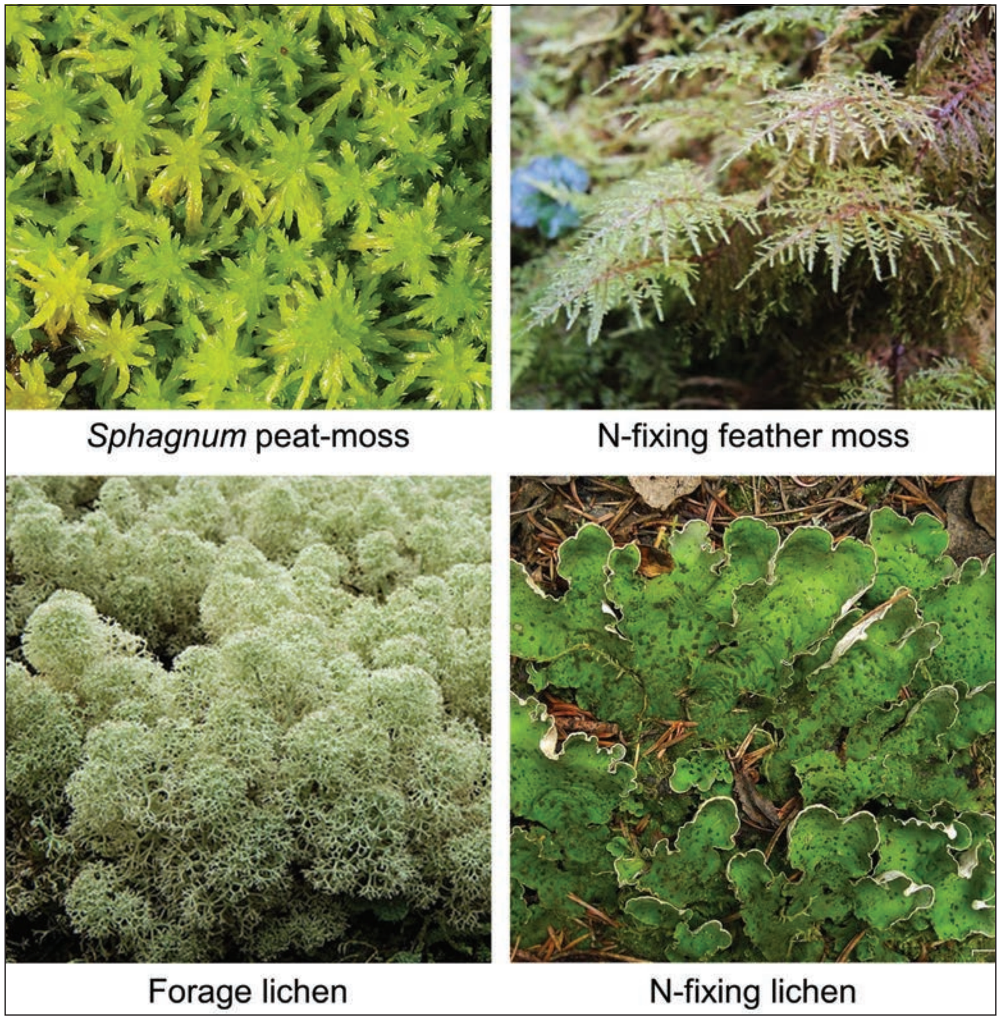

Figure 26—Four of the 13 functional groups used in the Ground Layer Indicator (see table 18 for all groups). The indicator measures depth and cover of all 13 functional groups to estimate biomass, carbon, and nitrogen (N).

Forest Inventory and Analysis

Figure 27—A microquad used to measure cover of lichen and moss functional groups in the ground layer.

Environmental influences and validation—

To identify the best environmental and stand-level factors explaining ground layer attributes, we used nonparametric multiplicative regression (NPMR) (McCune 2006, McCune and Mefford 2011), which estimates mean responses as a smoothed function of all possible interactions of an optimized predictor subset. To validate measurements, we used a separate, multiobserver dataset to evaluate whether observers might estimate plot-level biomass differently: in August 2015, six observers used the Ground Layer Indicator (Smith et al. 2015) at premarked sampling units in two plots in north central Minnesota (one upland forest and one peat moss wetland). From a separate-means linear mixed model, a finding of no significant difference among observers' biomass estimates would lend credibility to Ground Layer Indicator measurements from both Minnesota and Alaska.

Results

Carbon and nitrogen pools in boreal ground layers—

Functional group abundances differed across the study area (table 18). Most frequent and abundant were nitrogen-fixing feather mosses, often forming extensive, thick carpets. *Sphagnum* peat mosses were less frequent but often achieved highest within-plot biomass. Forage lichens were moderate in frequency but also had considerable biomass where encountered (table 18). On average, there were 6.6 functional groups per plot. Moss and lichen functional groups reflected the capacity to fix nitrogen, provide wildlife forage, indicate disturbance, alter hydrology, or signal nutrient-enriched conditions (among other functions; table 18).

Across the study area, there was an estimated total of 12,588 (± 1,356) thousand tons of ground layer biomass (tables 19 and 21). Of this, there was an estimated 5,586 (± 601) thousand tons of carbon and 138 (± 15) thousand tons of nitrogen in ground layers (table 19). Ground layer biomass per acre across the inventory unit was 5.53 (± 0.60) tons per acre (table 20). There was 2.46 (± 0.26) tons per acre of C, and 122 (± 13) pounds per acre of nitrogen (table 20).

Forest types—

Black spruce forest types had by far the greatest total (table 19) and per-acre mean (table 20) ground layer biomass across the study area. Total biomass and nutrient stores in black spruce forest types were roughly seven times that in white spruce and Alaska birch forest types (table 19). As a per-plot average, mean biomass and mean nutrient content in black spruce forest types were roughly double that of white spruce forest types, and nearly four times that of most hardwood forest types (table 20). Within the TVSF and the TNWR, most (75 percent) of the ground layer biomass was found in black spruce forest types (table 21). Black spruce forest types on both the TVSF and the TNWR also had the highest estimates of ground layer biomass on a per-acre basis (table 22). Black spruce forest types on the TVSF tended to have greater ground layer biomass per acre than TNWR.

Table 18—Estimates by functional group for forested lands, based on the ground layer measurements at 96 plots in the study area[a]

Functional group	Functions	Mass		Carbon		Nitrogen (N)		Cover	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
		Pounds per acre						*Percent*	
Biotic soil crust	Soil trapping, soil water influx, disturbance indicator	3	1	1	0	<0.1	<0.1	<0.1	<0.1
Orange lichens	Indicate nutrient overenrichment	0	0	0	0	<0.1	<0.1	<0.1	<0.1
Forage lichens	Wildlife forage (caribou, etc.)	394	93	175	41	2	1	6	1
Other foliose lichens	Invertebrate habitat, bare site colonization	9	2	4	1	<0.1	<0.1	<0.1	<0.1
Other fruticose lichens	Invertebrate habitat, bare site colonization	70	16	31	7	1	<0.1	2	<0.1
N-fixing foliose lichens	N-fixation, nutrient cycling	148	28	66	13	4	1	4	1
N-fixing fruticose lichens	N-fixation, increases albedo	32	22	14	10	1	1	1	<0.1
Other feather mosses	Rainfall interception, soil cooling	645	184	286	82	8	2	7	2
N-fixing feather mosses	Broad-area N-fixation, soil cooling	6,818	802	3,026	356	78	9	57	5
Sphagnum peat moss	Carbon storage (peat), water regulation, soil cooling	1,853	619	823	275	17	6	10	3
Turf (acrocarp) mosses	Soil accrual, bare site colonization	1,050	147	466	65	11	1	18	2
Flat (thalloid) liverworts	Soil/detritus binding, water infiltration	29	20	13	9	0	0	1	<0.1
Stem-and-leaf liverworts	Soil/detritus binding, water infiltration	16	7	7	3	0	0	0	0

Note: The units for mass, carbon, and N are in pounds per acre. SE = standard error.
[a] Each of the mutually exclusive groups integrates growth forms, potential indicator status, and ecosystem effects.

Table 19—Estimates of ground layer biomass, carbon, and nitrogen stocks by forest type for forested lands in the study area

Forest type	Mass		Carbon		Nitrogen	
	Total	SE	Total	SE	Total	SE
	Thousand tons					
Black spruce	9,551	1,472	4,238	653	104	16
White spruce	1276	439	566	195	15	5
Aspen	199	133	89	59	2	1
Alaska birch	1,508	340	669	150	17	4
Balsam poplar	11	7	5	2	0	0
Nonstocked	43	39	18	17	0	0
Total	12,588	1356	5,586	601	138	15

SE = standard error.

Table 20—Estimates of ground layer biomass, carbon, and nitrogen per unit acre by forest type for forested lands in the two inventory units in the study area

	Mass		Carbon		Nitrogen	
Forest type	Mean	SE	Mean	SE	Mean	SE
	Tons per acre				*Pounds per acre*	
White spruce	4.18	0.95	1.85	0.42	95	21
Black spruce	8.58	0.92	3.81	0.41	187	19
Aspen	2.36	0.85	1.05	0.38	52	19
Alaska birch	2.35	0.38	1.04	0.17	52	9
Balsam poplar	0.11	0.04	0.05	0.02	3	1
Nonstocked	1.22	1.22	0.54	0.54	25	25
Total	5.53	0.60	2.46	0.26	122	13

Note: The units for nitrogen are pounds per acre. SE = standard error.

Table 21—Estimated ground layer biomass stocks in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Thousand tons			
Black spruce	7,748	1,432	1,803	341	9,551	1,472
White spruce	968	397	308	187	1,276	439
Aspen	199	133	—	—	199	133
Birch	1,214	305	294	149	1,508	340
Poplar	11	7	—	—	11	7
Nonstocked	43	39	—	—	43	39
Total	10,183	1,322	2,405	304	12,588	1,356

SE = standard error. — = no samples fell in this combination of classes.

Table 22—Estimated ground layer biomass per acre in forest types on the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR)

Forest type	TVSF	SE	TNWR	SE	Total	SE
			Tons per acre			
Black spruce	10.5	1.3	4.8	0.7	8.6	0.9
White spruce	3.9	1.1	5.4	1.5	4.2	0.9
Aspen	2.4	0.8	—	—	2.4	0.8
Birch	2.3	0.4	2.7	0.7	2.4	0.4
Poplar	0.1	0.04	—	—	0.1	0.04
Nonstocked	1.22	0	—	—	1.2	0
Total biomass	5.9	0.7	4.5	0.5	5.5	0.6

SE = standard error. — = no samples fell in this combination of classes.

Environmental influences and validation—

From the NPMR models, the best predictors of ground layer attributes were related to solar radiation and vegetation attributes like forb cover and stand age. Specifically, ground layer carbon and nitrogen were greatest in older stands and lowest in plots with high forb cover and high solar radiation. From the comparison of estimates based on multiple observers in Minnesota, mean biomass did not differ among observers after accounting for site differences (F = 0.77, p = 0.57) (fig. 28), suggesting good repeatability of the measurement method.

