McCARTHY CREEK FOREST RESOURCE INVENTORY

Michael G. Loso

Resource Report, NPS/AR/NRTR-2005-52



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Cover photo: Wetlands on a forested bench east of McCarthy Creek, upstream from its confluence with the East Fork. Beetle-killed white spruce dominate the middle ground, and Green Butte is visible behind. Photograph by author Michael Loso, July 7, 2004.



United States Department of the Interior
National Park Service
Alaska Region

SUMMARY

I conducted a forest resource inventory in the upper McCarthy Creek valley to assist with the management of subsistence timber harvest. Densities, standing volumes, productivity, site index, and demographic characteristics of white spruce were determined at 72 subplots in three mapped physiographic units: Flatwoods, Slopes, and Floodplains. Flatwoods (238 hectares in the study area) include black spruce and willows, have relatively low productivity, and show moderate recruitment. Slopes (772 ha) include birch and alder, have moderate productivity, and show low recruitment. Floodplains (63 ha) include balsam poplar and willows, have slightly higher productivity, and show the highest recruitment.

Relative to other parts of southcentral Alaska, all of the forests in upper McCarthy Creek have low potential productivity (site index = 56.0). Actual productivity is currently even lower because standing densities of white spruce are low, and because a major spruce beetle epidemic has killed much of the standing timber. Throughout the study area, measured gross productivity is low (0.22 m^3/ha/yr) and net productivity is negative. Because spruce beetle activity was quite high in the summers of both 2003 and 2004, and spruce beetles have a 1-2 year life cycle, substantial additional mortality is expected in the study area next summer and perhaps afterwards.

All of the sampled sites have mixed age distributions that suggest they developed in the absence of large fires. Using age-specific mortality rates inferred from similar forests in the adjacent Kennicott Valley, I used a demographic model to predict the equilibrium densities of mature trees. In the absence of major episodic mortality (like spruce beetle epidemics or selective human harvesting), recruitment is just sufficient to account for the densities of mature trees on Flatwoods and Floodplains, and recruitment is insufficient to account for current densities on Slopes. In the last decade, however, beetles have killed 49%, 48%, and 80% of the mature trees on Flatwoods, Slopes, and Floodplains respectively. Under these circumstances, the model shows that recruitment is clearly insufficient to replace the dying trees. There is no sustainable way to harvest live white spruce, whether for houselogs or for firewood, under the current conditions.

Beetle-killed spruce may offer an alternative source of houselogs and firewood for subsistence harvest. About half of the dead trees are rotten, but a viable resource remains: at present, ~32, 40, and 88 sound useful houselogs per hectare are found on Flatwoods, Slopes, and Floodplains. In the entire study area, then, there are over 40,000 usable houselogs. Beetle-kill also provides a potentially valuable firewood resource: by volume, 72% of the white spruce wood in upper McCarthy Creek's forests is currently supplied by dead trees.

The vast majority of these, however, would be very difficult to access. Slopes cover the largest portion of the study area, but are generally inaccessible due to steep slopes, thick brush, and distance from the road. Floodplains are rare, but they include the most accessible sites and the largest trees. As a consequence, even a narrow corridor of easily accessible land (100 m to either side of the primary access alignment) may contain over 7000 usable, beetle-killed houselogs. From the perspective of white spruce productivity, the use of some fraction of the beetle-killed white spruce for houselogs or firewood should have minimal negative impacts. Other impacts of such harvest, on wildlife habitat, visitor experience, and understory vegetation, for example, may be substantial but are beyond the scope of this work.

INTRODUCTION

Within the administrative boundaries of Wrangell-St. Elias National Park and Preserve, U.S.A. (WRST), the Alaska National Interest Lands Conservation Act (ANILCA) provides for the subsistence use of certain renewable resources by local residents. Specifically, Title 36 CFR Section 13.49(a) authorizes local rural residents in park areas where subsistence uses are allowed to obtain permits for the cutting of standing timber for subsistence needs. In accordance with this regulation, the National Park Service (NPS) has issued a Subsistence Green Log Policy (National Park Service, 1989) that provides guidelines for non-commercial cutting of live standing timber for a primary residence within the park, when other sources of house logs are not feasible. This policy states, in part:

> "Of primary concern to the National Park Service is the maintenance and protection of forest resources and other park values. Subsistence green log permits will only be issued if it can be shown that harvest will not impair or otherwise degrade the viability of the forest resource and other park values."

In February 2004, NPS staff received five applications for house log harvest permits from residents of the Marvelous Millsite property along upper McCarthy Creek in WRST. Because no systematic study of forest conditions had yet been conducted in the McCarthy Creek valley, NPS staff determined that a forest resource inventory was necessary to ensure that any permitted harvest would meet the stated goals of maintaining and protecting forest resources and other park values. This report is being prepared to address that need.

I focus here on white spruce [*Picea glauca* (Moench) Voss], the tree species favored and most commonly used by rural residents for both firewood and houselogs. Within the area that encompassed the upper McCarthy Creek Valley, the primary goals of this study were to: A) map the distribution of white spruce forest types; B) characterize the standing densities and volumes of all tree species; C) estimate the actual and potential productivity of white spruce, including characterization of the extent and intensity of an ongoing spruce beetle outbreak; D) model the population dynamics of white spruce; and E) relate these data to historic, current, and potential future impacts of human harvesting.

METHODS

Study Area

The McCarthy Creek Valley encompasses a mixture of glaciers, rocky moraines, forest, shrubland, and alpine tundra. The study area (61°29' N, 142°47' W; Figure 1) encompasses only the forested land deemed accessible for subsistence use by the permit applicants. Based on interviews with the applicants, the major obstacle to houselog transport is "Eight Mile Hill." This steep hill (on the primary access alignment along the west side of McCarthy Creek upstream from the confluence with Nikolai Creek, Figure 1) renders impractical the freighting of heavy logs between lower McCarthy Creek and the applicants' Marvelous Millsite property. The study area consequently encompasses only the forested land upstream of this location. Forested land is defined as having or potentially supporting >10% canopy cover by one or more of the Valley's five tree species (Viereck et al., 1992):

white spruce	*Picea glauca* (Moench) Voss
black spruce	*Picea mariana* (Mill.) B. S. P.

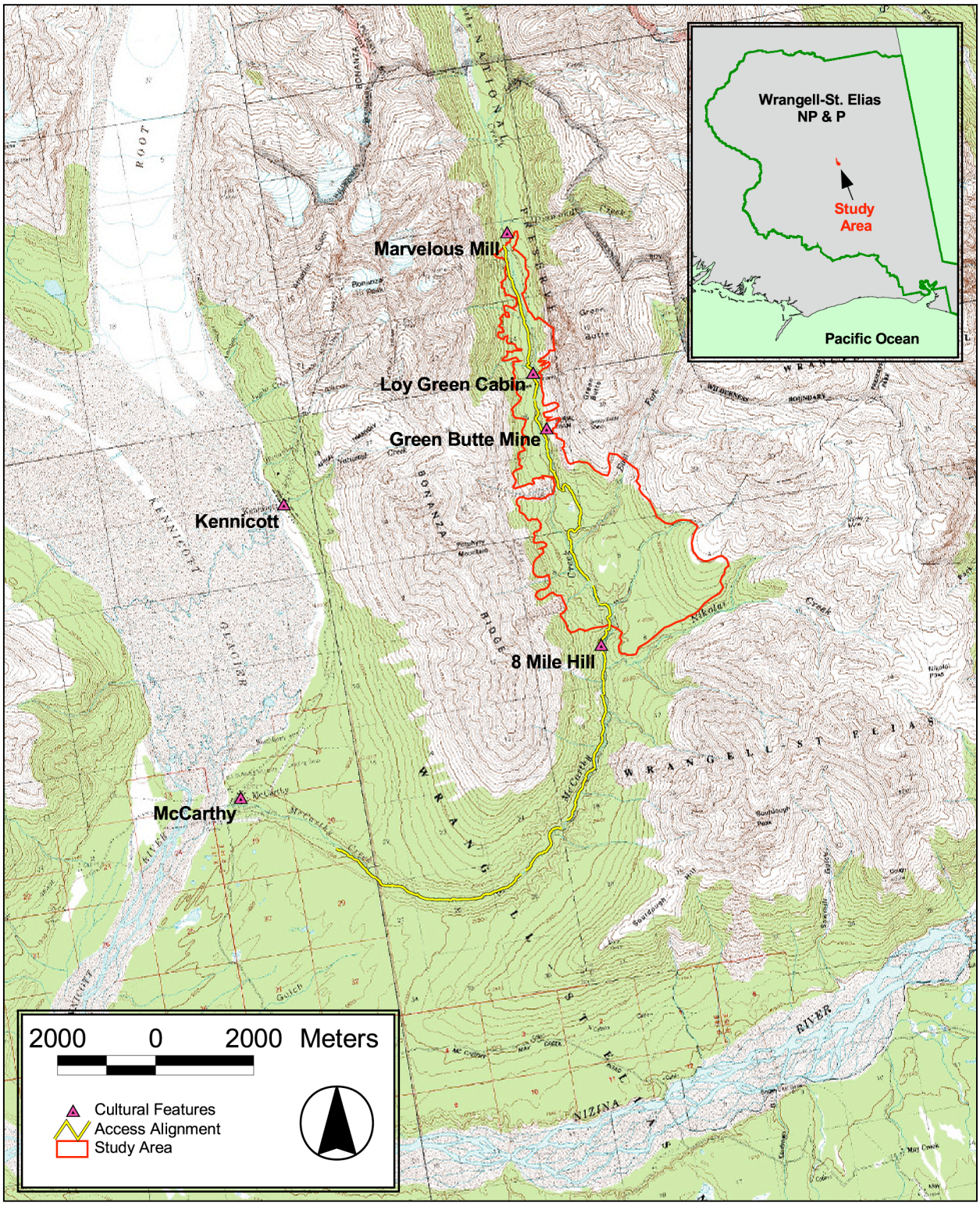


FIGURE 1. Location of the study area (red polygon) and select cultural features in McCarthy Creek and the adjacent Kennicott Valley. INSET: General location within Wrangell-St. Elias National Park and Preserve (green polygon), southcentral Alaska.

balsam poplar	*Populus balsamifera* L.
quaking aspen	*Populus tremuloides* Michx.
paper birch	*Betula papyrifera* Marsh. var. *humilis* (Reg.) Fern. & Raup

The general outline of forested land in the study area encompasses 1290 hectares (3188 acres), of which 1073 hectares (2652 acres) contain productive white spruce forest. In the study area, forest elevation ranges from 670 m (2200') at the McCarthy - Nikolai Creek confluence to 1066 m (3500') at highest timberline.

