LOGGING IN ALASKA'S BOREAL FOREST: CREATION OF GRASSLANDS OR ENHANCEMENT OF MOOSE HABITAT

William B. Collins[1] and Charles C. Schwartz[2]

[1]Alaska Department of Fish and Game, 1800 Glenn Highway, Suite 4, Palmer, AK 99645; [2]Alaska Department of Fish and Game, 34828 Kalifornsky Beach Rd., Suite B, Soldotna, AK 99669

ABSTRACT: Timber harvest in Alaska's boreal forest can greatly enhance or severely reduce moose (*Alces alces*) habitat quality, depending on forest management objectives, timing and methods of harvest, and post-logging site preparation. Overstory removal associated with timely exposure of mineral soil favors establishment of early successional hardwoods important as moose browse. A combination of clear-cutting and soil scarification on mesic sites mimics fire, windfall, and fluvial erosion, important natural forces that drive regeneration of the boreal forest. When cut during dormancy, aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*) regenerate prolifically by root and stump sprouting. However, harvest of paper birch (*Betula papyrifera*) or white spruce (*Picea glauca*) with little or no disturbance to the organic mat covering the forest floor often results in establishment of a long-lived herbaceous disclimax dominated by bluejoint reedgrass (*Calamagrostis canadensis*). This disclimax may persist for 25 to 100 years or more, limiting re-establishment of important deciduous browse species utilized by moose. With proper timber harvest, soil scarification, and good seedling establishment, carrying capacity for moose based upon forage supply can increase 20-45 fold (4-9 moose/km^2) over mature forest. Increases of this magnitude are also observed following wild fire. Estimates of carrying capacity following poor harvest practices with no scarification seldom exceed 0.2 moose/km^2, similar to that of mature forest. Properly regenerated clearcuts yield high quantities of moose browse for approximately 20 years following logging. We discuss the importance of appropriate timber harvesting practices relative to moose and the boreal forest ecosystem in Alaska.

ALCES VOL. 34(2): 355-374 (1998)

Key words: boreal forest, browse production, carrying capacity, disclimax, habitat enhancement, herbicide, logging, moose, soil scarification

---

Within the boreal forest, moose benefit from increased availability of hardwoods following fire, fluvial disturbance, insect outbreaks, windfall and other disturbances, including timber harvest (Peterson 1955, LeResche *et al.* 1975, Peek *et al.* 1976, Kelsal *et al.* 1977, Cederlund and Markgren 1987, Lautenschlager *et al.* 1997). Fire is the most significant in terms of area affected. For example, moose on the Kenai Peninsula, Alaska reached densities of 3.6-4.4 moose/km^2 13-26 years following fire (Loranger *et al.* 1991). Peak densities occurred around 15 years post burn and declined at a rate of about 9 percent per year after that ($\lambda = 0.91$). Densities in old growth forest ranged from 0.1-0.2 moose/km^2.

During recent decades, fire suppression programs have greatly reduced wildfire as a retrogression event in the boreal forest. During the same period, demand for wood and fiber from the boreal forest has increased.

Moose habitat enhancement

Maintenance of adequate habitat for moose is a principal concern of wildlife managers in northern forests (Franzmann 1978). With progressive exclusion of fire from the boreal forest, other forms of disturbance—prescribed burning, logging, selected land clearing and other mechanical treatments—increasingly represent alternatives to maintain early seral diversity favorable to moose (Oldemeyer 1977).

Lykke and Cowan (1968) linked the dramatic increase in Scandinavian moose populations during this century to clear-cutting, which replaced selective cutting as the preferred system of timber harvest. From the standpoint of browse production, clear-cutting is more beneficial than selective cutting or thinning, primarily because it allows full sunlight to reach the forest floor and stimulate production of shade-intolerant browse species (Murphy and Ehrenreich 1965, Lautenschlager *et al.* 1997).