Discussion

Carbon and nitrogen pools in boreal ground layers—

Ground layers are a substantial C pool in boreal forests of interior Alaska, while at the same time enhancing a variety of ecosystem functions (table 18). Our finding of around 4,500 to 17,000 pounds per acre of biomass is within the range of variability

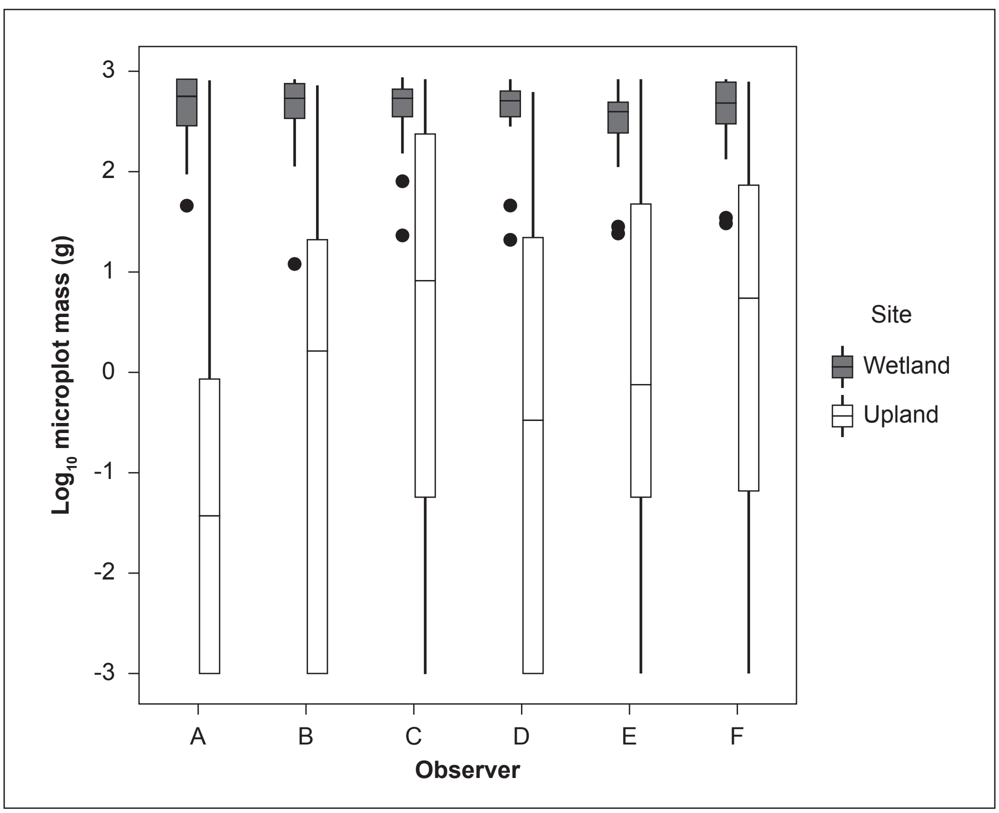

Figure 28—Mean biomass did not differ between six observers in Minnesota after accounting for differences between sites (F = 0.77, p = 0.57 from F-test). Agreement between observers suggests good repeatability of the Ground Layer Indicator. Boxes indicate the interquartile range of observations, lines within boxes are the median, whiskers extend to the 1.5 times the interquartile range, and dots are outlier observations.

observed in other moss and lichen mats of the Tanana River area (Barney and Van Cleve 1973, Mack et al. 2008), which gives a sense of the C storage capacity of boreal forest ground layers in interior Alaska. That multiple observers did not statistically differ indicates that estimates are realistic and repeatable. The high abundance of nitrogen-fixing feather mosses suggests large landscape nutrient effects: cyanobacteria in nitrogen-fixing feather mosses contribute the majority of biologically available nitrogen in boreal forest understories, an amount that can be nearly equal to the total amount of nitrogen entering from rainfall (Lagerström et al. 2007). Nitrogen input from feather mosses has ultimate consequences for nutrient ratios, plant growth, and ecosystem productivity (Lindo et al. 2013). Together, these findings imply that moss and lichen mats in the Tanana River region contribute substantially to forest nitrogen and organic carbon stores.

Environmental influences—
It is unclear whether observed patterns will hold as environmental conditions change in interior Alaska. We found that biomass, C and nitrogen were sensitive to a topographic proxy of solar radiation, suggesting that mass accumulation in ground layers is tied to sheltered thermal situations (and probably moist topographic positions as well). Carbon emissions from ground layers and peat will become an increasing possibility as droughts, climate warming, and melting permafrost cause dropping water tables (Fenner and Freeman 2011, Gorham 1991) and increasing fire risks (Kasischke and Stocks 2012). Future efforts to map landscape C could benefit from using topographic proxies of important hydrologic and thermal attributes.

We documented more biomass and carbon in old stands relative to younger stands, consistent with evidence that moss and lichen mats are C “sinks” in old, undisturbed boreal forests, but can be net C “sources” in recently burned stands and for several years after fires (Harden et al. 2000). This emphasizes the dual challenges that wildfires pose to C storage, not only from acute combustive losses (fig. 29), but also from legacy effects that can hinder growth and C uptake for decades. Carbon emissions from burned ground layers, as well as subsequent regrowth of fire-promoting vascular vegetation, could potentially amplify climate warming (Chapin et al. 2010, Kasischke and Stocks 2012, Turetsky et al. 2015). Anticipating these changes will require continued monitoring of vascular and nonvascular vegetation, as well as novel predictive approaches for mapping C pools.

National Park Service and Alaska Division of Forestry

Figure 29—An increasingly common sight: large wildfires in Alaska's boreal forests and tundra are releasing more carbon from moss and lichen mats than at any point in the last several thousand years.

Future extensions: carbon distribution mapping—
Mapping forest floor C has been a valuable product of FIA inventories (Woodall 2012). As inventories move forward, it will be critical to include ground layer mosses and lichens, as well as the deep organic peat layers (>8 inches deep) that frequently lie beneath them if we are to avoid grossly underestimating carbon (Bona et al. 2013, Chimner et al. 2014).

Carbon estimation in ground layers could also be linked with remote sensing approaches, which have previously been used to map forage lichen cover for caribou habitat, fire effects on moss mats, peatland drought status, ecosystem productivity of moss mats, and forest floor organic C (Harris and Bryant 2009; Kushida et al. 2004; Lewis et al. 2011; Nelson et al. 2013; Pastick et al. 2014, respectively). Recent LiDAR, hyperspectral and thermal imaging (G-LiHT) (see Andersen et al., this publication) could be calibrated with our ground layer biomass estimates to improve stratification of plot measurements and infer regional patterns. The wealth of potential information and tools at our disposal will provide opportunities for ground layer carbon estimation in Alaska, a part of our Nation that is at the forefront of ongoing global changes.

Ecosystem C Pools in the Tanana Pilot[8]

Boreal ecosystems account for about 50 percent of global forest ecosystem C stocks (Malhi et al. 1999). Unlike other forested ecosystems where trees contain a large proportion of ecosystem C, the majority of the C in these ecosystems often occurs in soils (DeLuca and Biosvenue 2012, Malhi et al. 1999, Tarnocai et al. 2009). The results of this pilot inventory found that soil organic layers plus mineral soil to a 1-inch depth had 47 to 84 percent of total ecosystem C (live tree, standing dead tree, DWM and soil), depending on forest type and location (figs. 30 and 31). White spruce forests on TVSF lands had the lowest proportion (45 percent) of ecosystem C contained in soils. Black spruce forests on TNWR lands had the highest (84 percent) proportion of total ecosystem C contained in soils. Aboveground live tree C accounted for 13 to 45 percent of total ecosystem C with black spruce forests on TNWR lands having the lowest (13 percent) percentage and white spruce forests on TVSF having the highest (45 percent) percentage (fig. 32). The standing dead tree (“snag”) pool was the smallest overall (2.2 percent of total C) and ranged from 0.5 percent in black spruce forests on the TNWR to 5.9 percent in white spruce forests on the TVSF. When converted to C (biomass × 0.5) (Harmon et al. 2008), DWM contributed a relatively small proportion of the total (live tree, snag, DWM, and

Soil organic layers plus mineral soil to a 1-inch depth had 47 to 84 percent of total ecosystem carbon.

[8] Author: Robert Pattison.

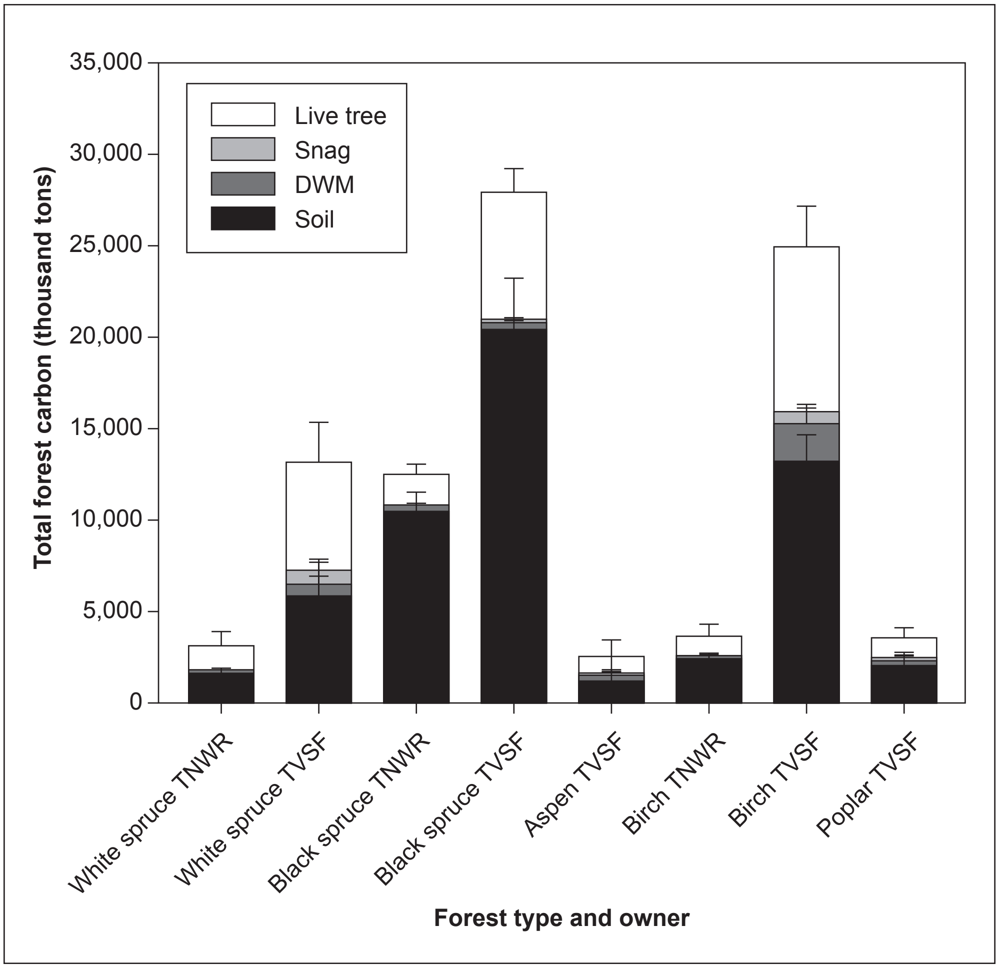

Figure 30—Estimated carbon in trees, down woody material (DWM) and soils in thousands of tons as a total for each of the forest in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Error bars represent + 1 standard error of the estimated totals for trees, DWM, and soils in each category.

soil) C. Black spruce forests on TVSF had the lowest proportion (1.4 percent) of total C in DWM, while aspen forest types on TVSF had the highest (14 percent) (fig. 30). These results are consistent with other studies (DeLuca and Biosvenue 2012) which have found that coarse woody debris (CWD) accounted for 8 to 11 percent of total ecosystem (tree, CWD, soil) C. Ground layer as a distinct pool accounted for 0 to 7 percent of total ecosystem (live tree, snag DWM, and soil) C (fig. 33). Poplar forests had the lowest ground layer content, and white spruce forests had the highest C in the ground layer (fig. 33).