The McCarthy Creek Valley is part of the Wrangellia terrane, a block of crustal rock that originated in the tropical Pacific Ocean (Plafker et al., 1994). As the island-arc moved north during the Triassic and Jurassic, greenstones, limestones, and shales accumulated; they now underlie much of the study area. Wrangellia docked with mainland Alaska in the late Cretaceous, followed by the Chugach and Yakutat terranes. The latter event resulted in an intrusion of Tertiary dacite porphyry that underlies the southwestern portion of the study area, and gave rise to Quaternary and Tertiary volcanic rocks in the upper Valley that now mantle some of the study area as glacial deposits (MacKevett, 1978). Such deposits, from Pleistocene advances of the McCarthy Creek glacier, have mostly been extensively reworked by Holocene colluvial processes (on hillslopes) and fluvial processes (in floodplains and river terraces). Flat benches of poorly drained lacustrine sediments are conspicuous in the middle to lower reaches of the study area between 762 m (2500') and 945 m (3100'), and reflect late-Wisconsin glacial impoundment of McCarthy Creek (Hecht and Garb, unpublished) and/or the Copper River (Ferrians, 1989).

Sampling

The study area was stratified into physiographic units through analysis of existing aerial photos, field reconnaissance, and surficial geology maps (Jones and Glass, 1993). After excluding areas without a significant white spruce component (active river bars, rock glaciers, black spruce muskeg, and bogs), three physiographic units were identified using the criteria of the USFS Forest Inventory and Analysis Program in their 2004 Inventory of Coastal Alaska (Anonymous, 2004). General characteristics of these units are given in Table 1.

I found considerable geomorphic variation within each physiographic unit, yet each of the three units exhibited a particular vegetative character that was readily discernible both in the field and in aerial photos. **Flatwoods** (USFS unit 21) are characterized by a conspicuous black spruce (*Picea mariana*) component that, along with scattered white spruce and a typically dense subcanopy of willows (*Salix* sp.) and dwarf birch (*Betula nana*), distinguish them from other units. The steeper slopes and moderately well-drained soils of **Slopes** (USFS unit 23 – they call this unit "Moist Coves") contain mature, open stands of white spruce and scattered paper birch (*Betula papyrifera*) over a very dense shrub layer of Sitka alder (*Alnus crispa*). The younger and better-drained soils of **Floodplains** (unit 25) support white spruce and balsam poplar (*Populus balsamifera*) over a variably dense layer of soapberry (*Shepherdia canadensis*). Quaking aspen (*Populus tremuloides*) was not found in any of the study sites.

Eighteen sites were chosen for intensive study. The sites were initially chosen from aerial photos to maximize sampling efficiency, emphasize accessible forest, and represent relatively homogenous stands. Following this initially subjective site selection process, the exact location of each site center was randomized in the following manner: A) approximate latitude and longitude of the site was determined

TABLE 1. Selected attributes of three physiographic units in upper McCarthy Creek.

Physiographic Unit Parameters	**Flatwoods**	**Slopes**	**Floodplains**
Unit code*	21	23	25
Site numbers	3, 4, 9, 12, 13, 14, 15, 16, 17	1, 2, 6, 7, 11	5, 8, 10, 18
Total area (ha)	238	772	63
<1000 m from road (ha)	190	508	63
<500 m from road (ha)	126	359	63
<100 m from road (ha)	38	51	47
Elevation range (m)	760 - 850	670-1070	670-820
Slopes (°)	0-10	5-35	0-3
Parent Material	Lacustrine silts and clays, capped with 1-several meters diverse colluvium	Weathered colluvial dacite porphyry, limestone, and basalt	Fluvial sands and gravels
Soil drainage	Moderately to poorly drained	Moderately-well drained	Well drained
Depositional environment	Latest Pleistocene/early Holocene lake clays from the exposed floor of ice-dammed Lake Ahtna, and perhaps McCarthy Creek if ever impounded by the Kennicott Glacier.	Deeply weathered bedrock and minor glacial till periodically mobilized by debris flows, rockslides, avalanches, and fluvial incision. Some relatively stable interfluves and benches.	Deposited and periodically reworked by McCarthy Creek in the late Holocene. Most terraces are 1-several hundred years old.
Dominant canopy trees (% cover)	*Picea glauca* 30-50 *Picea mariana* 0-20	*Picea glauca* 35-45 *Betula papyrifera* 0-20	*Picea glauca* 20-45 *Populus balsamifera* 10-60
Dominant subcanopy shrubs (% cover)	*Salix* sp. 35-70 *Betula nana* 0-30	*Alnus crispa* 20-80 *Viburnum edule* 15-35	*Salix* sp. 15-70 *Sheperdia canadensis* 10-70
Dominant groundcover (% cover)	graminoids 10-70 *Cornus canadensis* 0-30	*Cornus canadensis* 15-40 *Equisetum arvense* 15-25	*Mertensia panicula* 10-30 graminoids 20-30
Stand age	128	144	139
Evidence of historic logging	Yes	Yes	Yes
Primary disturbance	Spruce beetle outbreak	Spruce beetle outbreak	Spruce beetle outbreak

*from *Field Instructions for the Annual Inventory of Coastal Alaska*

from the aerial photo; B) coordinates were entered into a handheld GPS; C) once in the field, a bearing to the site was selected from the nearest section of existing access alignment; D) GPS was used to follow the bearing in as straight a line as possible; and E) the site center was established at the first location <25 m (according to the GPS) from the chosen coordinates and meeting the following criteria: no saturated soil or standing water during the growing season; no exposure of bedrock; and a minimum of 10% canopy cover by trees >3 meters tall. No sites violated these criteria. At each site, sampling was performed in a manner consistent with the methods employed by the USFS Forest Inventory and Analysis Program in their 2004 inventory of Coastal Alaska (Anonymous, 2004). Each site consists of four subplots 7.3 m (24.0') in radius (0.017 ha, 0.042 acre) and four accompanying microplots 2.1 m (6.8') in radius (0.001 ha, .003 acre). As shown in Figure 2, each subplot/microplot pair was separated from the others by 36.6 m (120'). Except where otherwise noted, these subplots were treated as the basic sampling unit for subsequent analysis.

Standing stems were tallied to calculate density for white spruce, black spruce, balsam poplar, and paper birch in four size classes: seedlings [<2.54 cm (1") dbh], saplings [≥2.54 cm (1") dbh & <12.7 cm (5") dbh], poles [≥12.7 cm (5") dbh & <25.4 cm (10")], and houselogs [≥25.4 cm (10")]. Seedlings were measured in microplots only, while all other size classes were tallied in subplots. All stems were assigned to one of five damage classes: healthy live, damaged live (applied only to beetle-infested trees that still bore green needles), dead <3 years, dead ≥3 years and <15 years, or dead ≥15 years. Fifteen years is the approximate regional duration of the current spruce beetle outbreak (Loso, 1998), and the majority of spruce beetle mortality specifically located in McCarthy Creek occurred within the last three years (Wittwer, 2004; Zogas, 2004). For dead trees, cause of death was recorded as either spruce beetles or, in the few cases where there was no clear evidence of beetle attack, unknown.

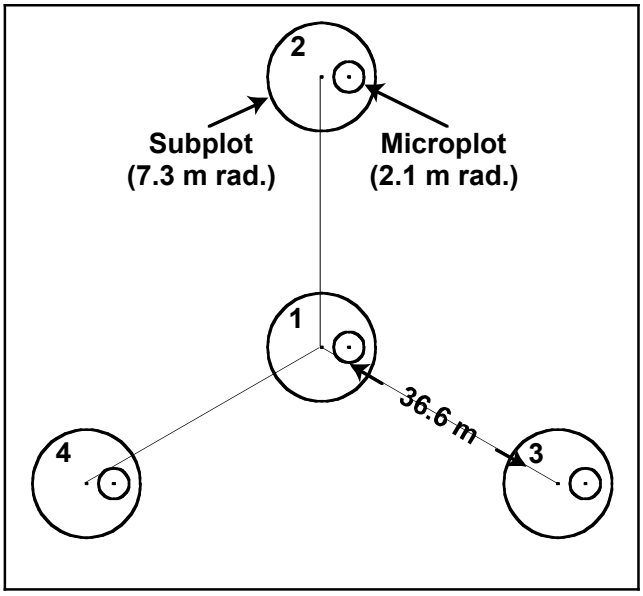


FIGURE 2. Configuration of subplots and microplots within each numbered study site. Follows USFS Forest Inventory and Analysis Program (Anonymous, 2004).

The height and dbh of saplings, poles, and logs of all species were recorded for subsequent calculations of standing volume. After 6 sites were sampled, I examined the correlation of height and dbh for each species, and determined that heights of stems <20 cm (7.9") dbh could subsequently be estimated by regressions of height on recorded dbh (shown in Figure 3). All of the height values for larger trees, including heights used later in calculations of white spruce site index, were measured directly. Height of all seedlings was recorded, and white spruce seedling substrate (mineral soil, duff, or rotten wood) was noted.

