Making Sense of Changing Forests in Alaska

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Forestry research in Alaska indicates that coniferous-dominated interior boreal forests are being replaced by deciduous trees due to recent climate warming and changes in the wildfire regime. Mann *et al.* 2012[1] suggested a dramatic shift in forest species dominance was already happening, since the 1990's. Interior Alaska forests have averaged about ⅔ coniferous to ⅓ deciduous over the last several hundred years. Using landscape disturbance models under various global climate scenarios, Mann's team predicted the ratio would soon be 1:1 and even reverse by mid-century, with hardwood stands comprising ⅔ of the forests. Now, 30 years of satellite imagery and improved vegetation mapping methods using new technology offer a chance to test their predictions.

Post-fire succession: When Alaska spruce forests burn the trees are killed, but black spruce stands tend to "self-replace" about ⅔ of the time—by seeding into the remnant moss layers[2]. On the other hand, it has been well-documented that "severe" (deep-burning) forest fires favor regrowth of hardwoods (birch, aspen and poplar). These species can grow fast in deeper active layers that result after severe fires in which most of the moss duff is removed[3]. This can result in a "relay succession" recovery where hardwoods dominate the canopy for a time before slower growing spruce can regain dominance of the canopy. In either case, if the stand reburns within about 50 years, small black spruce in the understory are destroyed before developing a robust seed bank, and the stands tend to become increasingly hardwood dominated. Ongoing studies to refine these parameters in eastern interior Alaska reveal that pure black spruce stands transitioned to deciduous forest about half the time after a severe fire[4]. Coniferous forest with even a small percentage of deciduous stems (> 7%) succeeded into a mixed-wood composition (50:50) and stands which had >30% pre-fire deciduous stems became exclusively deciduous.

Birch forest *Photo: Jon Gregg*

Why is a shift in forest species important? Spruce forests have vastly different properties than broadleaf forests. These differences include: higher flammability, lower water uptake, slower litter decomposition rates, different atmospheric heating properties (surface albedo), and carbon sequestration capacity. Of course, they also differ with respect to supplying wood, game, and berries to humans. Black spruce trees thrive in cold, moist soil conditions, and actually enhance these conditions by accumulating a deep mossy soil organic layer. The moss layer is often too moist--with snowmelt water, rainfall, and seasonally thawing ice below--to support combustion beyond a few centimeters deep. Most of the carbon (C) stored in these slow-growing forests is in the moss and soil organic layers. Warmer summers and extended burning seasons in late summer tend to allow the moss duff layers to dry faster and deeper. In western Canada, 90% of C combusted in extensive 2014 fires in black spruce forest came from the forest floor [5]. Deciduous trees, on the other hand, thrive in nutrient rich, dry and (relatively) warm soils, and reinforce these conditions with high decomposition rates, so the soil organic layer tends to be shallow. Their faster growth rate (productivity 5-7 times greater than black spruce forest) means that they store most of their C aboveground in the trees themselves[6]. Deciduous trees also require more water to sustain that rapid growth—a lot more! It was recently discovered that Alaska broadleaf trees take up 25% of available spring snowmelt water (compared to about 1% for spruce)[7]. But mature spruce forests (aged 70-120 years) win out when it comes to long-term C storage -- they had 4-10 times the C stored in their organic soils (2.0-5.7 kg C m^{-2}) compared to 50-year-old stands[8].

Was the forest shift prediction accurate?

Deep burning exposed the roots of burned spruce: *R. Jandt*

Back to the changing forest composition. What does the latest research tell us about the predictions of a decade ago? As part of a multi-year NASA study, Wang, *et al.* 2020[9] used an enormous data set of satellite-derived vegetation cover type estimates covering all Alaska and northwestern Canada from 1984 to 2014[9]. They documented a net loss of 14.7% (+/- 3%) coniferous forest along with an equivalent net gain of deciduous forest. These results seem consistent with the predicted forest composition shift caused by a more active fire regime in boreal forests relative to the last several millennia.

In an ongoing separate study, preliminary data showed that *in burned areas* of the boreal biome the ratio of deciduous to evergreen forest cover increased 14.4% (from 23.4% to 37.8%) from 2001-2016, which was 3.3 times higher than in unburned areas[10]. However, these same authors also documented that mixed and deciduous forest types may be burning more now compared to previous decades, perhaps even burning at a faster rate than they were being replaced during the study time window. In addition, by coupling two types of remotely sensed data for vegetation, the researchers could estimate forest biomass and tree-canopy structure. This analysis showed that recovering burned forest, whether it succeeded to deciduous forest or remained evergreen, still had overall lower biomass and canopy density compared to areas that did not burn. This finding has implications for management scenarios involving fire use to reduce future fuel loadings, and also for carbon sequestration studies. Separate investigations confirm the loss of forest biomass across eastern interior Alaska and predict this will become the modern trend as the climate warms[4]. Impacts on wildfire and permafrost dynamics will result in overall decreases in biomass (particularly for spruce within the interior Tanana Valley, despite increases in quaking aspen biomass) and result in a continued shift towards a higher deciduous fraction. To a lesser extent, increased biomass is seen at certain locations, such as cold or wet locations, and at high elevations, such as along the north slopes of the Alaska range[11]. In summary, recent studies seem to support the predictions made a decade ago[1] with respect to spruce forest declining and broadleaf and mixed forest increasing across interior Alaska.

What about negative feedbacks to boreal burning? Deciduous forests are more resistant to fires than spruce forests—a guiding principle of much fire suppression and fuel treatments strategy[12]. Under average summer conditions, coniferous forest is more conducive to large fire spread and accounts for at least half of the average yearly burned extent. Since hardwood forests are less flammable, why doesn't a negative feedback kick in to reduce flammability as deciduous forests become more common on the landscape? The short answer is that most mega-fires burn in unusually hot/dry summers, and once the fire weather gets extreme enough, deciduous forests and regenerating forests become equally receptive to burning[13]. The "unusual" heat is becoming more "usual" in recent decades, and future climate scenarios predict dramatic increases in high fire danger days.

As for the *future* of forests in Alaska, new models at the stand level are being developed which include the latest understanding of forest environmental drivers and physiological constraints[4,11]. A research study funded by the Department of Defense in eastern interior will be sharing findings regarding fire-prone areas of Alaska from Fairbanks to the Canadian border, complete with web visualization tools for managers (beta version: https://masseyr44.users.earthengine.app/view/decidfractreecoverserdpv1).

The takeaway: Alaska's boreal forest is undergoing major changes driven by the domino effects of changing climate. Boreal forests are experiencing changes in the fire regime, which through interactions with the ecological and physiological attributes of trees are causing widespread shifts in forest composition. Those shifts in turn are causing a shift towards net C release to the atmosphere which could accelerate global warming. Overall, these shifts in forest species dominance are a fascinating example of how even a relatively simple biome like boreal forest can have complex responses to changes in climate.

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Fire Science Highlights