In the past 2 decades, there has been considerable discussion about optimum size and spacing of clearcuts when habitat enhancement for moose is the principal consideration. According to Todesco *et al.* (1985), width recommendations have been based primarily on theory. They suggested that smaller openings trap more snow than larger ones, thereby causing moose to use larger openings when snow depths inhibit movement. Extreme variation associated with the rapid regrowth of forest cover within clearcuts 7-10 years following logging may, in part, explain much variation observed in distances moose browse away from forest edges (Neu *et al.* 1974, Stelfox *et al.* 1976, Stone 1977, Hamilton *et al.* 1980, McNicol and Gilbert 1980, Oldemeyer and Regelin 1980). Additionally, proper spacing of cuts relative to unharvested stands ensures retention of thermal cover important to moose (Renecker and Hudson 1986, Schwab and Pitt 1991).

Post-logging site preparation

Daniel *et al.* (1979) listed the following reasons why site preparation may be necessary following timber harvest: (1) removal of competing vegetation; (2) reduction of slash; (3) improvement of soil moisture conditions; (4) improved wildlife food and/or cover; and (5) shortened time for tree regeneration. Depending on tree species and site characteristics, site preparation objectives can be accomplished by the harvesting system itself, by burning of harvest residues and understory, by use of selective herbicides, or by post-harvest mechanical treatments. Mechanical site preparation can produce a great variety of soil conditions both favorable and unfavorable to hardwood seedling establishment (Orlander *et al.* 1990).

Mechanical site preparations typically scarify the forest floor exposing patches of mineral soil by stripping away the organic layer. Thorsen (1978) described several beneficial effects of scarification in boreal forests, including reduced competition for light, nutrients and water, and elevation of soil temperature to favor mineralization of nutrients and seedling root development. Removal of ground cover also allows soil to re-radiate heat during the night, thus reducing frost damage to new seedlings.

Thorsen (1978) observed that morainic soils of high silt and fine loam content, when scarified extensively, tended to frost heave seedlings. Scarification which is too deep and/or narrow can accumulate water or be covered by adjacent vegetation. Scarification can reduce nutrient supply where mineral soil is exposed, since nutrient-rich organic matter is cast aside. Warming of soil brought about by overstory removal and disruption of the organic mat may result in no change or an increase in soluble nitrogen, phosphorus and potassium associated with increased microbial mobilization of these nutrients (Van Cleave and Dyrness 1983). Mineralization of nutrients and availability to roots is accelerated by warming associated with exposure of mineral soil (Heilman 1968, Jansson 1987), but slows as moss or duff develop and once again insulate the soil.

Larger patches of exposed soil result in better tree regeneration than small patches (Aldridge 1967), especially for paper birch where germinants survive better on mineral soil than on litter or mosses (Perala 1987). However, Zasada *et al.* (1977) found that paper birch grows faster when roots have access to organic matter, and Teikmanis (1956) found more seedlings at edges of cultivation where soil qualities (organic mix) are superior. Thus, optimal exposure of soil represents a tradeoff between reduced competition and seedling access to nutrient-rich organic material. Seedling survival is also affected by competition or smothering from invading adjacent vegetation. This is especially true of grass and herbs which not only compete for nutrients, sunlight and water, but often mat under accumulated snow, pressing young hardwood seedlings to the ground and killing or further decreasing their competitive vigor during the next growing season.

A number of different kinds of equipment and methods are used to scarify forest soils following logging. Selection of the best method is influenced by fertility, wetness of mineral soil, and thicknesses of organic and mineral soil horizons. Application of any technique requires correct protocol as incorrect application or equipment operation can devastate a site by severely disrupting nutrient, moisture and temperature relationships.

In Fennoscandia, where preparation of planting sites for conifers is common practice, mesic soils are scarified in either continuous furrows or patches (Appelroth 1981) neither of which exceed 45 to 60 cm width. Similar scarification is preferred for conifer regeneration in Canadian boreal forests and utilizes much of the same equipment developed in Fennoscandia (Coates and Haeussler 1987).