To document the population structure of white spruce, the ages of 449 stems (both alive and dead) were determined. I cored all white spruce stems ≥6 cm (2.4") dbh at breast-height with an increment borer,

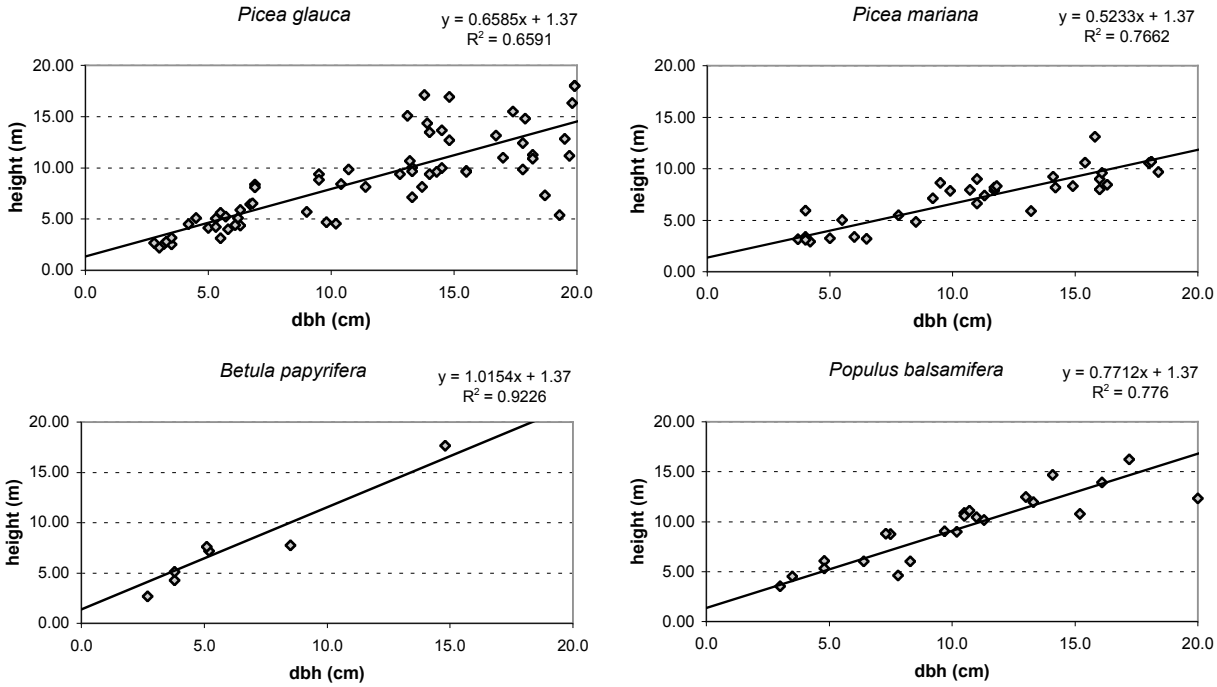


FIGURE 3. Relationship of height to diameter at breast height (dbh) for four different tree species in the upper McCarthy Creek valley. Regression equations are shown at upper right of each panel. These regressions were used to predict heights of additional trees smaller than 20 cm dbh; regressions are limited to trees with dbh < 20 cm to maximize variance reduction. Heights of trees with dbh ≥ 20 cm were always measured directly.

always to within 1 cm of the pith. Cores were shaved with a razor blade and examined under a dissecting microscope for number of annual rings and radial increment in the last 10 years. Counting errors are estimated to be less than ±5 years/100 years. On cores that missed the pith, number of missing rings was estimated based on an extrapolation of average ring width. To minimize destructive sampling of seedlings and saplings too small for an increment borer, ages of stems <6 cm dbh were estimated using a regression of age versus height developed in the adjacent Kennicott Valley (Loso, 1998).

Several environmental characteristics were recorded at each site. I noted the percentage cover of dominant vascular plant species in the canopy, subcanopy, and understory, and I examined shallow soil pits for soil drainage class, parent material type, and evidence of buried charcoal. Other indicators of disturbance history such as fire scars, tip-up mounds, age and number of cut stumps, beetle kills, down wood, cultural artifacts, and signs of geomorphic activity were noted. All fieldwork took place in July 2004.

Analysis

Physiographic units were initially hand drawn on 1:6000 scale aerial photographs. Delineated units were subsequently digitized using ArcView Geographical Information System (GIS) software. Rectified raster images of these and other aerial photographs were used as the base map while digitizing. The ArcView Geospatial Analyst was used to calculate total areas of mapped units, and also to generate buffer zones of varying widths along the primary access alignment. Areas of each physiographic unit contained within these buffer zones measure the relative accessibility of forest land from each unit.

The volumes of standing live and dead poles and houselogs (≥12.7 cm dbh) were calculated with Gregory and Haack's equations (for English units: 1964):

$$V_{\text{white spruce}} = -2.0555 + 0.2982D + 0.00181D^2H$$
$$V_{\text{balsam poplar}} = -3.2187 + 0.8281D - 0.05908D^2 - 0.01985H + 0.00199D^2H$$
$$V_{\text{paper birch}} = -2.5767 + 0.9524D - 0.10446D^2 - 0.03303H + 0.00282D^2H$$

where $V_{species}$ is tree volume (cubic feet) inside bark from a 0.3 m high stump to a 10.2 cm diameter top, H is tree height in feet, and D is diameter outside bark at breast-height. Cubic feet were converted to cubic meters ($m^3 = ft^3 \times 0.02832$). These equations were chosen as a best estimate for the amount of usable firewood in a given tree. Because no volume equation for black spruce was reported by Gregory and Haack, black spruce volume was calculated from the published white spruce equation and probably overestimated slightly due to the generally greater taper of black spruce (Vincent, 1965).

Actual productivity of white spruce for each landform unit ($meters^3$/hectare/year) was estimated by stand-table projection, a method considered most appropriate for uneven-aged, low-density stands such as those found in the Kennicott Valley (Avery and Burkhart, 1983). Live trees ≥12.7 cm dbh were grouped into 2.5 cm dbh size classes and annual increment determined using standard methodology (Beck, 1987). Production was computed as the sum of annual increment for each size class plus ingrowth. Two measures of actual productivity are presented: actual gross productivity, which measures the volume of wood added each year by living trees, and actual net productivity, which equals gross productivity minus the volume lost in mortality.

Site index is a commonly used means of estimating forest site quality, based upon the expected height of a given tree species at some arbitrary age (Hagglund, 1981). Site index was calculated for white spruce trees with Farr's equation (for English units: 1967a): $SI = H (0.49638 + 50.36166/A)$ where SI is site index, H is tree height in feet, and A is breast-height age in years. Site index was determined by applying this equation, in each study site, to the single tallest overstory tree that exhibited no sign of rot, subcanopy suppression, or physical damage. Farr's equation applies only to trees between 30 and 180 years old at breast-height; all trees used in this analysis fall within that age class. Grouped site index values for each physiographic unit are presented as means with standard errors of the mean, and are compared using one-way analysis of variance. Potential productivity was calculated by applying the average site index and stand age to standard yield tables (Farr, 1967b) which are based upon empirical data from well-stocked spruce stands in the Alaskan interior.

A demographic model was used to examine white spruce population dynamics, and specifically the relationship of white spruce recruitment to stand density. In this model, I distinguish between "typical" mortality patterns (defined here as the age-specific survivorship rates typical of mixed-age forest stands free of catastrophic exogenous disturbance) and "episodic" mortality (in this case, specifically including only human harvesting and spruce-beetle epidemics). Because forest stands in McCarthy Creek have been subjected to logging and possibly beetle attacks (Moffitt, 1922) repeatedly in the last century, I could not use age distributions of these stands to infer "typical" mortality patterns. Instead, I used age-specific survivorship rates derived from certain forest stands in the adjacent Kennicott Valley (~4-10 km from the study area) where there is no evidence of human harvest or historic spruce beetle outbreaks. Such stands reflect the long-term dynamics of forests where recruitment occurs in the understory and in small gaps created by individual tree mortality (Loso, 1998).

I used the same model structure as that used in the Kennicott Valley study, and further model details are available there (Loso, 1998). Recruitment age was defined as 40 years, and the lifespan of white spruce was defined as 299 years. Trees were considered mature at age 90, in this case meaning that they were generally old and large enough to be counted in volume estimates, harvested for firewood and/or houselogs, and attacked by spruce beetles. For any given tree that reaches recruitment age, then, the probability of reaching maturity is the cumulative product of the probabilities of surviving the five decades between 40 and 90. If the tree is then subject to episodic mortality, the probability of reaching each successive decade is the product of the probabilities of still being alive and of surviving both typical mortality (as defined by the Kennicott Valley dataset) and episodic mortality during the next decade. This yields:

$$N_m = \sum_{i=6}^{26} \left[R \left(\prod_{j=1}^{i-1} S_j \right) (1 - E)^{i-6} \right]$$

where N_m is the total number of mature trees per hectare, R is the number of trees reaching recruitment age (40) per decade, S_i is the probability of a single tree surviving "typical" mortality factors through the ten-year age class i, E is the proportion of mature trees subjected to episodic mortality in each decade, and $i_{1\text{-}26}$ is tree ages 40-49, 50-59, 60-69 … 290-299. For each of the three physiographic units in upper McCarthy Creek, I substituted measured values of R and N_m into the model and solved for E.

RESULTS

Physiographic Units

Eighteen study sites and the three primary physiographic units are mapped in Figure 4. Slopes cover the most terrain (772 ha), followed by Flatwoods (238 ha) and Floodplains (63 ha). Also mapped are Wetlands – poorly drained sites with either no trees or with virtually pure stands of black spruce. These cover 152 ha within the study area.

Buffer zones of 100, 500, and 1000 m from the primary access alignment (inset, Figure 4) serve as a means to quantify the accessibility of stands in different physiographic units. When accessibility is taken into account the order of magnitude difference in coverage between Slopes and Floodplains is diminished. Floodplains are all located very close to the existing alignment, and Table 1 shows that even a narrow 100 m buffer includes 74% of the total unit. In contrast, only 7% of Slopes and 16% of Flatwoods are enclosed within that same narrow buffer. Even a broad buffer of 1000 m to either side of the alignment encloses only 66% of Slopes and 80% of Flatwoods. Distance to the access alignment is not a perfect measure of accessibility, but unquantified access impediments that include steep slopes, avalanche hazard, and thick brush are most significant on Slopes and least significant on Floodplains, further compromising the usefulness of some stands in the Slopes unit and, to a lesser extent, Flatwoods.

