Exploring the Alaskan Black Spruce Ecosystem: Variability in Species Composition, Ecosystem Function, and Fire History

T.N. *Hollingsworth*

In this overview, I present extensive studies looking at the structure and function of the black spruce *(Picea mariana)* ecosystem of the boreal region of interior Alaska. One of the studies provides a classification of black spruce communities, the most abundant forest type in the region. Other studies examine large-scale processes that drive this community classification. This work helps lay the foundation for an appropriate vegetation mapping project in boreal Alaska.

Scale-Dependent Environmental Controls Over Species Composition in Alaskan Black Spruce Communities

The classification of black spruce plant communities in interior Alaska is the first published Braun-Blanquet classification done in interior Alaska. Black spruce communities occur in a variety of environmental conditions and are extremely adapted to fire disturbance. We described three black spruce community types and five subtypes based purely on floristics. We also related these communities to important environmental variables, and found that a complex soil drainage gradient underlies the community patterns seen in Alaskan boreal black spruce forests (see Hollingsworth et al. 2006). We defined our plant communities and subtypes as:

1. Acidic black spruce/lichen forest *(Picea mariana/Cetraria islandica):* fruticose lichens and many species of mosses dominate this community. It occurs in areas with an underlying mineral soil pH < 5.5 in both the uplands and lowlands of boreal Alaska. Although this community type exists in both wet and dry areas, there is one subtype that is restricted to wet areas:

   (a) Wet, acidic black spruce muskeg *(Picea mariana/Ledum decumbens/Sphagnum girgensohnii):* this is an open black spruce subtype that occurs in low-nutrient, permafrost soils.

2. Nonacidic black spruce/rose/horsetail forest *(Picea mariana/Rosa acicu/aris/Equisetum* spp.): this community is dominated by vascular species with the occasional presence of white spruce *(Picea glauca).* It occurs in well-drained areas of both the uplands and lowlands of boreal Alaska. It has two subtypes, one that is restricted to wet areas, and one that is restricted to drier areas.

   (a) Wet, nonacidic black spruce/larch fen *(Picea mariana/Larix laricina/Chamaedaphne calyculata):* this subtype is restricted to minerotrophic lowlands and is easily identifiable by the presence of Alaskan larch (dead or alive). The active layer can be shallow, but permafrost conditions are more variable than in the wet, acidic subtype. It is important to note that there is some overlap in species, such as *Betula nana, Rubus chamaemorus,* and *Eriophorum vaginatum,* with the wet, acidic subtype. These species are indicative of the moisture status of the site and not acidity.

   (b) Dry nonacidic black spruce forest *(Picea mariana/Cladina stellaris - Peltigera* malacea): this subtype occurs in xeric conditions, almost exclusively in the uplands, or at higher elevations.

Many community and ecosystem level studies in interior Alaska have focused on the uplands and floodplains in close proximity to Fairbanks, Alaska. By expanding our study area to include a larger spectrum of structural and functional variability, we see. that the black spruce communities of interior Alaska are related to the underlying pH of the parent material, as well as to differences in site drainage, The strong correlation between species composition and mineral soil pH has been observed in the Alaskan Arctic (Walker and Everett 1991).

Plant Community Composition as a Predictor of Regional Soil Carbon Storage in Alaskan Boreal Black Spruce Ecosystems

To be widely accessible and useful, vegetation mapping must not only include structural differences in plant communities, but also reflect functional ecosystem differences. Here, I ask what is the relationship between black spruce community patterns and ecosystem processes by examining the relationship between floristic composition and ecosystem parameters, such as soil carbon pools, the carbon-to-nitrogen (C/N) ratio of live black spruce needles, and normalized basal area increment (NBAI) of trees in black spruce communities of interior Alaska (Hollingsworth in press). I show that variability in ecosystem parameters in black spruce of interior Alaska exceeds the documented variability across a broad range of ecosystem types from around the Fairbanks area. The acidic black spruce/lichen forest *(Picea mariana/Cetraria islandica)* communities had significantly more carbon in the organic soil horizon than the nonacidic black spruce/rose/horsetail forest *(Picea mariana/Rosa aCicularis/Equisetum* spp.) but did not differ in any other measured ecosystem parameter. Species composition was as important as abiotic variables, such as topographic position, slope, and soil moisture, in predicting soil carbon storage, and in particular, *Sphagnum* plays an integral role in determining soil carbon amounts in black spruce communities. In conclusion, among the community properties analyzed, the presence of key groups of species, overall species composition, and diversity of certain functional types, especially *Sphagnum* moss species, are important predictors of soil carbon sequestration in the black spruce forest type.