The results of this study highlight the variability both in the amount of total ecosystem C found across forests and in how that C is distributed within forest ecosystems. There was close to a twofold variation in total ecosystem C across the forests in this study. There was also close to a twofold variation in the portion C

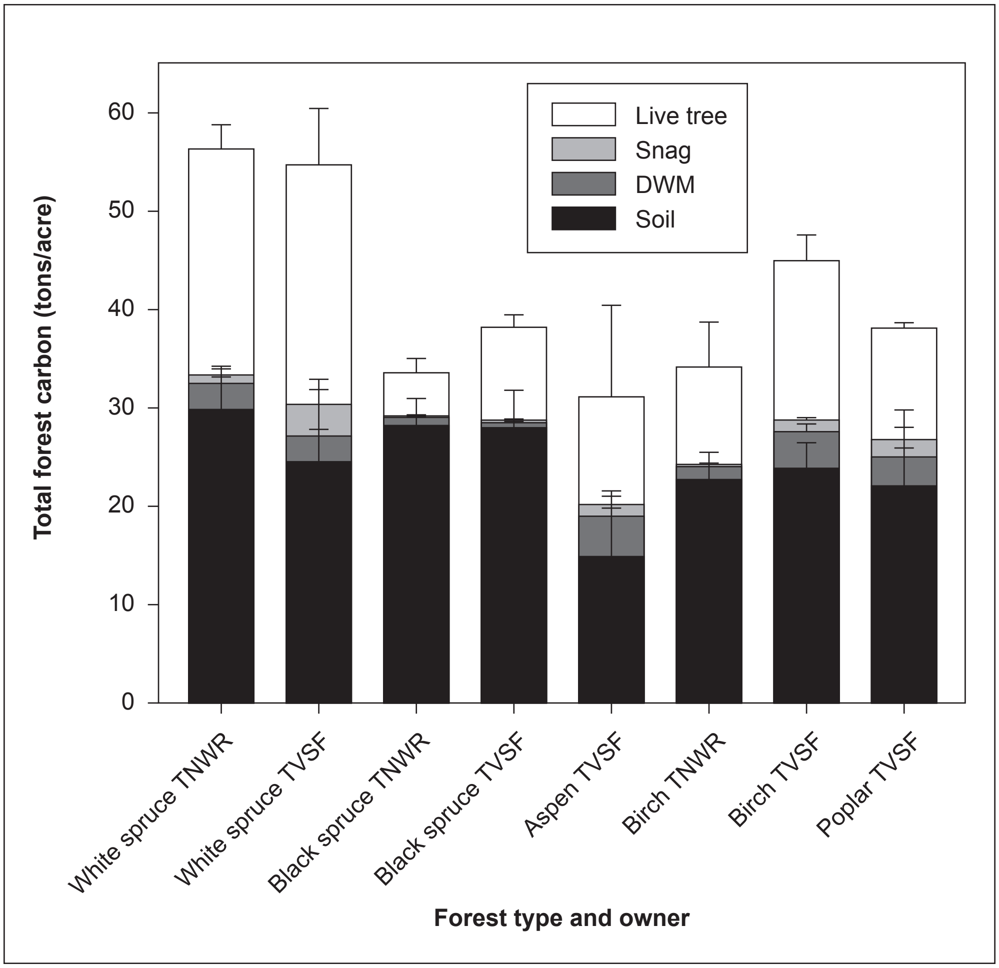

Figure 31—Estimated carbon in live tree, standing dead trees ("snag") down woody material (DWM) and soil in tons per acre as a total for each of the forest types in the Tanana Valley State Forest (TVSF) and Tetlin National Wildlife Refuge (TNWR). Error bars represent + 1 standard error of the estimated totals for trees, DWM, and soils in each category.

that was found in soils and more than a threefold variation in the percentage of C found in trees (fig. 31). The percentage of total ecosystem C found in soils in this study (45 to 84 percent) is consistent with that found in other boreal forests (De Luca and Boisvenue 2012); however, differences in methodology confound direct comparisons. In this study, black spruce forest soils contained up to 84 percent of the total ecosystem C, elsewhere black spruce forest soils contained 87 percent of ecosystem C (De Luca and Biosvenue 2012).

The inability to sample frozen soils particularly those in low-lying and poorly drained sites such as those dominated by black spruce suggests that soil C was underestimated in these forests. Ping et al. (2010) found that soil organic C in black spruce forests tended to increase as water drainage decreased. These sites are also the most likely to have frozen soils that limit sampling. These authors suggest that

Forest Inventory and Analysis

Figure 32—Field crew member measuring tree distance from a subplot center in a white spruce forest.

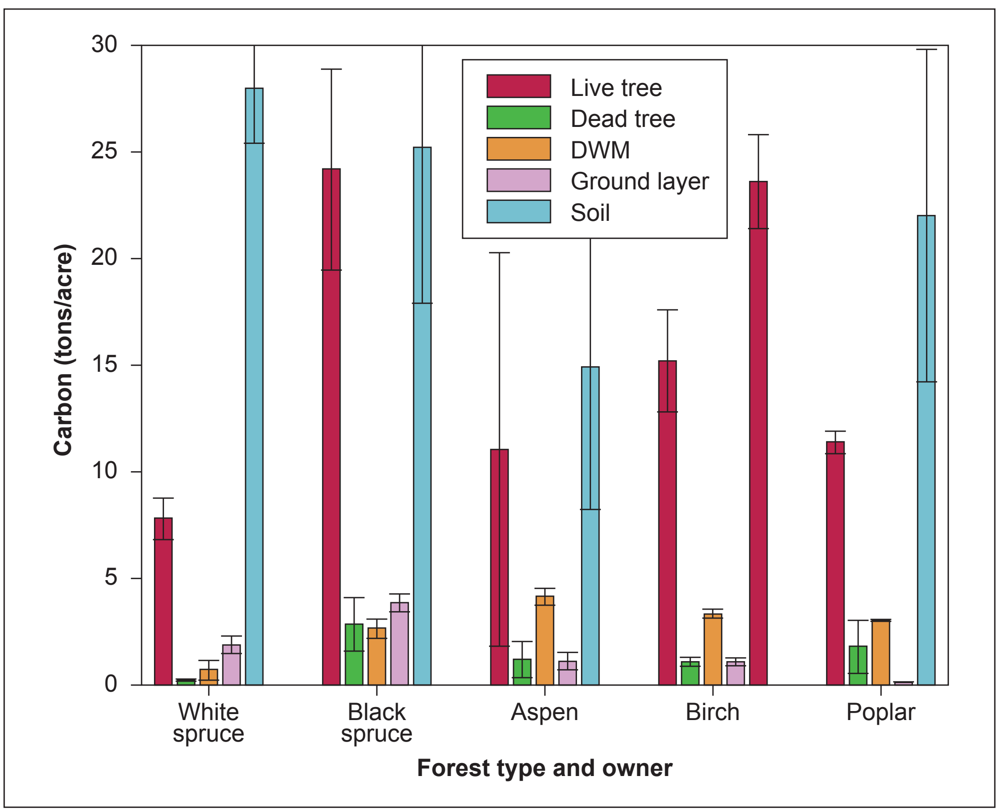

Figure 33—Amount of carbon in various pools by forest types. DWM = down woody material.

sampling at depths less than 40 inches can underestimate soil organic C by as much as 68 percent in black spruce forests. In spite of these limitations, the soil data from this inventory represent an important contribution to understanding soil C dynamics in a region that has limited sampling (Ping et al. 2010) and is vulnerable to climate change (Hinzmann et al. 2013).

Live trees represented another substantial C pool in these forests. The portion of ecosystem C found trees in this study (13 to 45 percent) is similar to that seen in other boreal forests (11 to 64 percent) (DeLuca and Biosvenue 2012). Within black spruce forests, those on the TNWR had the lowest portion (13 percent) of total ecosystem C in trees; this appeared to be the result of lower tree C in these forests (fig. 31).

While the ground layer did not represent a substantial contribution to total ecosystem C (fig. 33), understanding the composition of this layer can provide insights into ecosystem productivity and into soil C properties (Hollingsworth et al. 2008).

This study did not attempt to quantify the C content of understory vegetation. Other studies suggest that understory vegetation typically contains less than 1 percent of the total ecosystem C of boreal forests (DeLuca and Biosvenue 2012). Changes in vegetation composition, including but not limited to shrub encroachment (Johnstone et al. 2010), may alter the contribution of understory vegetation to total ecosystem C in boreal forests.

A USFS-NASA Partnership to Leverage Advanced Remote Sensing Technologies for Forest Inventory[9]

Introduction

To increase the precision of the inventory estimates, the relatively sparse FIA field plot sample collected in TVSF and TNWR was augmented with sampled airborne remotely sensed data acquired with the G-LiHT system to increase the precision of inventory parameter estimates. G-LiHT is a portable, airborne imaging system, developed at the NASA-Goddard Space Flight Center, which simultaneously maps the composition, structure, and function of terrestrial ecosystems using LiDAR, imaging spectroscopy, and thermal imaging. G-LiHT provides high-resolution ~3.3 ft (~1 m) data that are well suited for studying tree-level ecosystem dynamics, including assessment of forest health and productivity of forest stands and individual trees. In addition, G-LiHT data support local-scale mapping and regional-scale sampling of plant biomass, photosynthesis, and disturbance. The data are accurately georeferenced and can be matched very precisely with field plot data that are georeferenced using high-accuracy (dual-frequency, GLONASS-enabled) global positioning system.

G-LiHT is a portable, airborne imaging system that simultaneously maps the composition, structure, and function of terrestrial ecosystems using LiDAR, imaging spectroscopy, and thermal imaging.

[9] Authors: Hans-Erik Andersen, Chad Babcock, Robert Pattison, Bruce Cook, Doug Morton, and Andrew Finley.

Methods

G-LiHT collection—

G-LiHT airborne remote sensing data was acquired in July–August 2014 along single swaths 273 yd wide (250 m wide) spaced 5.78 mi (9.3 km) apart over the entire Tanana inventory unit of 52.1 mi^2 (135 000 km^2) (fig. 2). G-LiHT flight lines were aligned so as to (1) ensure coverage over every FIA plot established for the 2014 pilot and (2) capture as much variability in aboveground biomass as possible within each flight line.

G-LiHT remote sensing measurements—

LiDAR—Detailed specifications for the G-LiHT instrument are provided in Cook et al. (2013). The **airborne LiDAR** data collected in the project provides detailed information on the terrain surface morphology and forest structure within each data swath (fig. 34A and 34B).