Standing Density and Volume

White spruce densities ranged from 850 stems/ha on Slopes to 3540 stems/ha on Floodplains, with Flatwoods intermediate at 1580 stems/ha (Figure 5). Seedlings were the most abundant size class on all

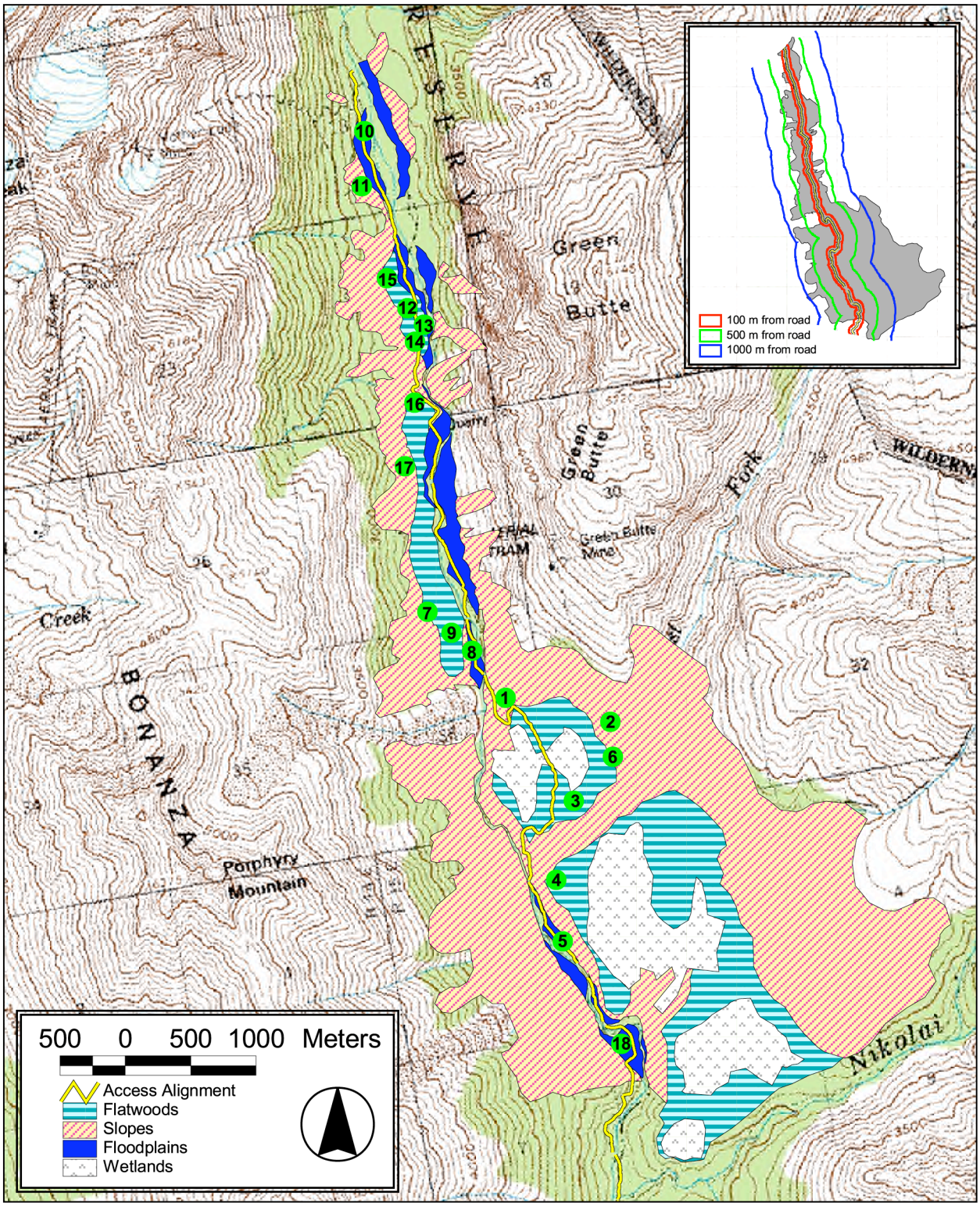


FIGURE 4. Study site locations (numbered green dots) and physiographic units in the upper McCarthy Creek Valley. INSET: Buffer corridors delineating forested portions of the study area (grey polygon) within 100, 500, and 1000 m of the primary access alignment.

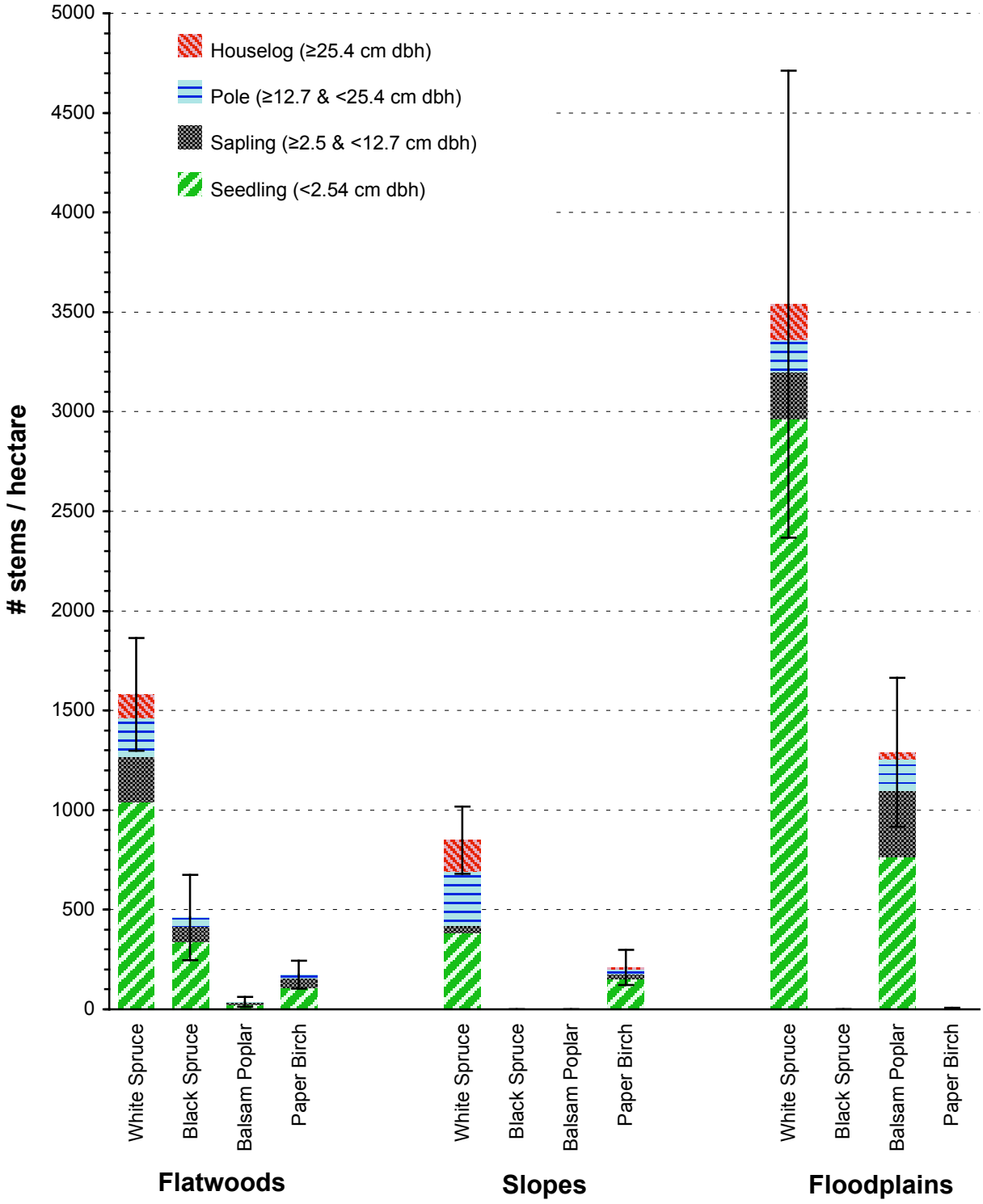


FIGURE 5. Stem density (combined live and dead standing stems/ha) of four tree species in upper McCarthy Creek, by physiographic unit. Error bars indicate standard error of the mean total density for all size classes. Relative contribution of each size class is shown by stacked colors.

physiographic units, contributing 65% of total density in Flatwoods, 45% on Slopes, and 84% on Floodplains. Overall variability of white spruce density was driven primarily by this variability in seedling density. The distinct vegetative character of each physiographic unit is reflected in the densities of other tree species (Figure 5). Flatwoods grow black spruce (460 stems/ha) and a minor component of paper birch (180 stems/ha), Slopes have only paper birch (210 stems/ha), and Floodplains are distinguished by high densities of balsam poplar (1290 stems/ha).

Houselog-sized white spruce always constitute a minority of the total stem density. Densities of stems in this size-class average 120, 160, and 180 per ha for Flatwoods, Slopes, and Floodplains respectively (Figure 5). Importantly, many (49%, 48%, and 80%, respectively) of these houselog-sized white spruce are dead, the vast majority due to an ongoing spruce beetle epidemic (Figure 6). When mortality is shown stratified by tree age class, it is clear that beetle mortality is highest in the oldest trees (Figure 7). The beetle epidemic has consequently had a disproportionate impact on houselog-sized trees, less than half of which remain sound and useful for cabin-building. After accounting for the remaining dead rotten trees, for the smaller numbers of damaged live trees (usually due to forkage or breakage of the main bole), and for losses to previous harvesting, the total number of useful houselogs per ha is significantly reduced from the total densities. Flatwoods average 49 useful houselogs per ha, Slopes 92/ha, and Floodplains 100/ha (Figure 6). Of these, 32, 40, and 88/ha, respectively, are beetle-killed trees; the remainder are currently green.

