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CHAPTER 12

Fire Influences in Abies-dominated Forests

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ABSTRACT

Abies-dominated forests have a relatively low fire hazard when compared with vegetation types dominated by *Pinus* or *Picea* species. Although large quantities of fuel are present, the humid climate of *Abies*-dominated areas reduces the probability of fire. When fires occur after prolonged drought periods, fir can be essentially eliminated from an area because it is not resistant to fire. *Abies* spp. tend to be shade-tolerant, late successional species and only in the absence of fire do they compete successfully with species established early in the post-fire pattern. *Abies*-dominated forests are more susceptible to fire following disturbance which damages or removes tree crowns, and in turn permits solar energy to reduce the moisture content of forest floor fuels. Forest harvesting is one of the recent disturbances, but it is thought that defoliation and tree mortality caused by insects also increase fire hazard. This 'insect-wildfire hypothesis' has been raised in a number of *Abies*-dominated areas around the world and seems intuitively plausible; yet there is little field evidence and very little experimental evidence to support the hypothesis.

12.1 INTRODUCTION

All species of the genus *Abies* are found at high altitudes and in boreal regions of the Northern Hemisphere. Of the approximately forty species, *Abies sibirica* Ledeb. is the most widely distributed and *Abies balsamea* (L.) Mill. is the second most widely distributed. These two species are the most boreal in distribution and approach the tree line (Liu, 1971).

The fir forests of the USSR cover approximately 25 million ha and are often found in association with spruce. Of the ten fir species found in the USSR, *Abies sibirica* is the most northerly and is found concentrated in the

north-eastern European part of Russia, in western Siberia, and in the southern half of central Siberia (Tseplyaev, 1965). One of the largest areas of fir is found in Krasnoyarsk Territory. Of the nine native fir species in North America only balsam fir (*Abies balsamea*) is considered a boreal species. It occurs throughout eastern and central Canada as a band stretching from central Labrador south to New York in the east and to central and northern Alberta in the west (Hosie, 1973). It may be found in pure stands, but is more commonly mixed with *Picea rubens* Sarg. in the east and with *Picea mariana* (Mill.) B.S.P., *Picea glauca* (Moench) Voss, *Larix laricina* (DuRoi) K. Koch, *Populus* spp. and *Betula papyrifera* Marsh. throughout its range.

Many investigators point out a comparatively low fire danger in *Abies*-dominated forests located in East and West Germany, the northern European part of the USSR, the western Siberian Plains, the southern Siberian Mountains and eastern Canada and the United States (Stickel, 1934; Melechov, 1947; Weck, 1950; Kurbatskii, 1964; Furyaev, 1970; Wein and Moore, 1977, 1979). The main reason for this is that *Abies*-dominated forests are often found in areas with moderate to high rainfall. The high relative humidities of the air, along with the rather dense canopy of trees which intercept radiation, result in relatively high moisture contents of the forest floor fuels. This makes ignition less probable.

However, there is some evidence that, under certain conditions, *Abies* forests are susceptible to severe fires. A prolonged drought period may be a prerequisite for such fires in fir forests. In contrast to broad-leaved and pine forests, where branch-pruning is common, little branch-pruning occurs in *Abies* stands. Thus there is continuous fuel from the forest floor to the tree crown, which increases the probability of crowning should fire occur. The periodic insect outbreaks in *Abies* forests may result in extensive tree mortality which may, in turn, increase the susceptibility of fir forests to a second fire.

12.2 FIRE FREQUENCIES

12.2.1 Natural Fire Frequencies

In general, there is poor quantification of natural fire frequencies in *Abies*-dominated forests. It is known from paleoecological work in eastern North America that fires (i.e., charcoal peaks in lake or bog sediments) were usually associated with major shifts in forest composition over the past 10 000 years (Green, 1976).