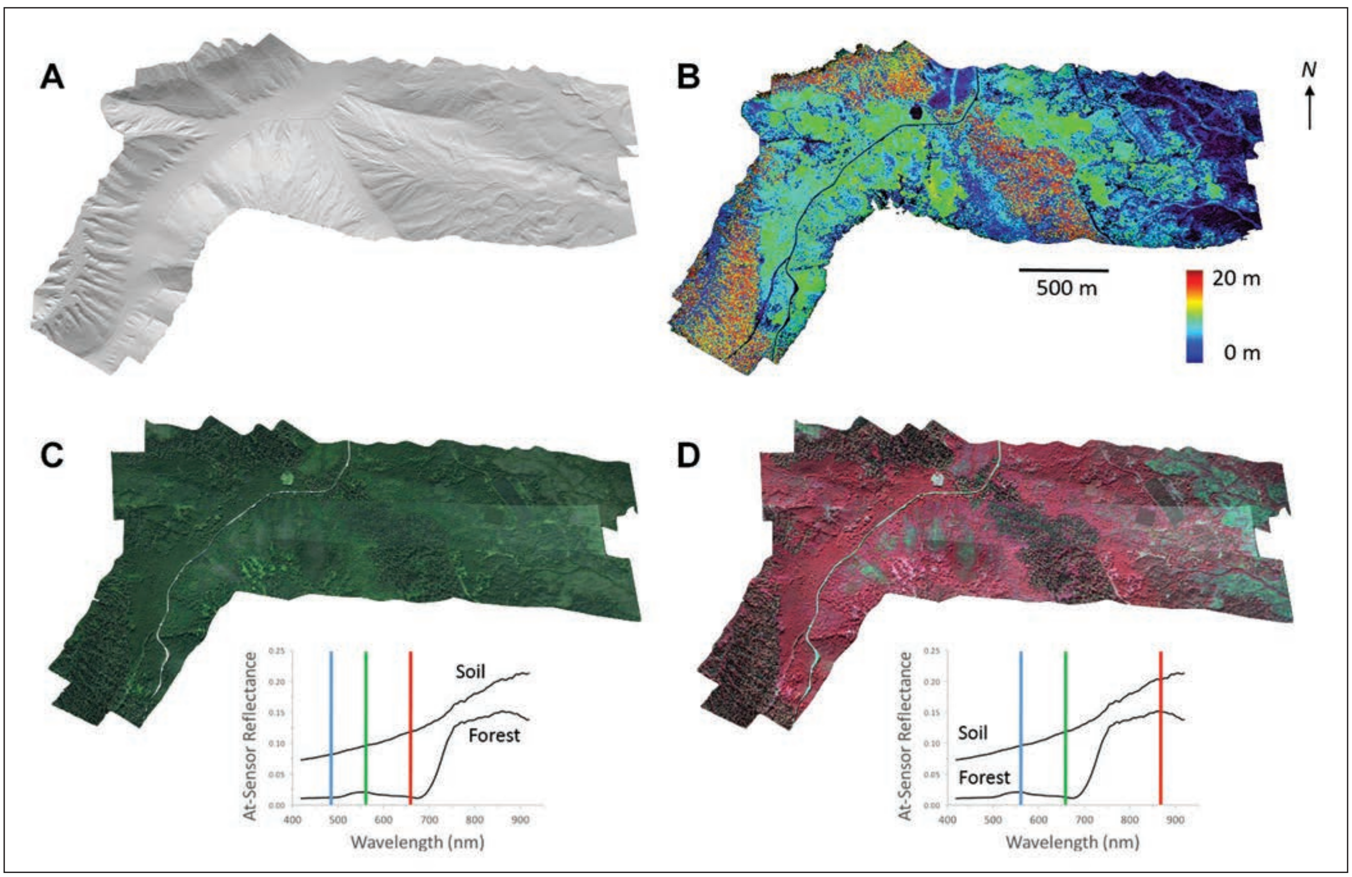

Figure 34—Examples of Goddard-LiDAR/Hyperspectral/Thermal measurements for an area within Bonanza Creek Experimental Forest: (a) LiDAR-derived terrain model, (b) LiDAR-derived canopy height model, (c) normal-color image derived from hyperspectral sensor data (continuous spectral profiles for various features (soil (left), forest (right)) are shown in insets), and (d) color-infrared image derived from hyperspectral sensor data.

The detailed LiDAR terrain model (fig. 34A) can be subtracted from a LiDAR-based canopy surface model to generate a high-resolution (e.g., 3.3-ft [1-m]) canopy height model (fig. 34B). High-resolution LiDAR-derived canopy height and cover information can then be used to characterize important structural conditions such as forest stand size class and canopy cover (Andersen 2009).

In addition, detailed terrain measurements could potentially be used to detect and characterize geomorphological features associated with permafrost distribution and change (fig. 35).

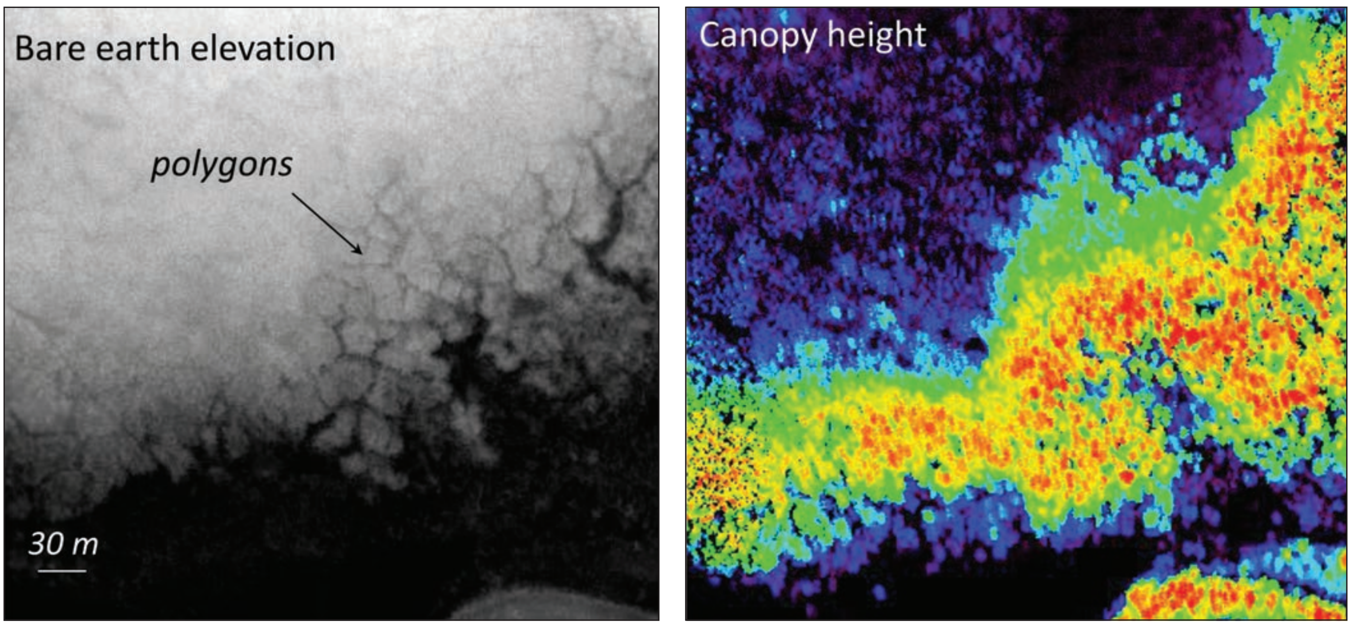

Figure 35—Example of small-scale geomorphological features (patterned ground [polygons] in permafrost soils) captured in Goddard-LiDAR/Hyperspectral/Thermal high-resolution LiDAR terrain model.

Hyperspectral imaging—G-LiHT's hyperspectral imaging sensor provides detailed information on the spectral reflectance properties of surface features that is highly complementary to the 3-D canopy structural information provided by LiDAR. At every image pixel, the hyperspectral sensor captures a spectrum of reflectance values ranging from the violet (420 nm) to the near-infrared (950 nm) with a spectral resolution of less than 5 nm and a spatial resolution of 3.3 ft (1 m). Spectral profiles associated with common surface types such as soil and forest are shown in figure 35. Products such as normal color (fig. 34C) and color-infrared (fig. 34D) high-resolution images can then be generated from hyperspectral image, and can provide useful information related to forest type and condition.

The full range of reflectance values can be used in a supervised classification algorithm to generate maps of forest or species type. For example, figure 36 shows the result of applying a Spectral Angle Mapper supervised classification method to G-LiHT hyperspectral data in a forest near Fairbanks, Alaska. Although hyperspectral image processing and analysis is highly complex and sensitive to a number of factors, including surface moisture, solar illumination conditions, etc., preliminary results show the potential of this data for characterizing composition (species class), condition (insect damage, drought stress), and mortality of vegetation within the scene.

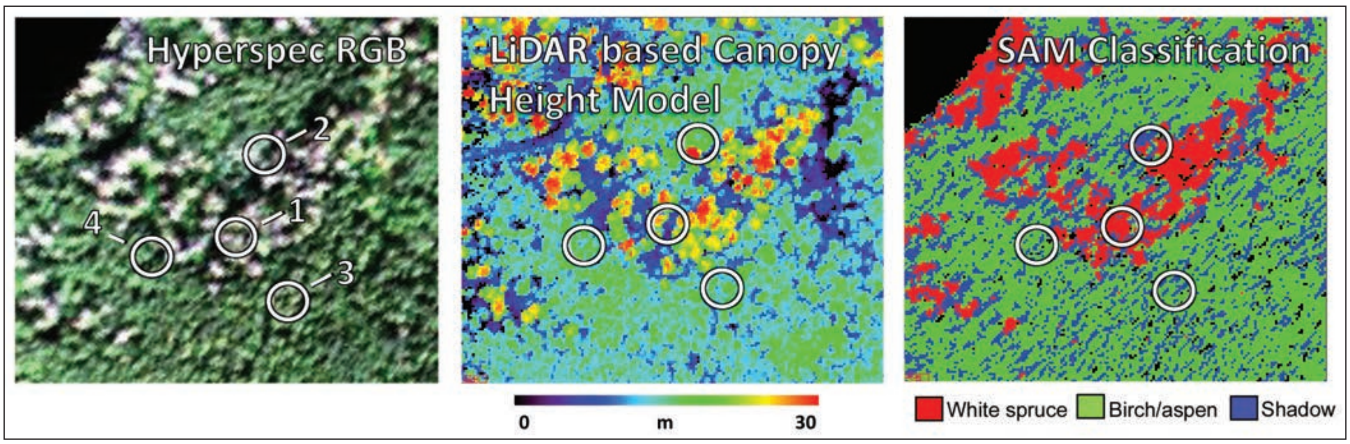

Figure 36—Forest type mapping using Spectral Angle Mapper (SAM) classification algorithm applied to Goddard-LiDAR/Hyperspectral/Thermal hyperspectral measurements. White circles depict Forest Inventory and Analysis subplots.

High-resolution digital camera—A Nikon D7100 digital single lens reflex (DSLR) camera with 20mm f/2.8D lens was mounted next to the G-LiHT sensor to acquire ultra-high resolution normal color frame imagery to supplement the G-LiHT measurements (fig. 37). Because the DSLR imagery was collected as an experiment in this project, there were limitations to the data; for example, approximately 50 percent of the field-of-view was blocked by the G-LiHT instrument and frame rate was too low to enable stereo collection. That being said, it is evident that the DSLR camera provided highly detailed information on many scene components, including CWD, ground cover (lichens, mosses), tree mortality, and hydrology.