The standing volume of pole and houselog-sized white spruce (≥12.7 cm dbh) averaged 95 m^3/ha throughout the study area, with a minimum of 67 m^3/ha in Flatwoods and a maximum of 130 m^3/ha on Slopes (Table 2). The seemingly contradictory facts that Slopes have the lowest total density and the highest standing volume are a reflection of that unit's preponderance of larger trees, or—stated another way, the paucity of seedlings and saplings. Volumes of other tree species reflect the vegetative character described earlier. As with stem density, a majority of the standing volume of white spruce has been impacted by the ongoing spruce beetle epidemic. Of the total standing volume of white spruce on Flatwoods, Slopes, and Floodplains, 72%, 57%, and 90% respectively now consist of dead timber.

Productivity

Two different measures of actual current productivity were derived: gross productivity (volume growth in m^3/ha/yr) and net productivity (volume growth minus the volume lost to mortality, also in m^3/ha/yr). Throughout the study area, annual radial increment averaged 0.97 mm/yr and varied only slightly among physiographic units (Table 2). Consequently, most variability in gross productivity – which ranged from 0.09 to 0.43 m^3/ha/yr with a study area average of 0.22 m^3/ha/yr – was the result of differences among units in the densities of live poles and houselogs. Net productivity has been severely impacted by the ongoing spruce beetle outbreak. Based on the inferred mean annual mortality rate over the last decade (which probably underestimates mortality during the last 3 years), calculated net productivity is negative in all physiographic units. Because negative productivity is not technically possible, these values are presented as zero in Table 2. The important point is that white spruce forests throughout the study area are currently losing more volume to the spruce beetle epidemic than they are regaining through growth of the existing trees.

Site quality, as measured by the relationship of white spruce height growth to age, did not significantly differ among physiographic units. Site index for the three physiographic units ranged from 50.6 to 63.0,

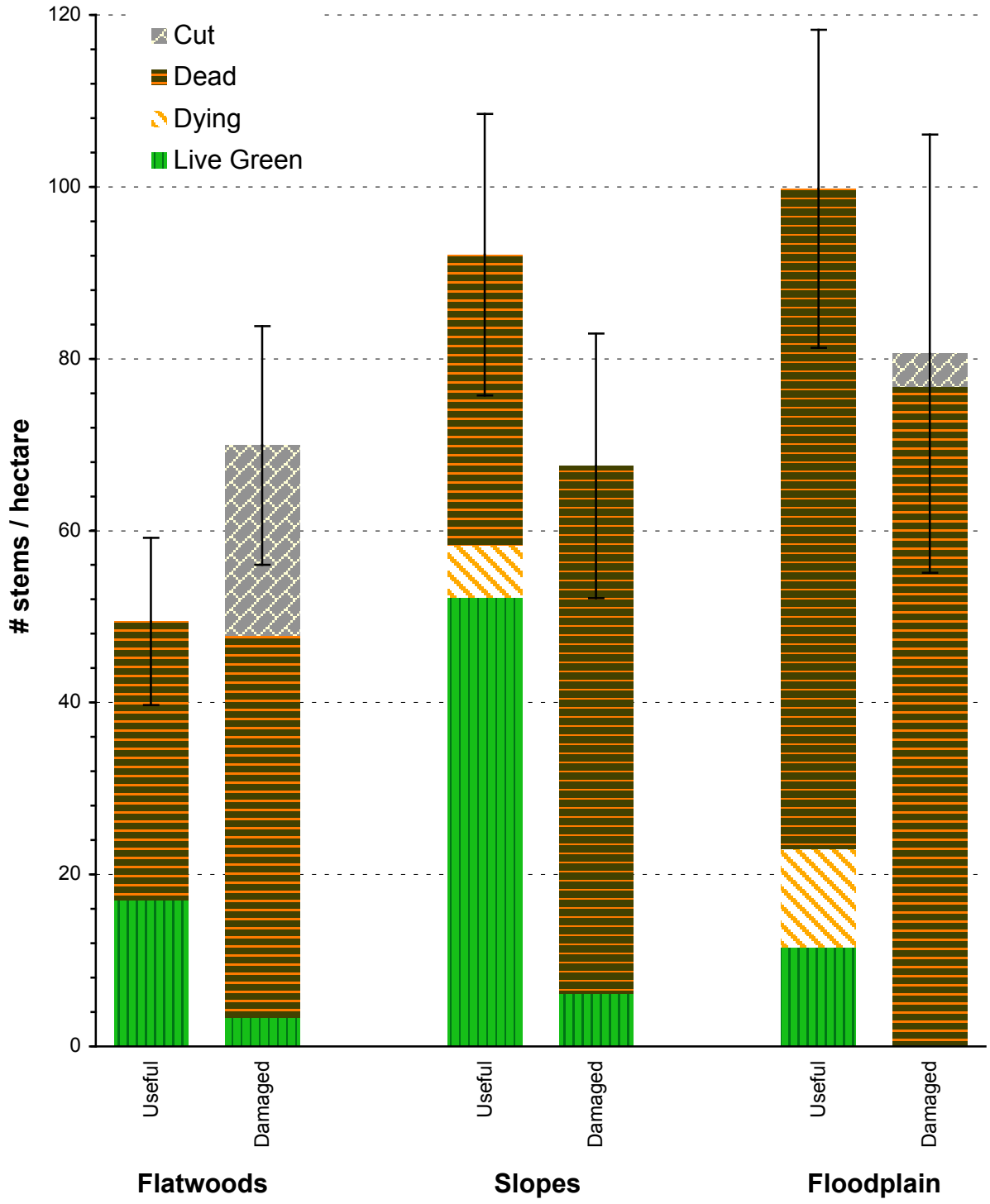


FIGURE 6. Densities of houselog-sized (dbh ≥ 25.4 cm) white spruce on three different physiographic units in upper McCarthy Creek. For each unit, stacked bars on left are trees considered useable for houselogs; trees on right are bent, broken, forked, or rotten. Each bar is broken down by tree damage class (live, dead, dying, or previously-harvested stump). Error bars are standard error of the mean for combined values.

TABLE 2. Productivity of white spruce, and standing volume of all tree species.

Physiographic unit	n =	Potential productivity (m^3/ha/yr)*	Mean radial increment (mm/yr)	Actual gross productivity (m^3/ha/yr)	Actual net productivity (m^3/ha/yr)**	Tree species	Mean live volume (m^3/ha)	Mean dead volume (m^3/ha)	Mean volume (total) ± 80% conf. int.
Flatwoods	36	0.35	0.89	0.17	0.00	White Spruce	18.40	48.21	66.61 ± 11.8
						Black Spruce	2.54	0.02	2.56 ± 1.6
						Balsam Poplar	0.21	0.00	0.21 ± 0.3
						Paper Birch	1.46	0.00	1.46 ± 1.9
Slopes	20	0.51	0.96	0.43	0.00	White Spruce	55.53	74.41	129.94 ± 18.5
						Black Spruce	0.00	0.00	0.00 ± 0.0
						Balsam Poplar	0.00	0.00	0.00 ± 0.0
						Paper Birch	6.77	0.10	6.87 ± 4.4
Floodplains	16	0.56	0.90	0.09	0.00	White Spruce	11.33	105.25	116.58 ± 26.0
						Black Spruce	0.00	0.00	0.00 ± 0.0
						Balsam Poplar	25.24	0.96	26.21 ± 10.5
						Paper Birch	0.00	0.00	0.00 ± 0.0
All	72	0.43	0.97	0.22	0.00	White Spruce	27.14	68.16	95.31 ± 10.4
						Black Spruce	1.27	0.01	1.28 ± 0.8
						Balsam Poplar	5.72	0.21	5.93 ± 2.8
						Paper Birch	2.61	0.03	2.64 ± 1.5

**from yield tables (Farr, 1967) based on site index and stand ages, assuming well stocked spruce forest*

*** mortality currently exceeds growth throughout the study area*

with the highest value on floodplains (Figure 8), but there was no significant difference among the site index values of the three units (ANOVA; F = 1.65; p>F = 0.2210). Overall, the average site index in McCarthy Creek (56.0) is only slightly lower than in the adjacent Kennicott Valley (59.13: Loso, 1998). The potential productivity of white spruce at current stand ages, derived from calculated site index and yield tables, ranged from 0.35 to 0.56 m^3/ha/yr (Table 2). On all physiographic units, these values are greater than calculated actual productivities.

Population Dynamics

I aged 449 white spruce in 18 study sites, and the oldest tree I cored had 330 rings at breast-height. Based on the predicted breast-height age of 34 years (Figure 4: Loso, 1998), this suggests an approximate true age of 364 years. An additional 79 trees were too rotten to be aged. These were largely older beetle-killed spruce, so age distributions from the 18 study sites (Figure 9) probably understate slightly the importance of older size classes. Most distributions show trees in a broad variety of age-classes, though some sites (notably #12-14) appear truncated at the older size classes, in part because of the bias just mentioned but primarily because of prior harvesting in those stands. In any case, none of the sampled stands are even-aged (Figure 9), nor show evidence of fire or other catastrophic stand-initiating disturbance. No charcoal or burned wood was found in any of the study sites, confirming that upper McCarthy Creek has remained free of large catastrophic fires for at least the last few centuries. Like forests in the adjacent Kennicott Valley, where Loso (1998) found no evidence of wildfire, forests in upper McCarthy Creek have developed in response to periodic creation of small gaps by windthrow,