Using time-series analyses on pollen and charcoal profiles in lake sediment, Green (1981) developed power spectra for a number of tree species. The

power spectrum for fir (for the period 4500–2100 BP) had peak frequencies close to fire (fir pollen frequency was higher just before fires) and in addition fir showed a cyclic trend of 100 to 130 years. Fires cannot be related to this cycle since charcoal peaks occurred at about 330 to 500 years. It is tempting to suggest that this shorter cycle might be related to budworm outbreaks, because Heinselman (1973) and others have noted that fir reaches sufficient abundance about 100 years after fire for budworm outbreaks to occur. Green (1981) also showed that this short cycle for fir was not found in modern forests (i.e., 2050 to 0 BP). The fir cycle was 200 to 250 years and the charcoal cycle was 140 to 150 years.

Some fires during recent historic periods have been documented in paleoecological studies (Anderson, 1979; M.P. Burzynski, unpublished data) but unfortunately measurements of pollen, charcoal, and other evidence of fire in lake and bog profiles are usually not sensitive enough to detect if there were significant changes in fire frequencies during early European settlement. It is also unfortunate that we have only very subjective information on the role that native North Americans played in influencing fire frequency.

Much more information on fire frequency is available from more recent times. According to long-term meteorological data, severe droughts and associated major fires occur on an average of every 30 years in western Siberia, but during the intervening years with normal rainfall, large-scale fires in the *Abies*-dominated forests are relatively rare (Furyaev, 1966).

A common method of determining fire frequency in many boreal forest vegetation types is to use tree-ring dating of fire scars (Heinselman, 1973). Unfortunately, this technique is not generally applicable in *Abies*-dominated forests, since *Abies* species are not resistant to fire and thus generally do not survive to produce fire scars. Only mixed stands of *Abies* with *Picea* or *Pinus* can provide some data on fire frequency, because the latter species often record fires through scarring.

For many countries, fire suppression records have been gathered systematically and, in some cases, these have been used to determine fire frequency. Wein and Moore (1977, 1979) have summarized the fire control records for the provinces of New Brunswick and Nova Scotia in eastern Canada. They found that the mean and median annual area burned for the 7.6 million ha area of New Brunswick were 0.15% and 0.03%, respectively. In comparison, the spruce-fir coastal vegetation type had a mean annual burn of 0.15%. In Nova Scotia, the mean annual burn for the spruce-fir coastal vegetation was 0.05%, whereas 0.18% of this zone was estimated to have burned per year before fire suppression was formalized in the 1920s.

Obviously, at this rate of burning the fire rotation period is hundreds of years. Unfortunately, data on natural fire frequencies are not available for the *Abies* forests in most circumpolar regions.

12.2.2 The Insect-wildfire Hypothesis

Abies forests appear to be very susceptible to periodic insect outbreaks, which cause defoliation or other damage to trees and often result in mortality of trees and stands over large areas. The hypothesis that the dead and dying forests remaining after insect outbreaks are more flammable or more susceptible to wildfire than undamaged forests has developed among laymen, many scientists, and forest managers as well. We have termed this the 'insect-wildfire hypothesis'; if there is a scientific basis for the hypothesis, then the frequency of wildfire in *Abies* forests could be affected by the frequency of insect outbreaks.

The balsam fir forests of North America have periodically been subjected to severe outbreaks of the spruce budworm (*Choristoneura fumiferana* Clem.), which have resulted in tree mortality over millions of hectares. Tree ring growth measurements have demonstrated the occurrence of budworm outbreaks from the early eighteenth century to the present (Blais, 1968). It has been estimated that 720 000 000 m³ of wood was killed during the 1910 to early 1920s outbreak, representing 40% to 50% of the host-tree volume present in eastern Canada at that time (Swaine and Craighead, 1924). Intensive studies of the biology, ecological relationships, and damage caused by the spruce budworm have been carried out since the late 1940s, and more is probably known about this insect-forest relationship than any other (e.g., Morris, 1963; Belyea *et al.*, 1975; Jennings *et al.*, 1979; Hudak and Raske, 1981; MacLean, 1980).