LiDAR-based biomass prediction—

Detailed LiDAR-derived metrics obtained from G-LiHT (e.g., height percentiles, canopy cover by height stratum, etc.) can be used to quantify 3-D canopy structure over an area at the scale of an FIA plot or subplot, thereby enabling prediction of inventory attributes (e.g., aboveground biomass) via linear regression analysis. For example, figure 38 shows the results of a regression analysis at FIA plots within TVSF and TNWR established in the 2014 Tanana pilot. Interestingly, the results indicate that the strength of the regression relationship between LiDAR-based predictor variables and field-measured AGB is increased by including a larger sample of small-diameter trees provided by the second microplot on each FIA subplot.

Figure 37—High-resolution image from digital single lens reflex camera collected concurrently with Goddard-LiDAR/Hyperspectral/Thermal.

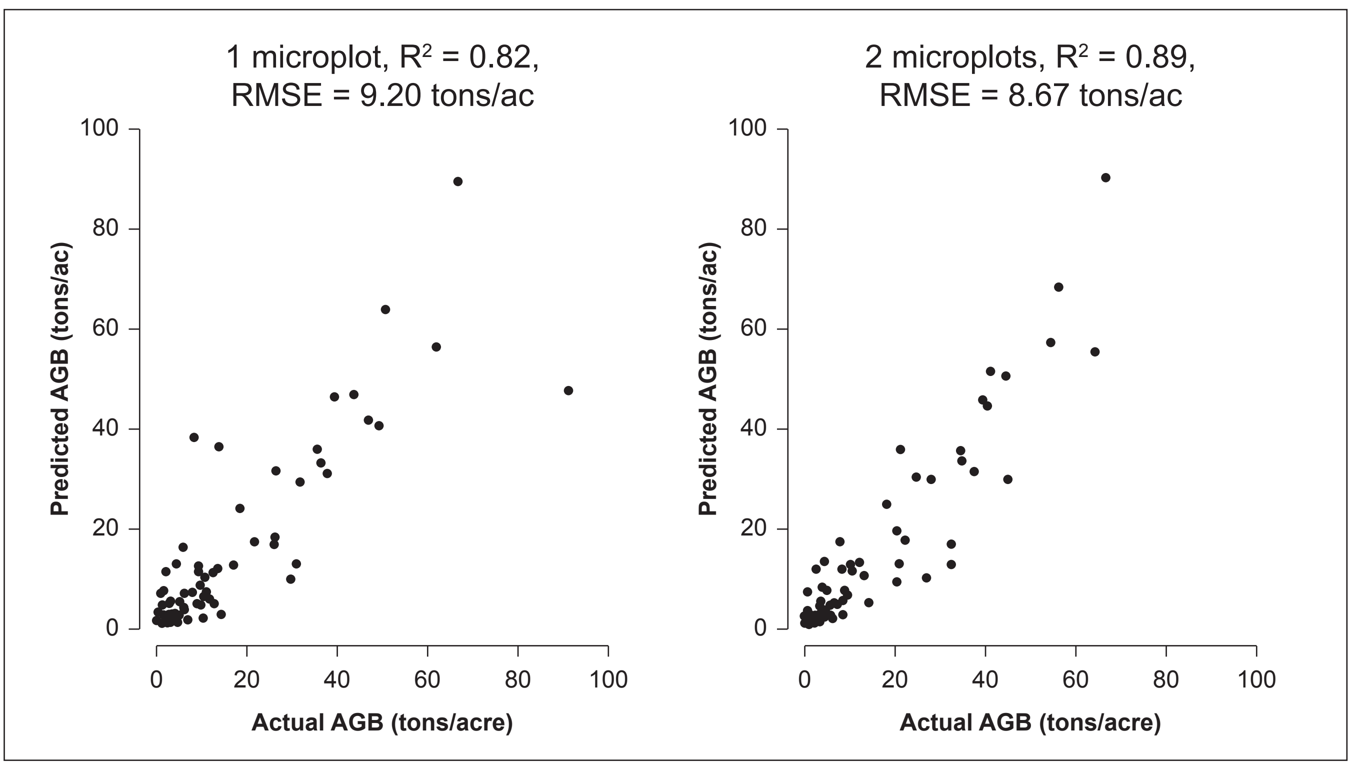

Figure 38—LiDAR-based predicted aboveground biomass (AGB) vs. actual (field-based) AGB for Forest Inventory and Analysis (FIA) plots with one microplot (left) and FIA plots with two microplots (right). RMSE = root mean squared error.

Future Work

Standard (design-unbiased, plot-based) FIA estimation approaches will be compared with model-assisted (i.e., approximately design-unbiased) and model-based approaches which utilize auxiliary information provided by G-LiHT-derived structural and spectral metrics (Bechtold and Patterson 2005, Gregoire et al. 2011, McRoberts et al. 2014, Särndal et al. 2003). Previous studies have indicated that the precision of aboveground carbon/biomass estimates—and the cost-efficiency of the inventory–can be increased through the combined use of airborne LiDAR data and field data in a two-phase, model-assisted sampling framework (Barrett et al. 2009, Ene et al. 2013). The accuracy and bias of the different approaches to estimation and inference will be evaluated using simulation (e.g., Ene et al. 2012).

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	305	Meters
Acres (ac)	.405	Hectares
Miles (mi)	1.609	Kilometers
Cubic feet (ft^3)	.0283	Cubic meters
Pounds (lb)	454	Grams
Pounds (lb)	.454	Kilograms
Tons (ton)	907	Kilograms
Tons (ton)	0.907	Tonnes or megagrams
Pounds per acre (lb/ac)	1.12	Kilograms per hectare
Pounds per acre	.00112	Tonnes per hectare
Tons per acre	2.24	Tonnes or megagrams per hectare
Cubic feet per acre (ft^3/ac)	.07	Cubic meters per hectare
Degrees Fahrenheit	.56(°F – 32)	Degrees Celsius

Literature Cited

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

Andersen, H.-E. 2009. Using airborne light detection and ranging (LiDAR) to characterize forest stand condition on the Kenai Peninsula of Alaska. Western Journal of Applied Forestry. 24(2): 95–102.

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.

Arctic Climate Impact Assessment. 2005. Arctic Climate Impact Assessment—scientific report. New York: Cambridge University Press. 1042 p.

Barber, V.A.; Juday, G.P.; Finney, B.P. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. Nature. 405(6787): 668–673.

Barney, R.J.; Van Cleve, K.V. 1973. Black spruce fuel weights and biomass in two interior Alaska stands. Canadian Journal of Forest Research. 3(2): 304–311.

Barrett, T.M.; Andersen, H.-E.; Winterberger, K.C. 2009. Integrating field and LiDAR data to monitor Alaska's boreal forest. In: Proceedings of the IUFRO division 4 conference: extending forest inventory and monitoring over space and time. Quebec City, Canada: International Union of Forest Research Organizations.

Barrett, T.M.; Gray, A.N. 2011. Potential of a national monitoring program for forests to assess change in high-latitude ecosystems. Biological Conservation. 144(5): 1285–1294.

Bechtold, W.A.; Patterson, P.L., eds. 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.; Juday, G.P.; Alix, C.; Barber, V.A.; Winslow, S.E.; Sousa, E.E.; Heiser, P.; Herriges, J.D.; Goetz, S.J. 2011. Changes in forest productivity across Alaska consistent with biome shift. Ecology Letters. 14(4): 373–379.

Berner, L.T.; Alexander, H.D.; Loranty, M.M.; Ganzlin, P.; Mack, M.C.; Davydov, S.P.; Goetz, S.J. 2015. Biomass allometry for alder, dwarf birch, and willow in boreal forest and tundra ecosystems of far northeastern Siberia and north-central Alaska. Forest Ecology and Management. 337: 110–118.

Boggs, K.; Boucher, T.V.; Kuo, T.T.; Fehringer, D.; Guyer, S. 2014. Vegetation map and classification: northern, western and interior Alaska, 2014 Update. Anchorage, AK: Alaska Natural Heritage Program, University of Alaska Anchorage. 80 p.

Boggs, K.; Garibaldi, A.; Stevens, J.L.; Grunblatt, J.; Helt, T. 2001. Denali National Park and Preserve landcover mapping project. Volume 2: Landcover classes and plant associations. Natural Resource Technical Report NPS/DENA/NRTR—2001/002. Fort Collins, CO: U.S. Department of the Interior, National Park Service.

Bona, K.A.; Fyles, J.W.; Shaw, C.; Kurz, W.A. 2013. Are mosses required to accurately predict upland black spruce forest soil carbon in national-scale forest C accounting models? Ecosystems. 16(6): 1071–1086.

Bond-Lamberty, B.; Wang, C.; Gower, S.T. 2002. Aboveground and belowground biomass and sapwood area allometric equations for six boreal tree species of northern Manitoba. Canadian Journal of Forest Research. 32: 1441–1450.

Cella, B.; Allen, J.; Butteri, P.; Cole, F.; Fleming, M.; Howard, K.; Koltun, J.; Long, G.; Martyn, P.; Murphy, K.; Noonan-Wright, E.; Passek, J.; Scott, J.; See, J.; Slaughter, K.; Sorbel, B.; Theisen, S. 2008. Alaska fuel model guide to Alaska vegetation. (Alaska Fire Science) FRAMES. 62 p. http://fire.ak.blm.gov/content/admin/awfcg_committees/GIS/e.%20Alaska%20Fuel%20Model%20Guidebook%20062008.pdf. (Currently in revision: https://www.frames.gov/files/4114/6482/2825/Intro_Revised_FuelModelGuide_Draft_May2016_Posted.pdf).

Chapin, F.S.; McGuire, A.D.; Ruess, R.W.; Hollingsworth, T.N.; Mack, M.C.; Johnstone, J.F.; Kasischke, E.S.; Euskirchen, E.S.; Jones, J.B.; Jorgenson, M.T.; Kielland, K. 2010. Resilience of Alaska's boreal forest to climatic change. Canadian Journal of Forest Research. 40(7): 1360–1370.

Chimner, R.A.; Ott, C.A.; Perry, C.H.; Kolka, R.K. 2014. Developing and evaluating rapid field methods to estimate peat carbon. Wetlands. 34(6): 1241–1246.

Chojnacky, D.C.; Milton, M. 2008. Measuring carbon in shrubs. In: Hoover, ed. Field measurements for forest carbon. New York: Springer: 45–72.

Cochran, W.G. 1977. Sampling techniques. New York: John Wiley and Sons. 428 p.

Cook, B.D.; Corp, L.; Nelson, R.; Middleton, E.; Morton, D.; McCorkel, J.; Masek, J.; Ranson, K.; Ly, V.; Montasano, P. 2013. NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) Airborne Imager. Remote Sensing. 5(8): 4045–4066. doi:10.3390/rs5084045.

Deluca, T.H.; Boisvenue, C. 2012. Boreal forest soil carbon: distribution, function and modelling. Forestry. 85(2): 161–184.

Dial, R.J.; Berg, E.E.; Timm, K.; McMahon, A.; Geck, J. 2007 Changes in the alpine forest-tundra ecotone commensurate with recent warming in southcentral Alaska: evidence from orthophotos and field plots. Journal of Geophysical Research. 112(G4): doi:10.1029/2007JG000453.

Dial, R.J.; Smeltz, T.S.; Sullivan, P.F.; Rinas, C.L.; Timm, K.; Geck, J.E.; Tobin, S.C.; Golden, T.S.; Berg, E.C. 2016. Shrubline but not treeline advance matches climate velocity in montane ecosystems of south-central Alaska. Global Change Biology. 22: 1841–1856.