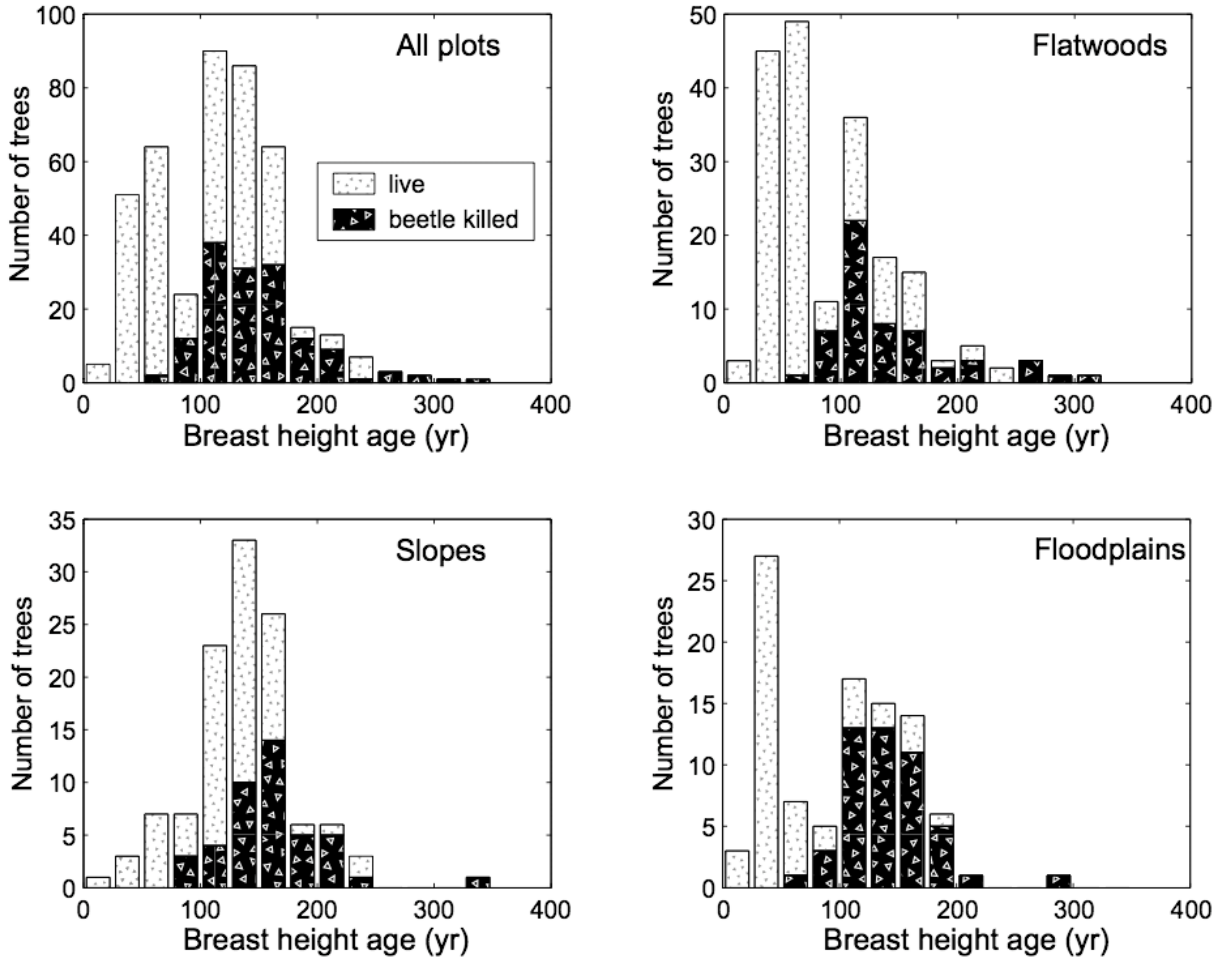


FIGURE 7. Breast-height ages (in 25-year bins) of white spruce in upper McCarthy Creek, shown divided into live and beetle-killed trees. Data from all dated trees (upper left panel) are shown stratified by physiographic region in the other three panels. Some larger trees with cores too rotten to date are also excluded: because larger beetle-killed trees are most commonly rotten, these plots slightly underestimate the proportion of beetle-killed trees in older age classes. Small trees (dbh<6.0 cm) were not cored and are excluded from this analysis. Average age at breast-height was 37 years in the adjacent Kennicott Valley (Figure 4: Loso, 1998), so these breast-height ages probably underestimate true tree age by a similar amount.

disease—including a possible spruce beetle epidemic in the 1920's (Moffitt, 1922), and prior selective harvest.

A demographic model suggests that recruitment in upper McCarthy Creek is currently too poor to maintain the current densities of mature trees (Table 3). Survival rates from the Kennicott Valley (Loso, 1998) were combined with current recruitment rates in upper McCarthy Creek to predict tree density in all three physiographic units. In a hypothetical case where there was no episodic mortality (neither spruce beetle epidemics nor human harvesting), the model predicts that Flatwoods and Floodplains would have higher densities of mature trees than are currently present, and Slopes would have slightly lower densities. In other words, forests on Slopes have a negative equilibrium episodic mortality rate,

indicating that they (like similar forests in the Kennicott Valley) have insufficient recruitment to maintain current tree densities *even in the absence of episodic mortality*. Flatwoods and Floodplains, in contrast, could sustain moderate rates of episodic mortality (15% and 11% loss of mature trees/decade) and still maintain current mature tree densities.

This may reflect gradual diminishment of spruce recruitment rates over decades and centuries of accumulation of litter and moss while the forest has been free of major disturbance (especially fire), or alternatively implies that forest density is maintained by rare, episodic high-recruitment events. Either way, the important fact is that episodic mortality is occurring at a very high rate on all units: in the last ten years, the combined efforts of beetles and humans have killed 49%, 48%, and 80% of mature trees on Flatwoods, Slopes, and Floodplains respectively. Even allowing for the simplicity of the model and the difficulty of predicting "typical" mortality patterns for long-lived organisms like white spruce, current episodic mortality is clearly much higher than can be sustained by the forests of upper McCarthy Creek. Any increase in spruce beetle mortality or human harvest would further decrease future densities of mature white spruce on these stands.

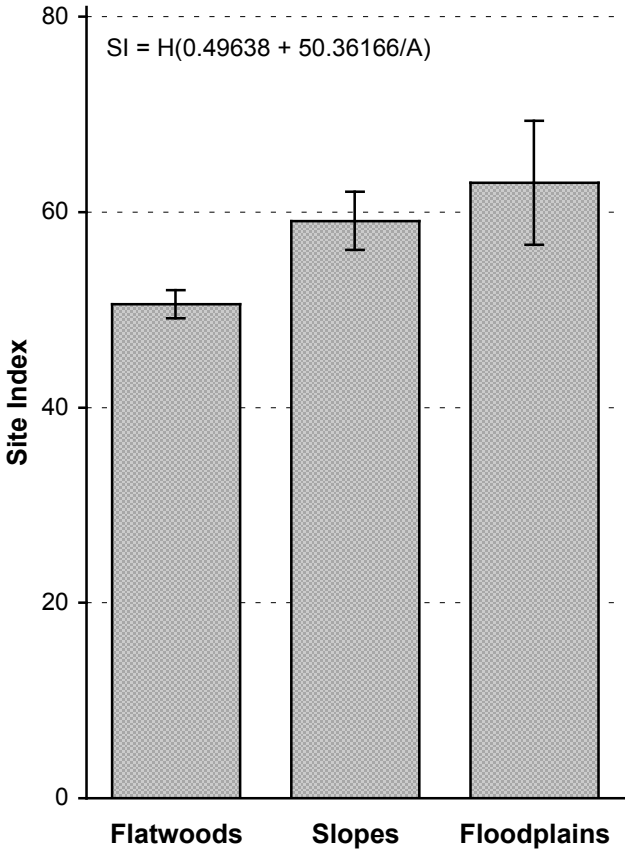


FIGURE 8. White spruce site index in three physiographic units of upper McCarthy Creek. Calculations are based on the equation shown at upper left, where H = tree height in feet and A = breast-height age in years (Farr 1967). Values are means ±SE based upon the single tallest canopy tree per study site.

Human Harvest

Compared with the more populous Kennicott Valley, where rail and subsequent road access allowed the importation of fuel and sawtimber that eased the demand for local white spruce (Loso, 1998), McCarthy Creek has a more substantial history of selective logging. Three broad categories of stump were found: mining era (~1911-1938), early park (~1970-1990), and Hale family (post-2000). The three categories were easily distinguished on the basis of appearance: mining era stumps are highly decomposed, early park era stumps are highly weathered and barkless but typically sound, and Hale family era stumps are fresh with logging slash still present (Figure 10).

Evidence of selective logging was found in all three physiographic units, generally within one to three hundred meters of the primary access alignment. Many of the stumps I encountered fell outside of established study sites, though a few were tallied formally and included in density calculations (Figure 5). Stumps were often found on the flattest, most accessible terrain, but occasionally stumps were