Several authors have suggested an increased fire hazard in budworm-killed balsam fir stands (e.g., Graham, 1923; Swaine and Craighead, 1924; Graham and Orr, 1940; Burgar, 1963; Flieger, 1970; Prebble, 1975). Historical information indicates that severe forest fires may follow budworm outbreaks, such as the Miramichi Fire of 1825 in New Brunswick and the Chapleau-Mississagi Fire of 1948 in Ontario. However, there is normally a low probability of fire in the spruce-balsam fir forests of eastern Canada (Wein and Moore, 1977, 1979).

During a spruce budworm outbreak, trees usually start to die after 4–5 years of severe defoliation, and when the outbreak collapses (usually after 10–15 years) mortality can claim 70–100% of the trees in most stands (MacLean, 1980). Dead trees provide drier aerial fuels than live trees, and a faster drying-out of surface fuels will occur as the canopies of dead stands allow both sun and wind to enter (Stocks and Bradshaw, 1981). In addition, accumulations of surface fuels increase as the trees and tree tops break and fall to the forest floor. This high fire hazard may be temporary, and its duration largely influenced by how rapidly the regeneration and the invading understorey vegetation provide a continuous cover (Flieger, 1970; Stocks and Bradshaw, 1981).

The insect-wildfire hypothesis has also been raised in the USSR, where it is thought that the fire danger in *Abies sibirica* forests increased dramatically after insect outbreaks (Furyaev, 1966). Furyaev examined the *Abies* forests after outbreaks of the Siberian silkworm (*Dendrolimus sibiricus* Tschv.) and the big coniferous long-horned beetle (*Monochamus urossovi* Fisch.). There were large outbreaks of these insects in the fir forests of Krasnoyarsk from 1967 to 1970 (Isaev and Krivosheina, 1976). Furyaev (1966) attributed the increased fire hazard following the insect outbreaks to several fuel factors: (1) light-tolerant grass and shrub species grew quickly with the opening of the tree canopy, and led to an accumulating layer of dead grass; (2) a large quantity of highly flammable fine fuels such as needles, dry twigs, and bark fell from the insect-killed trees and tended to form an evenly distributed layer over the area, which greatly facilitated fire spread; and (3) a large quantity of dry, large woody fuel in the form of tree boles fell to the ground about 10–15 years after the trees died.

Thus there is much observational evidence and limited historical evidence about the changed stand structure after insect outbreaks in *Abies* stands that suggests increased flammability or fire hazard in insect-killed forests. However, virtually no data exist at present to establish if the probability of fire is actually increased. In addition, there are three requirements for a spreading fire: (1) sufficient fuel of appropriate size and arrangement in space, (2) sufficient dryness of fuel to support a spreading combustion reaction, and (3) an ignition source (Van Wagner, Chapter 4, this volume). The hazard of the fuel component may be increased after an insect outbreak; but, if the weather is inappropriate or if the ignition source is lacking, an increase in fire frequency in insect-killed *Abies* forests will not occur.

12.3 FIRE BEHAVIOUR

In Siberia it is thought that fires which occur in forests damaged or destroyed by insects are different from other types of forest fires. Insect-damaged forests are susceptible to fire early in the spring, after snow-melt, and this fire hazard lasts throughout the entire season. The fires tend to spread very quickly through these evenly spread, high-quantity fuel conditions. Calculations have shown that the intensity of fires in these areas is about ten times that of surface fires in pine forests. The largest fires in insect-killed *Abies* forests in the USSR are comparable in character to crown fires, with an energy release of about 12 million kcal/m²/min.

In Canada it is generally understood how defoliated trees die, break down, and permit light to stimulate understorey species over a 15–20 year period (Ghent *et al.*, 1957; Baskerville, 1975; MacLean, 1980; and others). Although it is not understood how this affects fire hazard of the budworm-killed stand,