Ene, L.; Næsset, E.; Gobakken, T.; Gregoire, T.; Ståhl, G.; Holm, S. 2013. A simulation approach for accuracy assessment of two-phase post-stratified estimation in large-area LiDAR biomass surveys. Remote Sensing of Environment. 133: 210–224.

Ene, L.; Næsset, E.; Gobakken, T.; Gregoire, T.; Ståhl, G.; Nelson, R. 2012. Assessing the accuracy of regional LiDAR-based biomass estimation using a simulation approach. Remote Sensing of Environment. 123: 579–592.

Fenner, N.; Freeman, C. 2011. Drought-induced carbon loss in peatlands. Nature Geoscience. 4(12): 895–900.

Fresco, N.; Chapin, F.S., III. 2009. Assessing the potential for conversion to biomass fuels in interior Alaska. Res. Pap. PNW-RP-579. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 56 p.

Gorham, E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications. 1(2): 182–195.

Gregoire, T.G.; Ståhl, G.; Næsset, E.; Gobakken, T.; Nelson, R.; Holm, S. 2011. Model-assisted estimation of biomass in a LiDAR sample survey in Hedmark County, Norway. Canadian Journal of Forest Research. 41(1): 8395.

Hansen, W.D.; Chapin, F.S., III; Naughton, H.; Verbyla, D. 2016 Forest-landscape structure mediates effects of a spruce bark beetle (*Dedroctonus rufipennis*) outbreak on subsequent likelihood of burning in Alaskan boreal forest. Forest Ecology and Management. 369: 38–46.

Hanson, D. 2013 Timber inventory of state forest lands in the Tanana Valley 2013. Anchorage, AK: Alaska Department of Natural Resources, Division of Forestry. http://forestry.alaska.gov/timber/forestinventories. (17 October 2016).

Harden, J.W.; Trumbore, S.E.; Stocks, B.J.; Hirsch, A.; Gower, S.T.; O'neill, K.P.; Kasischke, E.S. 2000. The role of fire in the boreal carbon budget. Global Change Biology. 6(S1): 174–184.

Harmon, M.E.; Franklin, J.F.; Swanson, F.J.; Sollins, P.; Gregory, S.V.; Lattin, J.D.; Anderson, N.H.; Cline, S.P.; Aumen, N.G.; Sedell, J.R.; Lienkaemper, G.W.; Cromack, K.; Cummins, K.W. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. 15: 133–302.

Harmon, M.E.; Woodall, C.W.; Fasth, B.; Sexton, J. 2008. Woody detritus density and density reduction factors for tree species in the United States: a synthesis. Gen. Tech. Rep. NRS-29. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 84 p.

Harris, A.; Bryant, R.G. 2009. A multi-scale remote sensing approach for monitoring northern peatland hydrology: present possibilities and future challenges. Journal of Environmental Management. 90(7): 2178–2188.

Hasselquist, N.J.; Metcalfe, D.B.; Marshall, J.D.; Lucas, R.W; Högberg, P. 2016. Seasonality and nitrogen supply modify carbon partitioning in understory vegetation of a boreal coniferous forest. Ecology. 97(3): 671–683.

Hinzman, L.D.; Deal, C.J.; McGuire, A.D.; Mernild, S.H.; Polyakov, I.V.; Walsh, J.E. 2013. Trajectory of the Arctic as an integrated system. Ecological Applications. 23(8): 1837–1868.

Hollingsworth, T.N.; Schuur, E.A.G.; Chapin, F.S., III; Walker, M.D. 2008. Plant community composition as a predictor of regional soil carbon storage in Alaskan boreal black spruce ecosystems. Ecosystems. 11(4): 629–642.

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.

Homer, C.; Dewitz, J.; Fry, J.; Coan, M.; Hossain, N.; Larson, C.; Herold, N.; McKerrow, A.; VanDriel, J.N.; Wickham, J. 2007. Completion of the 2001 National Landcover Database for the conterminous United States. Photogrammetric Engineering and Remote Sensing. 73: 337–341.

Hu, F.S.; Higuera, P.E.; Duffy, P.; Chipman, M.L.; Rocha, A.V.; Young, A.M.; Kelly, R.; Dietze, M.C. 2015. Arctic tundra fires: natural variability and responses to climate change. Frontiers in Ecology and the Environment. 13(7): 369–377.

Hupp, J.; Brubaker, M.; Wilkinson, K.; Williamson, J. 2015. How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. International Journal of Circumpolar Health. International Journal of Circumpolar Health. 74. doi:10.3402/iijch.v74.28707.

Johnstone, J.F.; Hollingsworth, T.N.; Chapin, F.S., III. 2008. A key for predicting postfire successional trajectories in black spruce stands of interior Alaska. Gen. Tech. Rep. PNW-GTR-767. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37 p.

Johnstone, J.F.; Hollingsworth, T.N.; Chapin, F.S., III; Mack, M.C. 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. Global Change Biology. 16: 1281–1295.

Joly, K.; Jandt, R.R.; Klein, D.R. 2009. Decrease of lichens in Arctic ecosystems: the role of wildfire, caribou, reindeer, competition and climate in north-western Alaska. Polar Research. 28(3): 433–442.

Jorgenson, M.T.; Harden, J.; Kanevskiy, M.; O'Donnell, J.; Wickland, K.; Ewing, S.; Manies, K.; Zhuang, Q.; Shur, Y.; Striegl, R.; Koch, J. 2013. Reorganization of vegetation, hydrology, and soil carbon after permafrost degradation across heterogeneous boreal landscapes. Environmental Research Letters. 8: 035017

Jorgenson, M.T.; Racine, C.H.; Walters, J.C.; Osterkamp, T.E. 2001. Permafrost degradation and ecological changes in central Alaska. Climate Change. 48: 551–579.

Jorgenson, M.T.; Romanovsky, V.; Harden, J.; Shur, Y.; O'Donnell, J.; Schuur, E.A.; Kanevskiy, M.; Marchenko, S. 2010. Resilience and vulnerability of permafrost to climate change. Canadian Journal of Forest Research. 40(7): 1219–1236.

Juday, G.P.; Alix, C.; Grant, T.A. 2015. Spatial coherence and change of opposite white spruce temperature sensitivities on floodplains in Alaska confirms early-stage boreal biome shift. Forest Ecology and Management. 350: 46–61.

Kane, E.S.; Vogel, J.G. 2009. Patterns of total ecosystem carbon storage with changes in soil temperature in boreal black spruce forests. Ecosystems. 12(2): 322–335.

Kasischke, E.S.; Stocks, B.J., eds. 2012. Fire, climate change, and carbon cycling in the boreal forest. Springer Science and Business Media. 138.

Kasischke, E.S.; Turetsky, M.R. 2006. Recent changes in the fire regime across the North American boreal region—spatial and temporal patterns of burning across Canada and Alaska. Geophysical Research Letters. 33(9).

Kelly, R.; Chipman, M.L.; Higuera, P.E.; Stefanova, I.; Brubaker, L.B.; Hu, F.S. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. Proceedings of the National Academy of Sciences. 110(32): 13055–13060.

Kushida, K.; Kim, Y.; Tanaka, N.; Fukuda, M. 2004. Remote sensing of net ecosystem productivity based on component spectrum and soil respiration observation in a boreal forest, interior Alaska. Journal of Geophysical Research: Atmospheres. 109(D6).

Lagerström, A.; Nilsson, M.-C.; Zackrisson, O.; Wardle, D.A. 2007. Ecosystem input of nitrogen through biological fixation in feather mosses during ecosystem retrogression. Functional Ecology. 21: 1027–1033.

Larson, F.R.; Winterberger, K.C. 1988. Tables and equations for estimating volumes of trees in the Susitna River Basin, Alaska. Res. Note PNW-RN-478. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p.

Lewis, S.A.; Hudak, A.T.; Ottmar, R.D.; Robichaud, P.R.; Lentile, L.B.; Hood, S.M.; Cronan, J.B.; Morgan, P. 2011. Using hyperspectral imagery to estimate forest floor consumption from wildfire in boreal forests of Alaska, USA. International Journal of Wildland Fire. 20(2): 255–271.

Lindo, Z.; Nilsson, M.C.; Gundale, M.J. 2013. Bryophyte-cyanobacteria associations as regulators of the northern latitude carbon balance in response to global change. Global Change Biology. 19(7): 2022–2035.

Mack, M.C.; Treseder, K.K.; Manies, K.L.; Harden, J.W.; Schuur, E.A.; Vogel, J.G.; Randerson, J.T.; Chapin F.S., III. 2008. Recovery of aboveground plant biomass and productivity after fire in mesic and dry black spruce forests of interior Alaska. Ecosystems. 11(2): 209–225.

Malhi, Y.; Baldocchi, D.D.; Jarvis, P.G. 1999. The carbon balance of tropical, temperate and boreal forests. Plant, Cell and Environment. 22(6): 715–740.

Malone, T.; Liang, J.; Packee, E.C. 2009. Cooperative Alaska Forest Inventory. Gen. Tech. Rep. PNW-GTR-785. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.

Mann, D.H.; Rupp, S.; Olson, M.A.; Duffy, P.A. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? Arctic, Antarctic, and Alpine Research. 44(3): 319–331.

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

McCune, B. 2006. Non-parametric habitat models with automatic interactions. Journal of Vegetation Science. 17(6): 819–830.

McCune, B.; Mefford. 2011. Nonparametric multiplicative habitat modeling. version 2.25. Gleneden Beach, OR: MjM Software.

McRoberts, R.; Andersen, H.-E.; Naesset, E. 2014. Using airborne laser scanning to support forest sample surveys. In: Maltamo, M.; Naesset, E.; Vauhkonen, J., eds. Forestry applications of airborne laser scanning. Dordrecht, Netherlands: Springer. Chapter 14.

Mitchell, W. 1968. On the ecology of Sitka alder in the subalpine zone of south-central Alaska. In: Trappe, J.; Franklin, J.; Tarrat, R.; Hansen, G., eds Biology of alder. Proceedings from a symposium at the Northwest Scientific Association 40th annual meeting. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 45–56.

Nadler, I.A.; Wein, R.W. 1998. A new forest floor corer for rapid sampling, minimal disturbance and adequate precision. Silva Fennica. 32: 373–382.

Nelson, P.R.; Roland, C.; Macander, M.J.; McCune, B. 2013. Detecting continuous lichen abundance for mapping winter caribou forage at landscape spatial scales. Remote Sensing of Environment. 137: 43–54.

Nossov, D.R.; Hollingsworth, T.N.; Ruess, R.W.; Kielland, K. 2011. Development of *Alnus tenufolia* stands on an Alaskan floodplain: patterns of recruitment, disease, and succession. Journal of Ecology. 99: 621–633.

O'Neill, K.P.; Amacher, M.C.; Perry, C.H. 2005. Soils as an indicator of forest health: a guide to the collection, analysis, and interpretation of soil indicator data in the Forest Inventory and Analysis Program. Gen. Tech. Rep. GTR-NC-258. St. Paul, MN: U.S.Department of Agriculture, Forest Service, North Central Research Station. 53 p.

Pan, Y.; Birdsey, R.A.; Fang, J.; Houghton, R.; Kauppi, P.E.; Kurz, W.A.; Phillips, O.L.; Shvidenko, A.; Lewis, S.L.; Canadell, J.G.; Ciais, P. 2011. A large and persistent carbon sink in the world's forests. Science. 333(6045): 988–993.