Skidding of trees with intact branches can prepare a good seedbed on drier sites if done during snow-free periods and where the organic mat is not too thick (Safford 1983). Perala (1987) reported that disturbance by grazing aids in birch establishment but cautioned that continued heavy grazing hinders seedling survival. Overstory removal with its associated reduction in evapotranspiration results in increased soil moisture (Margolis and Brand 1990), further complicating site preparation in wetter forest sites. Such sites often must be drained by ditching and/or mounding.

In the Matanuska Valley, Alaska where natural regeneration of hardwoods was the primary management objective, Densmore (1988) evaluated 2 scarified clearcuts to determine the effectiveness of site treatment by flat blade and clearing blade (also called a root rake). She determined that scarification by clearing blade produced higher birch seedling density and growth rate. Scouler willow (*Salix scouleriana*) densities did not differ significantly between scarification treatments. However, birch and willow seedlings were "virtually absent" where scarification either was too shallow and had not exposed mineral soil or where it was too deep and exposed subsoil. Seedling densities and growth rates were greatest where the A-horizon was exposed, but considerably lower on exposed B-horizon. On B-horizon sites, the best growth occurred at edges where seedlings were apparently protected from needle ice and had access to nutrients in adjacent unscarified soil.

Densmore (1988) compared planting of green house-propagated, containerized willow seedlings with direct seeding of scarified sites and concluded that both methods were marginally effective. She recommended retention of mature willows within logged areas to ensure natural seeding.

Browse ecology

Paper birch, aspen, willows, and balsam poplar are well adapted to establishment on disturbed sites (Viereck and Shandelmeier 1980). All reproduce from seed where mineral soil is exposed and competition from herbaceous species is reduced. Each develop stump sprouts following clear-cutting, but according to Argus (1978) willows are premier in this regard. However, because willow is shade intolerant, densities are usually low in well developed paper birch - white spruce stands, and total production by sprouting may be minimal. Aspen and, to a lesser extent, balsam poplar reproduce well by root and stump sprouting. In the case of aspen, entire clones should be clear cut in order to eliminate apical dominance which suppresses adventitious bud development. Aspen stands treated in this manner may produce over 200,000 stems/ha (Gregory and Haack 1965). Paper birch does not root-sprout but does stump-sprout well when less than 40 to 60 years of age (Perala 1987).

Paper birch, aspen, willow and balsam poplar reproduce best by seed in large openings with full sunlight and exposed mineral soil (Argus 1978, Viereck and Schandelmeier 1980, Safford 1983, Zasada *et al.* 1983). These species often dominate early seral stages but decrease in importance with overstory development. Decreased availability of seedbeds associated with developing forests reduces opportunity for browse regeneration in later stages. Significant reduction of willows is also a result of competition for light by taller trees and shrubs (Argus 1978). Birch is also shade intolerant (Perala 1987).

Willow, balsam poplar and aspen produce large quantities of light, tufted seeds that are transported long distances by wind (Argus 1978, Viereck and Shandelmeier 1980). However, willow seeds are viable for only 2 to 3 weeks and, therefore, must readily encounter necessary seedbed and weather conditions in order to establish. While enhanced seedling establishment on mineral soils are usually ascribed to better moisture conditions, Zasada *et al.* (1983) determined that willow seeds fail to germinate on organic material, even when kept sufficiently moist.

Paper birch can be copious seed producers, covering the ground with up to 28,000 seeds/m^2 (Zasada and Gregory 1972). Seeds are winged and relatively heavy and fall within 30 to 60 m of the parent tree. Bjorkborn (1971) estimated paper birch seedfall at clearcut edges to be 60% of interior stand seedfall, but only 10% at 50 m into clearcuts. Therefore, Safford (1983) and Zasada and Gregory (1972) recommended that clearcuts of this species be less than 100 m wide or that they contain 7 to 12 well distributed seed trees per hectare.

Bluejoint reedgrass ecology

Bluejoint reedgrass (*Calamagrostis canadensis*) is the most common of over 100 species and subspecies of the genus *Calamagrostis*, ranging throughout Alaska and most northern latitudes (Tolmochev 1964). It prefers open, mesic sites in burned or cleared boreal forest (Laughlin 1969, Bliss 1973) but can inhabit a variety of settings, from wet lowlands to dry, windswept alpine ridges (Mitchell and Evans 1966).