some preliminary data are available on the subject. Canadian Forestry Service personnel at Sault Ste. Marie, Ontario, have established plots in a budworm-killed balsam fir stand and are burning them under moderate to high Canadian Fire Weather Index conditions. To date, two spring and two summer experimental burns have been conducted with widely differing results: the spring fires resulted in sustained crowning and spotting with extremely fast spread rates, whereas the summer fires were unable to spread (Stocks, 1979; Stocks and Bradshaw, 1981). The substantial difference between spring and summer fires appeared to be due to the lack of understorey vegetation in the spring, versus the proliferation of a lush green understorey in the summer (Stocks and Bradshaw, 1981). Two characteristics of a budworm-killed *Abies* forest were noted to affect the rate of fire spread. The loose bark on dead balsam fir trees readily ignites and serves as material for wind-carried firebrands when caught in the up-draught of heated air from the fire (Stocks and Bradshaw, 1981). High wind conditions will therefore produce greater rates of spread than in living forests. Also, the quantity of dead material on the forest floor of budworm-killed forests serves as excellent ignition sites for the fir-bark fire brands.

Stocks and Bradshaw (1981) have noted that the nature of the fuel in a budworm-killed forest may make fire suppression more difficult in several ways. Fallen dead material impedes access to the fire's perimeter and generally interferes with suppression activities. As well, standing dead trees are easily felled by wind, water bomber activity, or other machinery, presenting a serious danger to fire fighters. If initial attempts at suppressing a fire in budworm-killed timber fail, burning off the area between some natural barrier such as a river or road and the head of the fire should present the least danger to fire fighters.

12.4 EFFECTS OF FIRE ON ECOSYSTEM COMPONENTS

Although there is much information available on *Abies*-dominated forests (e.g., a review of *Abies balsamea* by Bakuzis and Hansen (1965)), these forests have not played a prominent part in the reviews of forest fire effects. In this section an attempt will be made to identify those aspects of *Abies*-dominated forests that differ from conditions in other forest types.

12.4.1 Primary Producers

Fire in *Abies*-dominated forests appears to convert *Abies* stands to other tree species rather than to perpetuate *Abies*. *Picea* or *Pinus* species, in contrast, have adapted to survive fire or to provide a post-fire seed source. Foresters have long been aware that *Picea-Abies* forests are often converted to *Picea* forests by fire (Candy, 1951; MacLean, 1960; and others). *Abies* species have

