Spruce and Fire in Northwest Canada and Alaska

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FIRE is an integral feature of the northern forest environment (as shown by the ubiquitous presence of charcoal in the upper soil horizons) and the widely-distributed boreal broadleaf trees and conifers are well adapted to it. Aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), white birch (*Betula papyrifera* Marsh), tamarack (*Larix laricina* (Du Roi) K. Koch) and jackpine (*Pinus banksiana* Lamb.) are the usual pioneers on most sites immediately after fire. The spruces—both the white (*Picea glauca* (Moench) Voss) and the black (*P. mariana* (Mill.) B.S.P.)—are frequently early invaders too; at first inconspicuous because of a slower growth rate but later making their appearance as components of mixed stands which eventually they dominate. Only balsam fir (*Abies balsamea* (L.) Mill.) seems poorly adapted to fire survival, and its presence in any abundance usually indicates both a relatively "fireproof" moist site and an old forest.

In this paper I want to review certain aspects of the fire ecology of the spruces, chiefly white spruce, in the boreal forest area from the "prairie provinces" to the Northwest Territories, Yukon and adjacent Alaska. The state of knowledge in this field has been well summarized in a number of studies and reviews published over the last 15 years, for example Rowe (1955), Lutz (1956), Wagg (1964), Lacate *et al.* (1965), Jarvis *et al.* (1966), Kayll (1968), Zasada and Gregory (1969). To selected references from these general accounts I intend to add some further observations and to raise a few questions that I hope will be pertinent and of interest.

SOME SILVICAL CHARACTERISTICS OF SPRUCE

From the moist east to the drier west and northwest in the boreal region, white spruce becomes increasingly prominent in forest stands (Halliday and Brown, 1943); occupying upland morainic materials, the slopes and floodplains of river valleys, and glacio-fluvial and aeolian deposits, on which latter landforms it is particularly conspicuous both at the transition to tundra in the north and to prairie in the south.

Like the other boreal conifers it is a "weedy" species, dependent on small, prolifically-produced seeds for migration and on a minimum of competition for early survival. It begins to produce seed at 40-60 years of age on good sites, although when open-grown—especially under extremes of environment—it is much more precocious than this. Large quantities of seed are produced every few years by mature stands. Waldron (1965) reported as much as 5,625,000 per acre in a 100-year mixedwood stand in Manitoba where also over a 9-year period there was never a complete failure in seed production. Although most of the seed is scattered in the autumn, a small proportion is held in the cones and shed during the following winter, spring and summer. This may explain the sometimes unexpected regeneration of the species following summer fires.

The small winged seed, transported by wind and water, usually germinates in the early summer to produce a slender seedling whose top and root in the first season reach lengths of only an inch or two. Consequently mortality is high due to competition from vigorous perennials which not only deprive the small spruce seedlings of light and moisture but also crush them in the fall under a leaf mat, to which the weight of snow is later added. Regeneration is therefore successful where competitors have been destroyed or cannot themselves grow, such places being severely-burned forest floors and exposed mineral soil free of broadleaf accumulation, and the decayed acid wood of old tree trunks and stumps.

One additional characteristic of white spruce is noteworthy; the tree has a dense, relatively narrow crown which both contributes to the accumulation of needles around the bole and shelters them from precipitation. This, plus the red squirrels' penchant for creating middens of cone scales around tree bases, results in a potentially flammable mass of material under individual mature spruce.

Black spruce compared to white spruce is smaller, and it usually occupies wet peaty soils in dense stands. Also it differs in maturing sexually at an earlier age and in retaining much seed in its partially opened cones. It is capable of reproducing vegetatively by layering, its lower branches rooting where they touch the ground.

SPRUCE AND FIRE ON UPLAND SITES

A common sequence of forest development begins with fire disturbance on upland sites and proceeds through a broadleaf tree stage to the spruce "climax," as described by many students of boreal vegetation (for example Moss 1953 and 1955).

It is generally agreed however that severity of fire has an important bearing on the success or failure of spruce regeneration. Light surface burns, such as occur in early spring when the subsurface humus is wet, do not provide suitable conditions for spruce seedling survival. The perennating parts of broadleaf trees, shrubs and herbs are not destroyed by light fires but rather are stimulated to vigorous growth by the opening of the canopy and the release of nutrients to the soil. Kiil (1970) recently documented this effect following an experimental spring burn in an Alberta spruce-aspen stand. Rather surprisingly, the residual conifers (averaging 14 inches dbh and 75 feet tall) survived this fire while the associated mature aspen and balsam poplar were harder hit.