Pastick, N.J.; Rigge, M.; Wylie, B.K.; Jorgenson, M.T.; Rose, J.R.; Johnson, K.D.; Ji, L. 2014. Distribution and landscape controls of organic layer thickness and carbon within the Alaskan Yukon River Basin. Geoderma. 230: 79–94.

Pedlar, J.H.; Pearce, J.L.; Venier, L.A.; McKenney, D.W. 2002. Coarse woody debris in relation to disturbance and forest type in boreal Canada. Forest Ecology and Management. 158(1): 189–194.

Ping, C.L.; Michaelson, G.J.; Kane, E.S.; Packee, E.C.; Stiles, C.A.; Swanson, D.K.; Zaman, N.D. 2010. Carbon stores and biogeochemical properties of soils under black spruce forest, Alaska. Soil Science Society of America Journal. 74(3): 969–978.

Roland, C.A.; Schmidt, J.H.; Nicklen, E.F. 2013. Landscape-scale patterns in tree occupancy and abundance in subarctic Alaska. Ecological Monographs. 83: 19–48.

Rupp, S. 2011. Rising temperatures trigger ecological changes in the boreal forest in Alaska. Joint Fire Science Program Fire Science Brief. Issue 130. https://akfireconsortium.wordpress.com/2011/10/28/new-jfsp-brief-rising-temps-trigger-ecological-changes-in-the-boreal-forest-of-alaska/. (25 June 2015).

Särndal, C.; Swensson, B.; Wretman, J. 2003. Model-assisted survey sampling. New York: Springer. 798 p.

Scott, C.T.; Bechtold, W.A.; Reams, G.A.; Smith, W.D.; Westfall, J.A.; Hansen, M.H.; Moisen, G.G. 2005. Sample-based estimators used by the Forest Inventory and Analysis national information management system. In: Bechtold, W.A.; Patterson, P.L., eds. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 43–67.

Sherriff, R.L.; Berg, E.E.; Miller, A.E. 2011. Climate variability and spruce beetle (*Dendroctonus rufipennis*) outbreaks in south-central and southwest Alaska. Ecology. 92(7): 1459–1470.

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

Smith, R.J.; Benavides, J.C.; Jovan, S.; Amacher, M.; McCune, B. 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.

Stafford, J.M.; Wendler, G.; Curtis, J. 2000. Temperature and precipitation of Alaska: 50-year-trend analysis. Theoretical and Applied Climatology. 67: 33–44.

Standish, J.T. 1983. Development of a system to estimate quantity of biomass following logging in British Columbia forest to specified recovery criteria. Project No. 7952, D.S.S. Contract No. OSB80-0001. Vancouver, BC: Talisman Land Resource Consultants. 68 p. + appendices.

Sturm, M.; Racine, C.; Tape, K. 2001. Climate change: increasing shrub abundance in the Arctic. Nature. 411(6837): 546–547.

Tape, K.D.; Sturm, M.; Racine, C. 2006. The evidence for shrub expansion in northern Alaska and the Pan-Arctic. Global Change Biology. 12: 686–702.

Tarnocai, C.; Canadell, J.G.; Schuur, E.A.G.; Kuhry, P.; Mazhitova, G.; Zimov, S. 2009. Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochemical Cycles. 23(2): GB2023.

Trenberth, K.E.; Jones, P.D.; Ambenje, P.; Bojariu, R.; Easterling, D.; Klein Tank, A.; Parker, D.; Rahimzadeh, F.; Renwick, J.A.; Rusticucci, M.; Soden, B.; Zhai, P. 2007. Observations: surface and atmospheric climate change. In: Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; Miller, H.L., eds. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment. Report of the Intergovernmental Panel on Climate Change. United Kingdom and New York: Cambridge University Press: 235–336.

Turetsky, M.R.; Benscoter, B.; Page, S.; Rein, G.; van der Werf, G.R.; Watts, A. 2015. Global vulnerability of peatlands to fire and carbon loss. Nature Geoscience. 8(1): 11–14.

Turetsky, M.R.; Kane, E.S.; Harden, J.W.; Ottmar, R.D.; Manies, K.L.; Hoy, E.; Kasischke, E.S. 2011. Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. Nature Geoscience. 4(1): 27–31.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2007. Forest Inventory and Analysis national core field guide. Version 4.0. http://www.fia.fs.fed.us/library/field-guides-methods-proc/. (7 July 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2014a. Forest Inventory and Analysis national core field guide. Version 6.1. 141–157. http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2014/Core%20FIA%20field%20guide_6-1.pdf. (25 June 2015).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2014b. Forest Inventory and Analysis phase 3 field guide—soil measurements and sampling. Version 5.1. http://www.fia.fs.fed.us/library/field-guides-methods-proc/. (8 August 2016).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2014c. Forest Inventory and Analysis Tanana Pilot Field Supplement. http://www.fia.fs.fed.us/library/field-guides-methods-proc/. (7 July 2014).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2015. Forest health conditions in Alaska 2014. FS-R10-FHP. Publication R-10-PR-36. Anchorage, AK: Alaska Region. 88 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2016. Pacific Northwest Forest Inventory and Analysis field manuals for Alaska. http://www.fs.fed.us/pnw/rma/fia-topics/documentation/field-manuals/index.php. (20 May 2016).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2015. PLANTS Database. http://plants.usda.gov. (25 June 2015).

Van Cleve, K.; Dyrness, C.T.; Viereck, L.A.; Fox, J.; Chapin, F.S.; Oechel, W. 1983. Taiga ecosystems in interior Alaska. Bioscience. 33(1): 39–44.

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.

Viereck, L.A.; Dyrness, C.T.; Van Cleve, K.; Foote, M.J. 1983. Vegetation, soils, and forest productivity in selected forest types in interior Alaska. Canadian Journal of Forest Research. 13: 703–720.

Viereck, L.A.; Johnston, W.F. 1990. *Picea mariana* (Mill.) BSP black spruce. Silvics of North America. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Volume 1. Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 227–237.

Viereck, L.A.; Little, E.L. 2007. Alaska trees and shrubs. 2nd ed. Fairbanks, AK: University of Alaska Press. 359 p.

Wolken, J.M.; Hollingsworth, T.N.; Rupp, T.S.; Chapin, F.S.; Trainor, S.F.; Barrett, T.M.; Sullivan, P.F.; McGuire, A.D.; Euskirchen, E.S.; Hennon, P.E.; Beever, E.A. 2011 Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. Ecosphere. 2(11): 1–35.

Woodall, C.W. 2010. Carbon flux of down woody materials in forests of the north central United States. International Journal of Forestry Research.

Woodall, C.W.; Heath, L.S.; Domke, G.M.; Nichols, M.C. 2011. Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the U.S. forest inventory, 2010. Gen. Tech. Rep. NRS-88. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 30 p.

Woodall, C.W.; Monleon, V.J. 2008. Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program. Gen. Tech. Rep. NRS-22. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p.

Woodall, C.W.; Perry, C.H.; Westfall, J.A. 2012. An empirical assessment of forest floor carbon stock components across the United States. Forest Ecology and Management. 269: 1–9.

Yu, Z.C. 2012. Northern peatland carbon stocks and dynamics: a review. Biogeosciences. 9(10): 4071–4085.

Appendix

Table 23—Scientific and common names of vascular plant species recorded, their growth habits as recorded, wetland status, and constancy on plots by inventory method and owner

				Method/owner		
				VEG Profile		Full census
Scientific name	Common name	Growth habit(s)[a]	Wetland status[b]	TVSF	TNWR	TNWR
				Percentage of plots		
Alnus incana ssp. *tenuifolia*	Thinleaf alder	SH, tr		11.3	0	3.8
Alnus viridis	Green alder	SH	FAC	22.5	0	0
Alnus viridis ssp. *crispa*	Mountain alder	SH, SD		26.8	40.7	34.6
Alnus viridis ssp. *sinuata*	Sitka alder	SH		7	7.4	3.8
Amerorchis rotundifolia	Roundleaf orchid	FB		0	0	3.8
Andromeda polifolia	Bog rosemary	SH	FACW	0	0	11.5
Anemone parviflora	Smallflowered anemone	FB	FACU	0	0	3.8
Arctagrostis latifolia	Wideleaf polargrass	GR	FACW	0	3.7	7.7
Arctagrostis latifolia ssp. *arundinacea*	Wideleaf polargrass	GR		0	3.7	19.2
Arctagrostis latifolia ssp. *latifolia*	Wideleaf polargrass	GR		0	0	19.2
Arctostaphylos alpina	Alpine bearberry	SH		1.4	0	0
Arctostaphylos rubra	Red fruit bearberry	SH		5.6	11.1	61.5
Arctostaphylos uva-ursi	Kinnikinnick	SH	UPL	2.8	0	0
Betula glandulosa	Resin birch	SH	FAC	8.5	25.9	19.2
Betula nana	Dwarf birch	SH	FAC	15.5	44.4	42.3
Betula neoalaskana	Alaska birch	TT, SD	FACU	69	63	57.7
Calamagrostis canadensis	Bluejoint	GR	FAC	35.2	7.4	30.8
Calamagrostis purpurascens	Purple reedgrass	GR		1.4	0	0
Callitriche palustris	Vernal water-starwort	FB	OBL	0	3.7	0
Carex aquatilis	Water sedge	GR	OBL	4.2	7.4	7.7
Carex bigelowii	Bigelow's sedge	GR	FAC	0	0	3.8
Carex canescens	Silvery sedge	GR	FACW	1.4	0	0
Carex capitata	Capitate sedge	GR	FAC	0	0	7.7
Carex chordorrhiza	Creeping sedge	GR	OBL	1.4	0	0
Carex concinna	Low northern sedge	GR	FAC	0	3.7	11.5
Carex disperma	Softleaf sedge	GR	FACW	0	0	3.8
Carex echinata	Star sedge	GR	OBL	0	3.7	0
Carex gynocrates	Northern bog sedge	GR	OBL	0	0	7.7
Carex lasiocarpa	Woollyfruit sedge	GR	OBL	0	0	3.8
Carex lenticularis	Lakeshore sedge	GR	OBL	1.4	0	0
Carex leptalea	Bristlystalked sedge	GR	OBL	0	0	3.8
Carex limosa	Mud sedge	GR	OBL	0	0	3.8

Table 23—Scientific and common names of vascular plant species recorded, their growth habits as recorded, wetland status, and constancy on plots by inventory method and owner (continued)