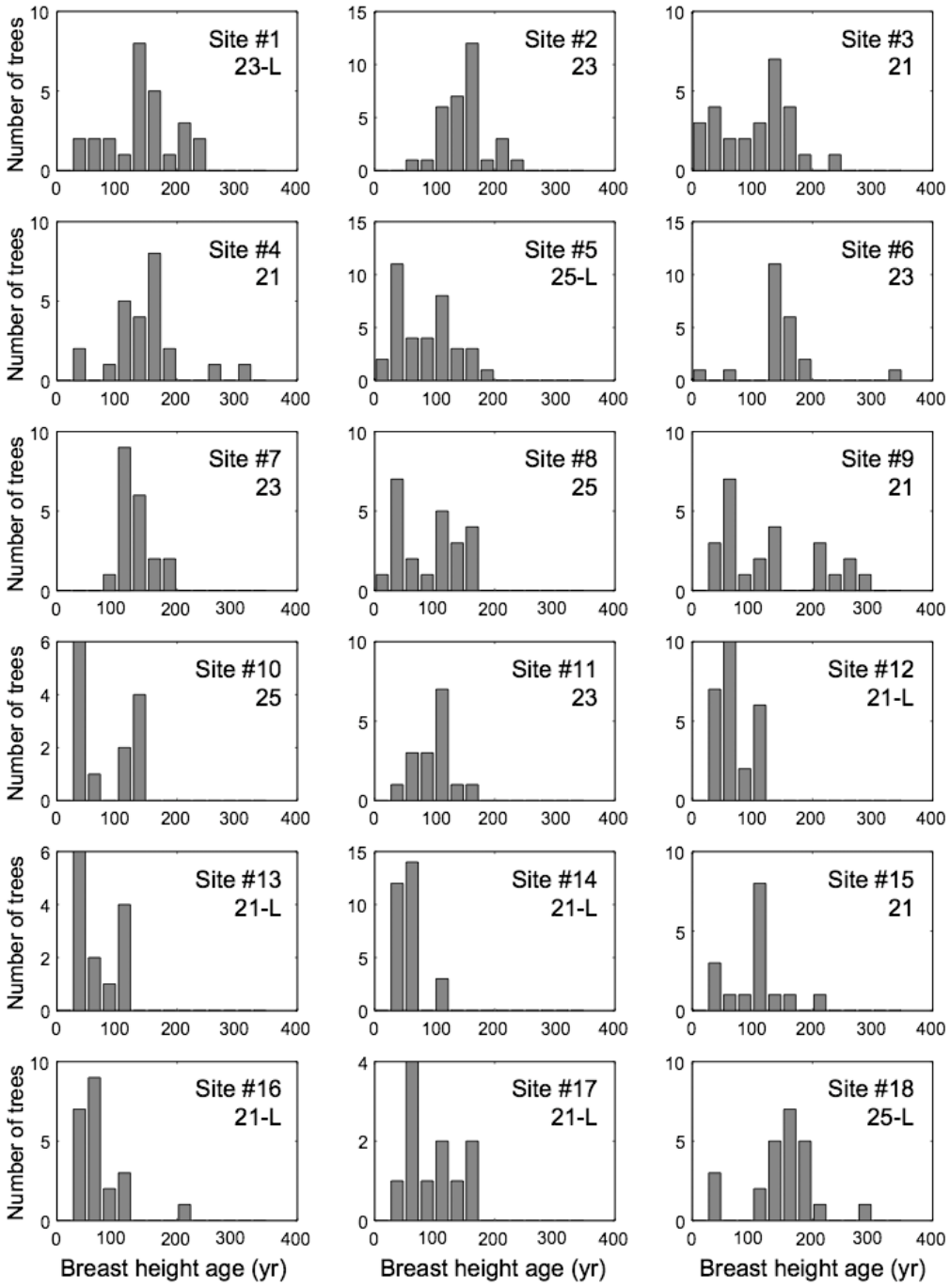


FIGURE 9. Breast-height ages (in 25-year bins) of all datable white spruce on 18 study sites in upper McCarthy Creek. Numerals below site numbers refer to physiographic unit: 21 = Flatwoods, 23 = Slopes, 25 = Floodplains; 'L' indicates that there was evidence of historic logging in the plot. Small trees (dbh < 6 cm) were not cored and are excluded from this analysis. Some larger trees with cores too rotten to date are also excluded. Average age at breast-height was 37 years in the adjacent Kennicott Valley (Figure 4: Loso 1998), so these breast-height ages probably underestimate true tree age by a similar amount.

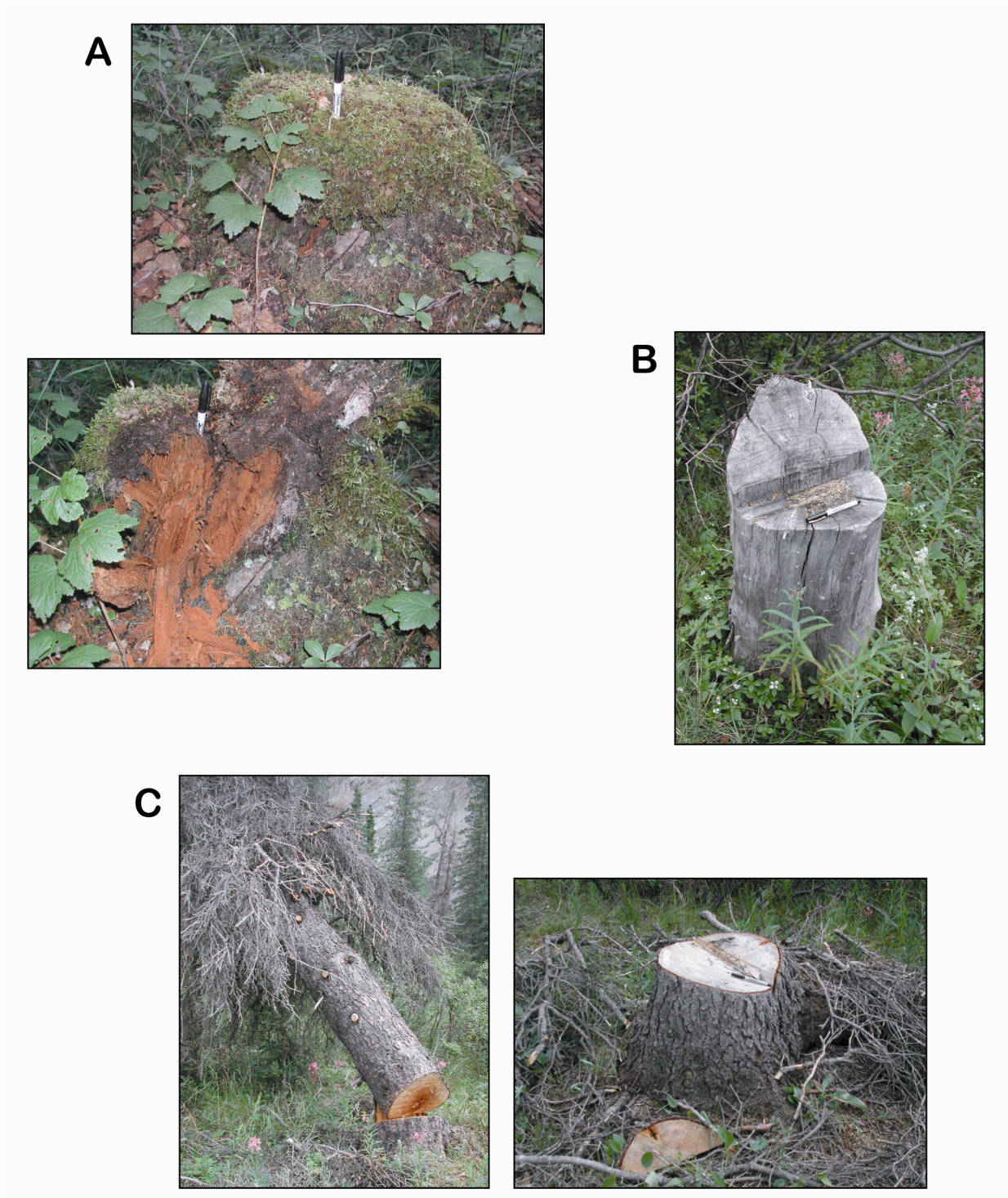


FIGURE 10. Photographs of logged stumps from McCarthy Creek, depicting three generations of selective logging: **A.** mining era stumps (~1911 - 1938) are decomposed and easily crumble; **B**. early park era stumps (~1970 - 1990) are weathered and barkless but typically sound; and **C**. Hale family era stumps (post - 2000) are fresh with logging slash (and sometimes the whole tree) still present.

TABLE 3. Model results comparing white spruce recruitment to mature tree density.

variable	unit	**Flatwoods**	**Slopes**	**Floodplains**	**Kennicott[§]**
Current recruitment rate	# recruits/ha/decade	91	36	60	30
Current tree density	# mature/ha	425	421	329	354
Modeled tree density without episodic mortality*	# mature/ha	888	351	584	287
Modeled equilibrium episodic mortality rate†	% mature/decade	15%	-3%	11%	-3%
Current episodic mortality rate	% mature/decade	49%	48%	80%	34%

* Episodic mortality includes human harvest and spruce beetle attack

† Percentage of mature trees that could be lost to episodic mortality each decade and still maintain current densities. Negative numbers indicate recruitment cannot maintain current densities.

§ Data collected in the adjacent Kennicott Valley in 1996; model results from Loso 1998.

encountered in surprisingly steep and densely vegetated stands. Mining era stumps were most common within a few kilometers of the Green Butte Mine, and early park era stumps were found almost exclusively in the woods near the Loy Green cabin (Figure 1). A more systematic effort was made to map the occurrence of cut stumps from the Hale family era.

In recent years, especially including winters of 2002-03 and 2003-04, the Hale family has obtained much of their firewood from beetle-killed white spruce in an area informally known as "the woodlot," located west of McCarthy Creek on a bench just north of the Green Butte mining operation (Figure 11). The woodlot is very accessible; it is mostly flat, it has a relatively brush-free understory, and it is close to both the existing road and the Hale family residence at the Marvelous Millsite. Sites 12-15 lay wholly or partly within the woodlot and numerous fresh stumps were encountered in the course of sampling these locations. In total, 13 subplots were randomly located within the mapped boundaries of the woodlot (Figure 11). In addition to the normal sampling conducted at each of these sites, cut stumps were counted at each site in expanded subplots of 14.6 m radius. The mean number of Hale family era stumps in each expanded subplot averaged 2.38 with an 80% confidence interval of 0.75. This yields a cumulative harvest intensity of 35.6 trees per hectare, suggesting a total modern harvest of 295 trees in the 8.3 ha woodlot.

To evaluate the plausibility of this estimate, it can be used to estimate the fireweed consumption of a 2-cabin family over the course of 2 winters. The average diameter of cut stumps in the woodlot was 31.2 cm, and throughout the study area white spruce of that size (with diameters ranging from 28 to 34 cm) had an average volume of 0.40 m^3. If a family used 12 cords (30 m^3) of firewood per cabin per year, they would have had to harvest approximately 297 trees in 2002-03 and 2003-04 to meet the needs of two cabins – very nearly the total harvest estimated in the field. Based on interviews with local residents of the nearby Kennicott Valley, Loso (1998) estimated that the average annual firewood consumption was 8 cords/cabin. Welbourn (1982) interviewed foresters and researchers from around the state, and

estimated that the average annual firewood consumption was 7-8 cords in the Copper Basin, and as high as 10-15 cords in the Delta area. The point is not that the Hale family consumed exactly 12 cords per year in two different cabins, but rather that the estimated harvest of 295 trees can be plausibly explained solely in terms of the family's firewood needs.