Severe fires which consume the humus layer totally or nearly so are much more effective in eliminating competition, for most forest plants have their perennating parts in the organic horizon. The exposed or thinly covered mineral soil then provides a suitable seed bed for spruce germination and seeding survival, as has been reported by numerous observers. The presence of basic wood ash does not deter spruce regeneration, and in the Riding Mountain National Park, Manitoba, where in the early 40's burned blowdown slash created a thick ash layer, patches of vigorous saplings can now be seen conforming to the fired areas.

The pre-requisite for severe fire, a deep accumulation of fine dry fuel, is found more often under spruce than under broadleaf trees. Therefore in mixed stands there is a tendency for severe burning under spruce and for light burning under aspen, so that spruce seedlings tend to reappear in the former and aspen suckers in the latter locations (Rowe 1955, Lutz 1956). The perpetuation of individuals and stands in the same places is also frequently seen where communities of aspen succeed aspen and spruce succeed spruce, to the confusion of those who *a priori* expect that spruce must follow aspen!

Under normal climatic conditions, the surficial soil materials also influence the likelihood and nature of fires. Thus well-drained landforms will more often be susceptible to burning than poorly drained ones, a point to be returned to later. However, in very dry seasons (for example 1937 in northern Saskatchewan) all landforms are susceptible and the severest fires can occur on normally moist to wet sites where organic matter accumulation is greatest. Such sites on fine textured soils or in valleys may then be rendered particularly favourable for spruce regeneration.

SPRUCE AND FIRE ON LOWLAND SITES

In the far northwest the most extensive and productive white spruce stands are found on the floodplains of large rivers such as the Peace, Slave, Liard, MacKenzie, Peel, Yukon and Tanana. The origin of these dense, tall and relatively pure stands is not entirely clear. Adjacent uplands carry fire forests of pine, black spruce, aspen and birch.

Raup (1935) explained the white spruce forests of the lower Peace River as the final stage of a primary succession, initiated on emerging sand bars by invasion of willow and proceeding through a balsam poplar stage to the spruce climax. This implies a somewhat unevenaged final stand. However, Horton (in Lacate *et al.* 1965) noted that these same stands tended to be even-aged and that they frequently showed other fire signs such as charcoal in underlying humus and alluvial layers, presence of charred snags, and fire scars along type boundaries. He concluded that although the classic primary succession was likely operative on recent fluvial deposits, most of the lowland spruce had developed via secondary successions, after fire had interrupted the pioneer broadleaf tree and shrub stages. Blyth, who participated in the same study on the lower Peace River, observed the likely causative factor; a lightning strike that ignited a snag in a lowland spruce-poplar stand. However, in discussing the predominantly mature and overmature character of the floodplain spruce forests he raised by implication a puzzling problem; how to account for the "remarkable fire history" before about 1800 (that presumably produced these stands) compared to the period since then?

Jeffrey (1961) agreed that most of the floodplain spruce on the lower Peace River originated following fire but he showed that some even-aged stands were due to wind throw while others of uneven age and structure apparently represented the end point of slow vegetation change from balsam poplar to spruce in the classic successional sense. In neither of the latter cases was fire necessarily involved. He pointed out too that while the presence of charcoal on a site is *prima facie* evidence of the influence of fire on succession, care is needed in drawing conclusions about its impact. The *type* of fire and its severity (i.e. whether or not it exposes mineral soil) is more important than the *fact* of fire, he said, and though the occurrence of charcoal is supporting evidence for the theory of "fire origin" it does not necessarily follow that fire triggered the genesis of the currently visible forests. On the floodplains of the lower Liard River, Jeffrey (1964) found both spruce-birch forests that apparently had a fire history and spruce-poplar forests that had none. He reported fire to be a major influence in that region, mentioning the tremendous summer fire in 1942 that burned with particular severity in the older floodplains, the adjacent terraces and through the MacKenzie Lowland.

Wagg (1964) examined forests along the Peace and Slave Rivers and gathered additional evidence that most spruce stands on the floodplains are the result of catastrophes which removed the original vegetation. His observations indicate, for example, that a large portion of the Peace River delta burned between 1780 and 1810. However he argued that since fires tend to expose mineral soil in patches—exposing 30-40 percent of the burned area according to Lutz (1956)—one might expect a clumped distribution of trees if fire were the primary agent of regeneration. As he found a somewhat uniform distribution of spruce, he suspected a more likely causative agent to be periodic flooding. Thus Wagg concluded that "many succeeding spruce stands originated after fire and specifically fire followed by alluvial deposits." In this hypothesis fire removes the stand and prepares the area, but spruce regeneration is not accomplished until a flood provides the mineral soil substrate. He stressed too the beneficial effects of shallow flood deposits on the growth rate of spruce seedlings established previously on decayed wood, and noted that thick deposits of alluvium that quickly raised the levels of point bars can bring about the concurrent establishment of willow, alder, balsam poplar *and* white spruce, thus telescoping succession into one multi-species stage.