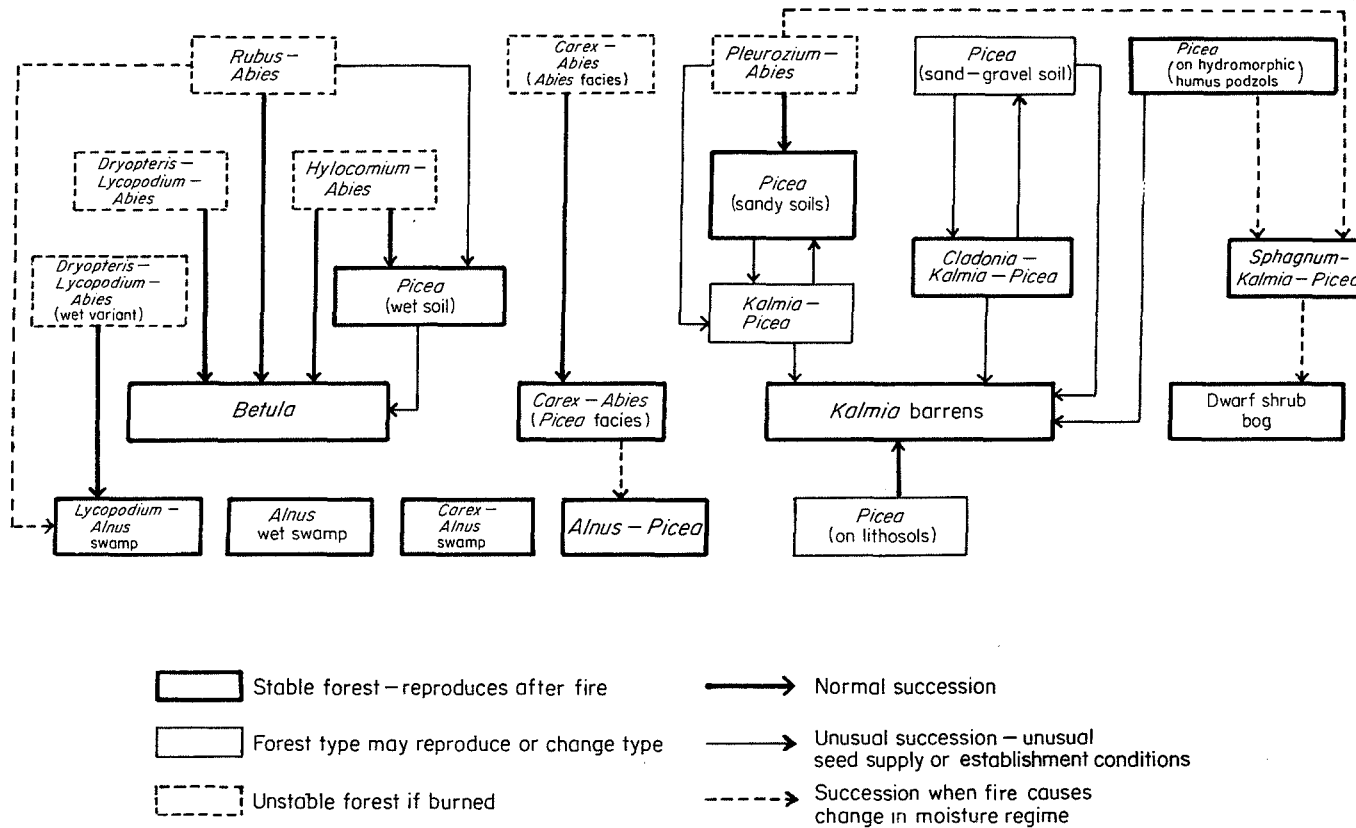


Figure 12.1 *Abies-Picea* forest succession patterns after fire for central Newfoundland, Canada (adapted from Damman, 1964. Reproduced with permission of A.W.H. Damman and the Society of American Foresters)

extremely thin bark and thus generally do not survive fire; they do not bank seeds in the forest floor or soil and also do not disseminate seeds over very long distances. Because many *Abies* species are very shade-tolerant, seedlings and small trees are often found in the understorey of the stands. Thus, *Abies* species fit into the 'avoiders' classification of Rowe (Chapter 8, this volume).

An example of *Abies-Picea* forest succession patterns has been suggested by Damman (1964) for the province of Newfoundland in eastern Canada (Figure 12.1). It should be noted that the black spruce forests, birch forests, *Kalmia* barrens, and the very wet habitats are self-perpetuating after burning. However, all *Abies* forests change type when burned.

In essence, *Abies* forests are not resistant or resilient in terms of surviving fire over the short term or the long term; they will survive in an area only if a fire is of extremely low intensity or if patches of unburned forest are left. Even if the trees are only damaged, fungal diseases and insect attack will quickly destroy the stand structure. It is possible with the opening of the forest canopy after fire that a second fire can burn through the area and cause even greater changes in species composition.

The existence of large tracts of nearly even-aged balsam fir forests in eastern Canada (e.g., northwestern New Brunswick and the Cape Breton Highlands) suggests that these forests came about as a result of some natural disturbance. Baskerville (1975) has argued that the degree to which the spruce budworm is the driving force of balsam fir forest succession depends on the extent to which the budworm can periodically devastate the forest. It is quite clear that the even-aged nature of certain balsam fir stands in eastern Canada has directly resulted from recent budworm outbreaks (Baskerville, 1975; Baskerville and MacLean, 1979); the advance regeneration under a fir stand at the time of a budworm outbreak develops into the next stand on that site. However, it appears that the influence of budworm on forest succession becomes less pronounced in Quebec and Ontario, because other factors, such as fire, become more important. The composition of the forest changes with fires, and the tendency is to favour species less susceptible to budworm damage. Following fire, species such as *Populus* or *Betula* spp. may occupy the site for many years. Since the turn of the century, fire control has improved and *Abies*-dominated forests have increased. Also, by protecting large areas of mature and overmature forest with insecticides, there has been an inadvertent increase in the extent of *Abies* forests that was conducive to budworm outbreaks. It appears that many human influences in the forest since the settlement of North America have favoured balsam fir (Lorimer, 1977).