				Method/owner		
				VEG Profile		Full census
Scientific name	Common name	Growth habit(s)[a]	Wetland status[b]	TVSF	TNWR	TNWR
				Percentage of plots		
Carex magellanica	Boreal bog sedge	GR	OBL	1.4	0	15.4
Carex membranacea	Fragile sedge	GR	FACW	1.4	0	0
Carex microchaeta	Smallawned sedge	GR	FAC	2.8	3.7	11.5
Carex saxatilis	Rock sedge	GR	FACW	0	3.7	11.5
Carex stylosa	Variegated sedge	GR	FACW	1.4	0	0
Carex utriculata	Northwest territory sedge	GR	OBL	0	7.4	0
Carex vaginata	Sheathed sedge	GR	OBL	0	0	3.8
Ceratophyllum demersum	Coon's tail	FB	OBL	0	3.7	3.8
Chamaedaphne calyculata	Leatherleaf	SH	FACW	2.8	3.7	23.1
Chamerion angustifolium ssp. *angustifolium*	Fireweed	FB		15.5	7.4	23.1
Cicuta virosa	Mackenzie's water hemlock	FB	OBL	0	0	3.8
Circaea alpina	Small enchanter's nightshade	FB	FACW	1.4	0	0
Comarum palustre	Purple marshlocks	FB	OBL	1.4	0	7.7
Cornus canadensis	Bunchberry dogwood	FB	FACU	18.3	0	0
Cornus sericea ssp. *sericea*	Redosier dogwood	SH		2.8	0	0
Cornus suecica	Lapland cornel	SH	FAC	1.4	0	0
Cystopteris fragilis	Brittle bladderfern	FB	FACU	0	0	3.8
Dasiphora fruticosa ssp. *floribunda*	Shrubby cinquefoil	SH		1.4	11.1	30.8
Delphinium glaucum	Sierra larkspur	SH	FACW	0	0	3.8
Drosera rotundifolia	Roundleaf sundew	FB	OBL	0	0	3.8
Dryas integrifolia	Entireleaf mountain-avens	FB	FACU	0	0	3.8
Empetrum nigrum	Black crowberry	SH	FAC	11.3	33.3	53.8
Epilobium palustre	Marsh willowherb	FB	OBL	0	0	3.8
Equisetum arvense	Field horsetail	FB	FAC	23.9	11.1	46.2
Equisetum fluviatile	Water horsetail	FB	OBL	4.2	3.7	0
Equisetum palustre	Marsh horsetail	FB	FACW	2.8	3.7	0
Equisetum pratense	Meadow horsetail	FB	FACW	1.4	7.4	11.5
Equisetum scirpoides	Dwarf scouringrush	FB	FACU	1.4	7.4	46.2
Equisetum sylvaticum	Woodland horsetail	FB	FAC	18.3	25.9	23.1
Erigeron acris	Bitter fleabane	FB	FAC	0	0	3.8
Erigeron elatus	Swamp boreal-daisy	FB		0	0	3.8
Erigeron lonchophyllus	Shortray fleabane	FB	FACW	0	0	3.8

Table 23—Scientific and common names of vascular plant species recorded, their growth habits as recorded, wetland status, and constancy on plots by inventory method and owner (continued)

				Method/owner		
				VEG Profile		Full census
Scientific name	Common name	Growth habit(s)[a]	Wetland status[b]	TVSF	TNWR	TNWR
				Percentage of plots		
Eriophorum	Cottongrass	GR		0	3.7	3.8
Eriophorum brachyantherum	Northland cottonsedge	GR	OBL	0	11.1	19.2
Eriophorum vaginatum	Tussock cottongrass	GR	FACW	7	25.9	26.9
Festuca altaica	Altai fescue	GR	FAC	2.8	0	7.7
Festuca rubra	Red fescue	GR	FAC	0	0	7.7
Fragaria virginiana	Virginia strawberry	FB	UPL	1.4	0	0
Geocaulon lividum	False toadflax	FB	FACU	22.5	25.9	42.3
Glyceria grandis var. *grandis*	American mannagrass	GR		0	0	3.8
Goodyera repens	Lesser rattlesnake plantain	FB	FAC	0	0	3.8
Hedysarum alpinum	Alpine sweetvetch	FB	FACU	0	3.7	7.7
Huperzia selago var. *selago*	Fir clubmoss	SH		0	0	3.8
Iris	Iris	FB		0	0	3.8
Iris setosa	Beachhead iris	FB	FAC	1.4	0	3.8
Larix laricina	Tamarack	SD	FACW	7	0	0
Ledum groenlandicum	Bog labrador tea	SH		57.7	77.8	96.2
Ledum palustre ssp. *decumbens*	Marsh labrador tea	SH		8.5	25.9	34.6
Lemna minor	Common duckweed	FB	OBL	0	3.7	0
Linnaea borealis	Twinflower	FB	FACU	9.9	3.7	11.5
Lupinus	Lupine	FB		0	3.7	3.8
Lupinus arcticus	Arctic lupine	FB	FACU	1.4	0	7.7
Lycopodium annotinum	Stiff clubmoss	SH		4.2	3.7	15.4
Lycopodium complanatum	Groundcedar	SH		4.2	0	0
Lycopodium lagopus	One-cone clubmoss	SH	FACU	0	0	3.8
Lycopodium obscurum	Rare clubmoss	SH		1.4	0	0
Menyanthes trifoliata	Buckbean	FB	OBL	1.4	0	3.8
Mertensia paniculata	Tall bluebells	FB	FACU	8.5	7.4	26.9
Moehringia lateriflora	Bluntleaf sandwort	FB	FACU	1.4	0	0
Moneses uniflora	Single delight	FB	FACU	0	0	26.9
Orthilia secunda	Sidebells wintergreen	FB	FACU	0	3.7	30.8
Oxytropis deflexa	Nodding locoweed	FB	FACU	0	0	3.8
Oxytropis deflexa var. *foliolosa*	Nodding locoweed	FB		0	0	3.8
Parnassia palustris var. *tenuis*	Marsh grass of parnassus	FB		0	0	7.7
Parrya nudicaulis	Nakedstem wallflower	FB		0	0	3.8
Pedicularis	Lousewort	FB		0	0	3.8

Table 23—Scientific and common names of vascular plant species recorded, their growth habits as recorded, wetland status, and constancy on plots by inventory method and owner (continued)

				Method/owner		
				VEG Profile		Full census
Scientific name	Common name	Growth habit(s)[a]	Wetland status[b]	TVSF	TNWR	TNWR
				Percentage of plots		
Pedicularis labradorica	Labrador lousewort	FB	FACW	0	0	7.7
Pedicularis parviflora	Smallflower lousewort	FB	FACW	0	0	3.8
Petasites frigidus	Arctic sweet coltsfoot	FB	FACW	1.4	14.8	19.2
Petasites frigidus var. *frigidus*	Arctic sweet coltsfoot	FB		0	0	7.7
Picea glauca	White spruce	TT, SD	FACU	63.4	44.4	46.2
Picea mariana	Black spruce	TT, SD	FACW	59.2	92.6	92.3
Poa arctica ssp. *lanata*	Arctic bluegrass	GR		0	0	3.8
Polygonum alpinum	Alaska wild rhubarb	FB		5.6	0	3.8
Polygonum viviparum	Alpine bistort	FB		0	0	3.8
Populus balsamifera	Balsam poplar	TT, SD	FACU	7	3.7	3.8
Populus tremuloides	Quaking aspen	TT, SD	FACU	18.3	11.1	15.4
Pyrola	Wintergreen	FB		0	0	7.7
Pyrola asarifolia	Liverleaf wintergreen	FB	FACU	0	3.7	19.2
Pyrola chlorantha	Greenflowered wintergreen	FB	FACU	0	0	7.7
Pyrola grandiflora	Largeflowered wintergreen	FB	FAC	0	0	3.8
Ranunculus	Buttercup	FB		0	0	3.8
Ranunculus lapponicus	Lapland buttercup	FB		0	0	7.7
Ribes hudsonianum	Northern black currant	SH	FAC	1.4	0	0
Ribes triste	Red currant	SH	FAC	2.8	0	11.5
Rosa	Rose	SH		0	3.7	0
Rosa acicularis	Prickly rose	SH	FACU	42.3	18.5	46.2
Rubus arcticus	Arctic raspberry	SH	FAC	0	0	3.8
Rubus chamaemorus	Cloudberry	FB, SH	FACW	14.1	7.4	42.3
Rubus idaeus	American red raspberry	SH	FACU	4.2	0	0
Rumex aquaticus var. *fenestratus*	Western dock	FB		0	0	11.5
Salix	Willow	SH		4.2	0	0
Salix alaxensis	Feltleaf willow	SH, tr	FAC	5.6	3.7	19.2
Salix arbusculoides	Littletree willow	SH, tr	FACW	1.4	11.1	34.6
Salix barclayi	Barclay's willow	SH, tr	FAC	1.4	3.7	3.8
Salix barrattiana	Barratt's willow	SH	FACW	1.4	0	0
Salix bebbiana	Bebb willow	SH, SD	FAC	16.9	3.7	3.8
Salix boothii	Booth's willow	SH, tr	OBL	0	0	3.8
Salix commutata	Undergreen willow	SH	FAC	0	0	3.8

Table 23—Scientific and common names of vascular plant species recorded, their growth habits as recorded, wetland status, and constancy on plots by inventory method and owner (continued)

				Method/owner		
				VEG Profile		Full census
Scientific name	Common name	Growth habit(s)[a]	Wetland status[b]	TVSF	TNWR	TNWR
				Percentage of plots		
Salix glauca	Grayleaf willow	SH, tr	FAC	5.6	51.9	84.6
Salix hastata	Halberd willow	SH	FAC	4.2	0	7.7
Salix interior	Sandbar willow	SH	FACW	7	0	15.4
Salix monticola	Park willow	SH		1.4	0	15.4
Salix myrtillifolia	Blueberry willow	SH	FACW	7	14.8	26.9
Salix planifolia	Diamondleaf willow	SH	FACW	1.4	0	11.5
Salix pseudomonticola	False mountain willow	SH	FAC	1.4	3.7	3.8
Salix pulchra	Tealeaf willow	SH	FACW	8.5	0	7.7
Salix richardsonii	Richardson's willow	SH	FACW	0	3.7	0
Salix scouleriana	Scouler's willow	SH, SD	FAC	1.4	3.7	3.8
Saussurea angustifolia	Narrowleaf saw-wort	FB	FAC	0	0	30.8
Saussurea angustifolia var. *yukonensis*	Narrowleaf saw-wort	FB		0	0	3.8
Senecio congestus	Marsh fleabane	FB		0	0	3.8
Shepherdia canadensis	Russet buffaloberry	SH	FACU	1.4	3.7	7.7
Sorbus scopulina	Greene's mountain ash	SH	FACU	1.4	0	0
Spiraea	Spirea	SH		1.4	0	0
Spiraea stevenii	Beauverd spirea	SH	FACU	5.6	0	3.8
Spiranthes romanzoffiana	Hooded lady's tresses	FB	OBL	0	0	3.8
Stellaria longifolia	Longleaf starwort	FB	FAC	0	0	3.8
Taraxacum officinale ssp. *ceratophorum*	Common dandelion (native)	FB		0	0	3.8
Tofieldia pusilla	Scotch false asphodel	FB	FAC	0	0	7.7
Triantha glutinosa	Sticky tofieldia	FB	FACW	0	0	3.8
Trichophorum cespitosum	Tufted bulrush	GR		0	0	3.8
Triglochin maritima	Seaside arrowgrass	GR	OBL	0	0	3.8
Typha latifolia	Broadleaf cattail	FB	OBL	0	3.7	0
Vaccinium	Blueberry	SH		1.4	0	0
Vaccinium oxycoccos	Small cranberry	SH	OBL	0	0	19.2
Vaccinium uliginosum	Bog blueberry	SH	FAC	25.4	70.4	92.3
Vaccinium vitis-idaea	Lingonberry	SH	FAC	67.6	85.2	100
Valeriana capitata	Captiate valerian	FB	FAC	0	0	11.5
Viburnum edule	High bush cranberry	SH	FACU	12.7	0	0

[a] Growth habits: FB = forb; GR = grass-like; SH = shrub or subshrub; tr = potential for tree form; TT = tally tree.
[b] Wetland status: FAC = facultative (occur in wetlands and non-wetlands); FACW = facultative wetland (usually occur in wetlands); FACU = facultative upland (usually occur in non-wetlands); OBL = obligate wetland (almost always occur in wetlands); UPL = obligate upland (almost never occur in wetlands).

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