In the summer of 1970 we examined some of the forests along the upper Liard River near Watson Lake on the Alaska Highway, locating on the floodplains a number of burned areas, old and recent, along with evidence that at least some spruce forests had originated there after fires, either with or without subsequent flooding. An interesting observation was that in old forests, where the ground is criss-crossed with much deadfall, fire may burn deeply between rotten logs and stumps without consuming them. Two favoured seed beds for spruce are subsequently available; thinly-covered mineral soil, and decayed spruce wood. In one area of substantial size we found vigorous and abundant spruce seedlings and saplings growing on these adjacent substrata in the absence of any broadleaf trees, an example of one pure spruce stand succeeding another. We concluded as others have that fire is frequently an important factor in the generation of spruce forests on the lowland as on upland sites.

LANDFORMS, FIRE AND FOREST PATTERNS

White spruce obviously has regenerative characteristics that allow it to survive in a certain fire environment, i.e. one where the time interval between successive burns is longer than the time for the trees to mature to their seedbearing stage. Because of differences in droughtiness, different landforms and topographic positions on landforms vary in their susceptibility to fire. Coarse-textured surficial materials and south-facing hill slopes dry out more rapidly and in general are burned over more frequently than fine materials and north slopes, although very coarse materials with insufficient ground cover to carry fire may be an exception. Usually on upland fire-prone sites, white spruce will be eliminated and replaced by species such as jackpine and black spruce with shorter reproductive cycles and with seed reserves in retentive cones. In this connection Raup and Denny (1945) suggested that most of the land area in the northwest along the Alaska Highway would eventually, if undisturbed, support white spruce forests. It is the short-period fire cycle on uplands that prevents the take-over by white spruce, producing instead a mosaic of forest types suited to the terrain. In other words, the patterning of vegetation to landforms reflects certain synchronies between fire occurrence and the characteristic reproductive cycles of species.

SPRUCE RANGES AND FIRE

The time required to reach reproductive maturity is not the only critical factor bearing on regeneration success. Also important are frequency of seedbearing years as well as amount and viability of seed produced, and there is evidence that for trees these characteristics decrease with increasing latitude (Lutz 1956). The treelessness of the tundra has been explained by Tikhomirov (1962) as due not so much to an unfavourable environment for tree growth as to a lack of viable seed. Therefore the impress of fire on the landscape must be more pronounced and visible over longer time periods in the north than in the south. While several fires a century may be needed to relegate white spruce to an insignificant position in the southern landscape, the same effect may be produced by a fire every few centuries at arctic tree line. By this logic, relatively rare fires could effectively prevent extension of forest into tundra for long periods, or could drastically shift tree lines southward to what subsequently may appear to be an environmentally-induced, stable position.

In the north we find that at their latitudinal limits both spruces occupy wet sites: black spruce where the substratum is wet, cold, acid and peaty, and white spruce along streams and alluvial bottoms. But white spruce and black spruce also appear in park-like stands on dry upland sites such as old raised deltas, eskers and sand hills (Ritchie 1959, Savile 1963, Hustich 1966). Characteristic of these habitats, in addition to the well separated trees, is a sparse ground cover. Some such outpost stands have been explained (Bryson *et al.* 1965, Laren 1965 and 1967) as representing relicts surviving from a climatically more favourable period when the forest border lay farther north than it does at the present time.

However as with low wet areas, the relatively fire-proof nature of the droughty landforms should be considered, i.e. they are areas of vegetational stability so far as disturbance by burning is concerned (Rowe 1966). This hypothesis should be closely examined in searching for explanations of the distributions of the two spruce species at northern tree line. As earlier pointed out, black spruce is better adapted to recurring fire than white spruce because it produces seed at an earlier age and retains it for several years in semi-closed cones. These characteristics plus its ability to reproduce vegetatively by layering, make it a persistent tree over a range of sites. On the other hand, white spruce is more selective of site. Alluvial lowlands provide one favourable environment, the other being sparsely-vegetated dry sites where obviously there is little opportunity for fire to spread from tree to tree.

Evidence for the hypothesis is also found when the southern limits of white spruce are examined. Again the tree is commonly found in local wet spots or scattered through sand hills. Open stands examined near the southern limit of distribution near Saskatoon, Saskatchewan and Brandon, Manitoba, commonly occupy the upper slopes and crests of stabilized dunes, and are clearly older than the deciduous trees and shrubs that occupy the intervening dune depressions. The inference that they have escaped fires that burned through the denser vegetation of the adjacent better sites seems reasonable, providing an explanation for the observed range limits.

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