In the USSR, Smirnov (1970) has emphasized that post-fire succession patterns are very site-specific, and take the form of grasslands, wet meadows, shrublands, and swampy areas. Although grassland conditions are sometimes formed when forest floor organic matter has been removed by fire and

erosion has occurred, *Abies* forests tend to show this response only in small areas. There are many areas of *Abies*-dominated forests that have become wastelands because high frequency and intensity of fires have degraded the areas to low-bush, heath species. These areas are usually found on north exposures and steep slopes and are frequently used for producing *Vaccinium* spp. fruit. These areas are quite common in the Karpathian Mountains, the Balkans, and other mountain regions of eastern and western Europe (Smirnov, 1970). The first pioneers of burned areas are frequently the mosses, *Ceratodon purpureus* and *Funaria hygrometrica*. Before fire *Hylocomium splendens* is usually the dominant species, but following fire the more light-requiring and less moisture-requiring *Pleurozium schreberi* invades. It is thought that the water-holding ability of the post-fire moss cover may be seven to ten times less than that of the pre-fire mosses because of the decreased abundance and thickness of mosses after fire.

Smirnov (1970) has grouped the post-fire shrub species according to their ability to invade burned areas. He also recognized that some species invade quickly after fire and also persist for a long period of time. These include *Alnus fruticosa* and *Rhododendron* species on eroded slopes, *Lonicera altaica* on damp slopes, and *Spiraea media* on dry slopes. Smirnov (1970) suggested that there are other species that invade the more moist and fertile soils (e.g. *Alnus* spp.) but, since trees so readily compete on these sites, it appears that fire does not lead to the spread of these shrub species.

For some of the coastal fir forests of eastern North America it is thought that trees can be replaced by shrublands of *Alnus rugosa* or *Acer spicatum* which grow on high-fertility soils or by dwarf shrublands of *Kalmia angustifolia* or *Gaylussacia baccata*. Damman (1964, 1971, 1975), Niering and Goodwin (1974), and Strang (1972) emphasize that these shrub communities remain stable for decades and effectively resist invasion of trees.

12.4.2 Secondary Producers

As in other northern ecosystems, spring and summer fires in *Abies* forests cause the destruction of egg clutches and young birds, and post-fire conditions result in changes in the animal complexes. These changes in the bird and mammal populations also affect vegetation recovery through such activities as browsing or disseminating seeds. During the early stages of post-fire succession in the USSR, the typical representatives of the taiga fauna (wood-grouse, squirrels, hazel-grouse, and sable) disappear for several decades. But this changed habitat is suitable for other species, and so mouse-like rodents and their predators increase (Pospelov, 1957). During low-intensity surface fires, the small mammals are not killed, and the numbers are about the same on burned and unburned areas. The rodents tend to concentrate where the cover of grass and low-bush vegetation is highest.

This concentration of rodents often inhibits the regeneration of large-seeded plant species because the seeds are eaten. The high density of young shoots of *Populus* spp. and *Betula* spp. available following fire results in greater utilization by moose, deer, and marals. We know that these vertebrates cause considerable damage to tree regeneration on burned areas.

Many birds which require forest edges are especially attracted to the post-fire *Abies* taiga communities. The many small, low-intensity burns in these moist forests lead to a greater mosaic than in other forest types. Burning an *Abies* forest results in great changes in bird numbers. Sometimes the number of ground-nesting birds increases sharply under early post-fire conditions when there are only bushes on the burned plots. In other cases, birds tend to be fewer in species and smaller in size (Reimers and Malishev, 1963).

Virtually no literature exists on post-fire changes in bird and mammal populations of *Abies* forests in North America; however, a more general review of population changes with succession was carried out by Fox (Chapter 9, this volume).