DISCUSSION

White spruce stands in upper McCarthy Creek exhibit the general characteristics of old-growth forest (Oliver, 1981): loss of overstory integrity, complicated forest structure with numerous height classes including understory advance regeneration, and mixed-age distributions. These characteristics are apparently uncommon in southcentral and interior Alaska, where recurrent fires favor even-aged populations. In the Kennicott Valley, Loso (1998) described old-growth white spruce growing on hillsides with a dense alder understory, but old-growth stands in upper McCarthy Creek occur in a wide variety of settings that include Flatwoods, Slopes, and Floodplains. Low recruitment is a conspicuous feature of old-growth stands in the Kennicott Valley, and is apparent in the McCarthy Creek forests also. Along McCarthy Creek, recruitment is lowest on the physiographic unit which is most directly analogous to the Kennicott Valley old-growth stands (Slopes), but I used a simple demographic model to test the sufficiency of recruitment on each unit independently.

In the hypothetical absence of episodic disturbance (beetle epidemic or human harvest), the model suggests that recruitment rates on Floodplains and Flatwoods would be sufficient to maintain current densities of mature trees. On Slopes, where recruitment rates are lower and more comparable to those in old-growth stands of the Kennicott Valley, recruitment would be just below the level necessary to maintain current densities. Given potential errors in the model (described more fully in Loso, 1998), these results equivocate on a question of ecological interest: does a sustainable climax state exist for old-growth white spruce forests? On a more practical issue, however, the model is clear: in the last decade the beetle epidemic has exceeded the forest's ability to generate new seedlings by a very wide margin. Trees are being killed much more rapidly than they are being recruited into the population in all three physiographic units.

For those trees that remain green and healthy, site quality in the upper McCarthy Creek valley is relatively poor. Values observed throughout the study area (46-86, mean 56) were widely dispersed, but are overall lower than the adjacent Kennicott Valley (53-72, mean 59: Loso, 1998) and slightly lower than sites elsewhere in the southern Copper River Basin (50-64, mean 58: Farr, 1967b). In the Alaskan interior, where summers are longer and warmer, site index is generally much higher (70-90). Only on the Porcupine River, north of the Arctic Circle, did Farr (1967b) find an average site index (55) lower than that found in McCarthy Creek. The reasons for poor productivity in McCarthy Creek include elevation (much of the study area is near the altitudinal limit for white spruce), limited insolation (the valley is too narrow and deep for any given tree to receive a full day's direct sunlight), and poor drainage on some sites (particularly Flatwoods).

Potential productivity estimates derived from these low site index values are nonetheless exaggerated. There are two reasons for this. First, the yield tables used to estimate potential productivity (Farr, 1967b) are based upon *well-stocked* spruce forests in interior Alaska. The densities of pole and houselog-sized trees in McCarthy Creek are lower than those used to generate the yield tables. Second, and more importantly, actual productivity has been dramatically diminished by spruce beetle mortality. Gross

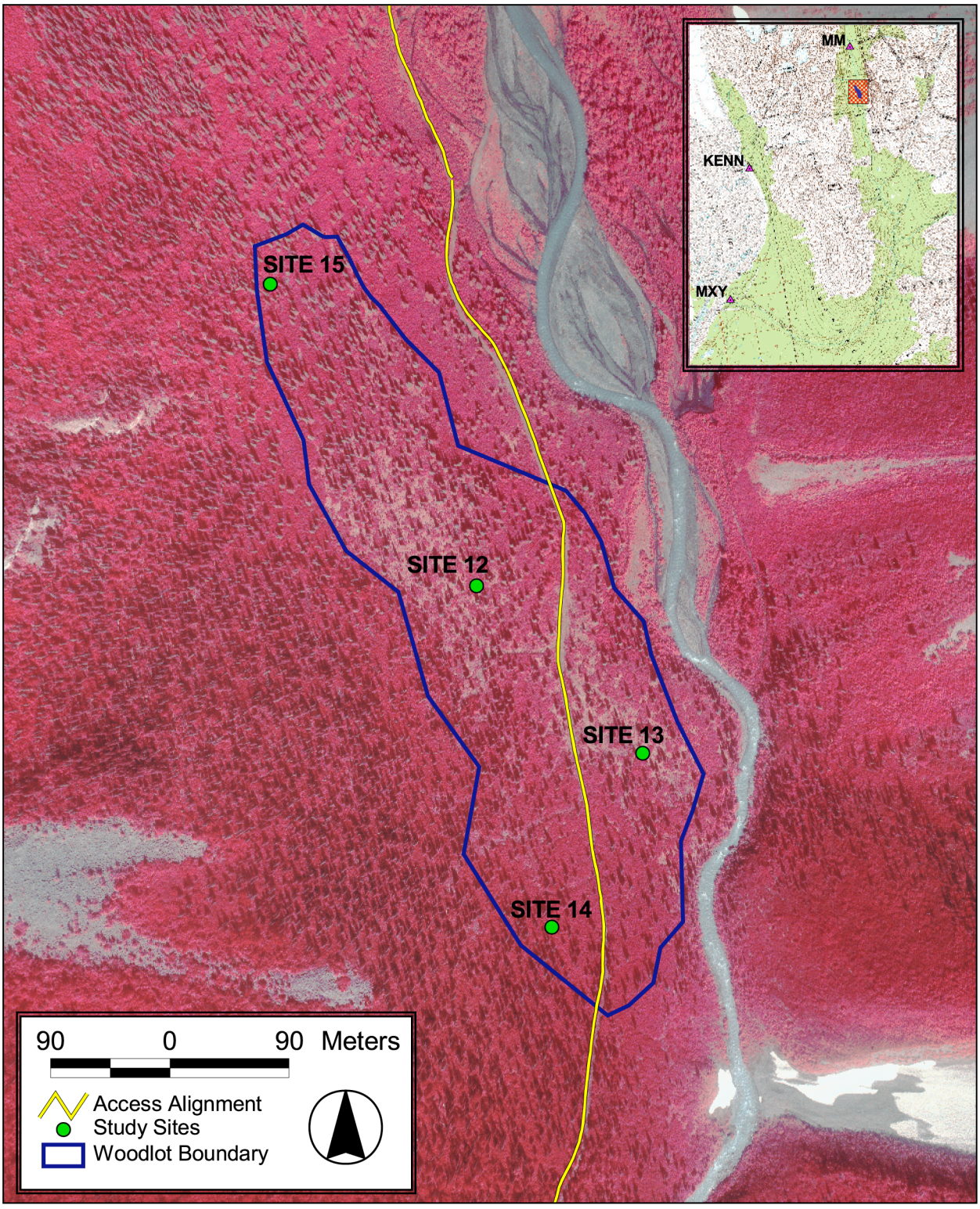


FIGURE 11. Approximate boundaries of "the woodlot," an area of recent intensive beetle-kill harvest by the permit applicants. Base map: 1:6000 scale color infra-red taken July 9, 2003. INSET: General location of the aerial photo and woodlot, showing locations of McCarthy (MXY), Kennicott (KENN), and Marvelous Millsite (MM) – the permit applicants' homestead.

productivity is diminished because fewer live trees remain to grow and add wood volume to the forest. Net productivity, which subtracts from gross productivity the volume of dying trees, is actually negative, indicating that the volume of live spruce in upper McCarthy Creek is growing smaller each year.

Mortality associated with the ongoing spruce beetle outbreak clearly overwhelms other, more subtle trends in forest dynamics. It is difficult to make quantitative predictions about the future of the outbreak, but the regional spruce beetle outbreak that began around 1990 was slow to reach McCarthy Creek, and is likely to worsen. Beetle-induced mortality was fairly low in the McCarthy Creek drainage until 2003, the year when a large fraction of the now-dead spruce was killed (Zogas, 2004). There are three reasons to suspect that these forests will suffer significant additional mortality in the next year and perhaps beyond: 1) spruce beetle outbreaks in other parts of the state have generally lasted longer than one or two years in any given stand; 2) spruce beetles populations react favorably to warm summers, and this summer (2004) was extremely warm and dry; and 3) spruce beetles typically have either one or two-year life cycles, implying that beetles which attacked and killed McCarthy Creek timber in 2003 or 2004 (or both) will launch their offspring in 2005. Forest productivity and live tree density are thus expected to be further diminished by this ongoing disturbance. In terms of firewood production, these effects should be mitigated somewhat by the opening or thinning of canopy gaps that release surviving trees from above and below-ground competition, stimulating increased volume growth. Neither beetle-kill nor selective human harvest, however, are likely to increase spruce recruitment, which is dependent primarily upon disturbance of the forest floor (Zasada and Gregory, 1969). In summary, the selective harvest of live white spruce for houselogs or firewood is currently unsustainable, and will remain that way for the foreseeable future.

On the other hand, the current beetle epidemic has created a bonanza of standing dead spruce. Dead trees now account for 71% of the total standing volume in upper McCarthy Creek. Most of this volume is potentially useful for firewood. Likewise, 49% of the houselog-sized white spruce likewise are dead, and 47% of those dead trees are sound and straight enough to be used for building. In the entire study area, that suggests there are over 40,000 usable houselogs. Even within a narrow corridor of easily accessible land (for example, 100 m [328 ft] to either side of the primary access alignment), there are probably over 7000 usable, beetle-killed houselogs. From the perspective of white spruce productivity, even a substantial harvest of houselogs or firewood from this resource should have minimal negative impacts. Other impacts of such harvest, on wildlife habitat, visitor experience, and understory vegetation, for example, may be substantial but are beyond the scope of this work.

CONCLUSIONS

White spruce forests in the upper McCarthy Creek valley have generally poor productivity and low recruitment. Three physiographic units serve as habitat for the bulk of the white spruce in the valley: Flatwoods have a prominent black spruce component, with relatively low productivity and moderate recruitment; Slopes have an alder component, with moderate productivity and low recruitment; and Floodplains have a balsam poplar component, with higher productivity and higher recruitment. A spruce beetle epidemic has recently gained momentum in the valley, and high mortality of larger, older white spruce was most conspicuous in 2003. Further losses are expected before the epidemic has run its course. As a consequence of this outbreak, mortality currently exceeds growth when viewed from the perspectives of either wood volume or population demography. For the foreseeable future, the harvest of

green trees is therefore unsustainable. Standing dead timber is abundant, and may provide a useful alternative to live green trees for houselogs and firewood.

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