Wildfire Legacy Effects Versus Environmental Controls in Alaska's Mature Black Spruce Forests: **the** Ghost of Disturbance Past

When considering a circumboreal vegetation mapping project of the boreal forest, one of the most important factors to consider is the treatment of large-scale disturbances, such as fire, and how they shape the vegetation patterns on the landscape. The current landscape of the boreal forest is a mosaic of vegetation that reflects both the relationship between vegetation and environment and legacies of previous disturbances. Therefore, understanding the long-term effects of fire on vegetation composition, and in particular, how the legacy of fire shapes the composition and distribution of boreal plant communities, is an important factor when designing regional and global vegetation maps.

In the boreal forest, fire is a key regulator of both the structure and functioning of forest communities; however, the composition of mature late-successional communities is often attributed to environmental influences, such as topography, and considered to be independent of fire history. Black spruce stands resulted from either a single, stand-replacing fire, multiple fire events creating multiple cohorts, or continuous recruitment after fire, with intervals at approximately 100 years. In addition, fire history (severity and time since disturbance) was highly correlated to the species composition of both the acidic black spruce/lichen forest *(Picea marianal Cetraria islandica)* and the nonacidic black sprucel rose/horsetail forest *(pice* a *mariana/Rosa acicularisl Equisetum* spp.). It is clear that the legacy of fire has a lasting effect on the vegetation composition of mature black spruce stands at the level of community subtypes (Le., wet, acidic black spruce muskeg *[Picea marianalLedum]* spruce subtype; wet, nonacidic black spruce/larch fen *[Picea mariana/Larix laricinal Chamaedaphne calyculata];* and dry, nonacidic black spruce forest *[Picea marianalCladina stellaris - Peltigera malacea])*. Most likely this high correlation at the subtype level is due to the intrinsic relationship between fire severity and site drainage and moisture. Based on the results, four mechanisms are presented that could lead to varying successional trajectories following fire.

1. Low Ground Burn Severity and High-Legacy Mechanism: low ground burn severity coupled with effective re-establishment of prefire vegetation always regenerates the prefire vegetation. These factors co-occur in the nonacidic wet subtype and both of the dry subtypes. Low ground burn severity fires always lead to regeneration of the same prefire community subtype because the understory species survive fire and regenerate vegetatively, with no long-term change in species composition. This mechanism occurs most frequently in the wet, nonacidic black spruce/larch fen (Picea mariana/Larixlaricina/Chamaedaphne calyculata), which has the longest time between fires and shows little evidence of severe ground fires due to high soil moisture.

2, High Ground Burn Severity and High and Recruitment Mechanism: this mechanism is specific to dry subtypes, where dry soils and shallow organic depths contribute to the greater likelihood of a severe ground fire. Severe ground fires produce a mineral soil seedbed that is viable for seedling recruitment and establishment by the pre-fire species. Consequently, the dry subtype is maintained after fire.

3. High Ground Burn Severity and Shift in Environment Mechanism: a shift in species composition away from the black spruce ecosystem is most likely to occur when severe ground fire changes the starting conditions or abiotic factors, and/or the relative abundances of the survivors enough to shift a wet subtype to a dry subtype. This shift can occur in both acidic and nonacidic communities.

4. High Burn Severity and New Tree Species Mechanism: the mechanisms described previously all assume that black spruce re-establishes, so differences among community subtypes develop as a result of changes in the understory species composition. However, if a new dominant tree established itself after fire, it could cause a shift to a new ecosystem type, for example, white spruce or aspen, This is most likely to occur if high crown severity reduces seed input from black spruce and/ or if high ground severity or environmental change from climate warming favors the etablishment of a different dominant tree species.

These mechanisms are extremely important when thinking about a large-scale mapping effort because they depict areas on the landscape that could be susceptible to shifts in species composition post-fire and, therefore, should be considered during the mapping process.

In this paper, I present a cohesive study on the black spruce communities in interior Alaska. These communities are named, correlated with important environmental variables, distinguished based on ecosystem parameters, and related to the fire history of that community. Although mapping was not done as part of this project, it is clear that this is the first step that needs to be taken in order to extensively map areas of the boreal forest. To be useful to a broad audience, a circumboreal vegetation map must name the units based on species composition and the correlated environmental factors and landscape-level disturbance patterns.

References

Hollingsworth, TN., Walker, M D., Chapin III, F S., Parsons, A L. (2006): Scale-dependent environmental controls over species composition in Alaskan black spruce communities. Canadian Journal of Forest Research 36 7: 1781-1796:16.

Hollingsworth, T.N., Schuur, E.A.G, Chapin III, F.S. & Walker, M.D. (in press): Plant community composition as a predictor of regional soil carbon storage in Alaskan boreal black spruce ecosystems. Ecoystems.

Walker, D.A. & Everett, K.R. (1991): Loess ecosystems of northern Alaska: regional gradient and toposequence at Prudhoe Bay. Ecol. Monogr. 61: 437-464.

TN. Hollingsworth
Boreal Ecology Cooperative Research Unit
U.S. Department of *Agriculture Forest Service*
Pacific Northwest Research Station
P.O. Box 756780
Fairbanks, Alaska 99775 *USA*
e-mail: t.hollingsworth@uaf.edu