12.4.3 Physical Environment

Due to the relatively low frequency of fire in *Abies*-dominated forests, soil movement on sloping areas may be somewhat more dramatic than in forests that have a higher fire frequency. Sapoznikov (1976) emphasized that erosion is related to the degree of loss of the forest floor organic matter during burning. Even low-intensity burns cause post-fire accelerated decomposition and the leaching of nutrients.

In lowland moist *Abies* ecosystems the possibility of post-fire soil erosion and complete burning of the organic matter on the forest floor is reduced. Thus leaching of nutrients released during the fire is reduced. In these areas, post-fire nutrient changes strongly influence the early successional-stage mosses on the clay-loam soils.

There is some evidence that repeated fires in the *Abies*-dominated forests of the USSR may lead to soil transformations from podzolic to organic soils. Stepanov (1925), for example, considered fire to be the main reason for the paludification or swamping of areas following burning. On the other hand, Sukachev (1926) felt that there was little scientific evidence to suggest that burning led to paludification or to a change in physical or chemical soil properties. Melechov (1947, 1948) suggested that swamping is inevitable since removal of the trees causes a decrease in transpiration; however, paludification slows or stops when young conifer trees become established. Piavtchenko (1952) noted that paludification only occurs where the thick peat already covers nutrient-poor soils and where the water table is close to the surface. The fact that moss cover is found in place of *Abies* trees after fire should not

necessarily be interpreted as the beginning of paludification. Furyaev (1974) stated that paludification of *Abies* forests in western Siberia occurs only in level watersheds and river valleys; more often fire results in a cover of grass plus *Polytrichum* and *Aulacomnium* mosses. In the middle Siberian plateau, fir forests may be replaced by low-growing *Ledum* spp.

In eastern North America thin impervious iron and manganese layers have been found in coarse soil deposits under peat in humid coastal areas of Newfoundland (Damman, 1971, 1975) and similar layers have been found under *Gaylussacia baccata* shrublands of Nova Scotia (Strang, 1972). The cause-effect relationship between the indurate soil layers and the fire-maintained vegetation type is unclear, but the layers lead to higher water tables and therefore paludification.

12.5 FIRE MANAGEMENT

As already suggested, fire suppression is not particularly difficult in *Abies*-dominated forests, but periodically dry years do give fire suppression problems. Fire suppression personnel in eastern Canada and the northeastern United States are presently concerned that the current spruce budworm outbreak may lead to widespread fires should low rainfall years be experienced in the near future.

The use of fire for silvicultural purposes has not received a great deal of attention in *Abies* forests; however, there is interest in converting spruce budworm-susceptible fir forests in eastern Canada to less susceptible species, and particularly to *Picea mariana*. Such species conversion would require intensive site-preparation because of the presence of understorey fir regeneration which will provide strong competition to planted spruce seedlings on many sites. The use of prescribed burning for site preparation will probably increase in the future because fire is very cost-effective, eliminates fir regeneration completely, and, if done properly, favourably prepares the site for spruce seedlings. Prescribed burning in *Abies* forests could also be used for removal of slash prior to planting, or for reduction of fire hazard.

Probably the most widespread use of fire in North American *Abies* forests has been to stimulate fruit production by *Vaccinium* species. Burning every second year is a common practice (Hall, 1954; Hall *et al.*, 1979).

12.6 CONCLUSIONS AND RESEARCH NEEDS

Abies-dominated forests compose a considerable proportion of the northern circumpolar region, but, because of low fire frequency, little fire research has been conducted. Available literature tends to be poorly quantified because the information on fire was usually gathered as part of a related study. There are several reasons why fire research is important in these forests.

Examination of the 'insect-wildfire hypothesis' for different stand types of *Abies* would seem to be one of the prime research needs regarding the ecological role of fire in *Abies* forests. In the light of the widespread spruce budworm outbreaks currently in progress over much of eastern North America, this research would be very timely. Other areas warranting research could include fire frequencies in *Abies* stands in different regions and their relation to climatic differences. Successional trends related to fire intensity and frequency would be particularly useful for fire managers because, at present, few detailed studies exist.

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