Mueller and Sims (1966) reported that bluejoint reedgrass (referred to hereafter as bluejoint) prefers fine textured, moist soils. Hernandez (1972) stated that bluejoint is a good pioneer of dry upland sites. In any case, bluejoint is widespread, and even where it occurs inconspicuously in mature forest it can quickly capitalize on any disturbance which reduces competition from overstory species (Mueller and Sims 1966, Crouch 1986, Lieffers *et al.* 1993). Bluejoint vigor is greatly reduced by shading (Lieffers and Stadt 1993).

Bluejoint readily monopolizes cutover areas of boreal forest in Alaska (Mitchell and Evans 1966), thereby eliminating favorable conditions for hardwood seed germination. Those hardwood seedlings which do begin to establish must compete with bluejoint for water and nutrients. Hardwood seedlings must also tolerate both shading and smothering effects of bluejoint. Bluejoint has an erect growth form, but during winter, snow accumulation crushes the previous summer's growth to the ground forming dense mats which flatten and/or smother small hardwood seedlings (Mitchell and Evans 1966, Blackmore and Corns 1979).

Bluejoint is a winter-hardy perennial that naturally propagates from seed or rhizome in mid-May. By mid-June it may reach heights of 1 - 2 m (Mitchell and Evans 1966). Its nutritional value rapidly declines after seedheads begin developing in late June (McKendrick 1983). Mitchell (1968) determined that bluejoint seeds are not dropped until late September, thereby ensuring that they will not germinate until the following spring when conditions are favorable for establishment. He also found that seedhead production increased by 700% in disturbed areas, individual seedheads producing a maximum of 150 seeds each. Conn (1990) found that seeds buried as deep as 15 cm retained 9% viability after 4.7 years.

Bluejoint can colonize disturbed sites by elongation of rhizomes (Mitchell 1968, McKendrick 1984). Disturbance of rhizomes may actually increase grass density if conditions are favorable for development of rhizome segments (Hernandez 1972). Powelson and Lieffers (1991) determined that rhizomes need to be chopped into pieces less than 1 nodal segment in length to reduce sprouting of dormant buds; coarse chopping leads to significant sprouting. Regardless of rhizome disturbance, bluejoint can completely colonize new openings by clonal spread in as little as 1 year (Ahlgren 1960), but typically requires 3 years (Hogg and Lieffers 1991). MacDonald and Lieffers (1993) concluded that bluejoint rhizomes follow an "opportunistic guerrilla" strategy, allocating nutrients in direction of the most favorable microsites, avoiding competition and resource-poor patches in favor of unexploited habitats.

Here we present our field evaluations of forest harvest practices and post logging treatments in terms of their effectiveness in stimulating hardwood regeneration to benefit moose. We predict impacts of post-logging regeneration on moose habitat, and we discuss these results relative to existing practices currently employed in Alaska. We also review the ecological principles underlying the most effective practices, and make suggestions where future research is necessary. We recognize that these principles have broad general application across the entire boreal forest, but are cognizant of site specific variation affecting choice of management application and actual results.

METHODS

The senior author surveyed 96 timber harvest sites in the Matanuska and Susitna Valleys of southcentral Alaska between 1990 and 1995 to determine the significance of overstory reduction, disturbance of ground cover, and size of clearings relative to enhanced habitat values for moose. Variations in logging practices associated with each cut were primarily products of individual logger's preferences rather than prescriptions driven by industry wide experience. Cuts ranged from 2 - 20 ha, most being approximately 10 ha.

In each cut, we estimated seedling and sprout densities of hardwood browse species by double sampling (Wilm *et al.* 1944) 3 - 7 years post-logging before natural thinning affected stem density. We visually estimated stem densities while walking entire cuts. On 1 of every 5 sites, we systematically distributed 35 to 60 5-m^2 plots to determine stem densities, age, length and weight of the entire plant, length and weight of current annual growth (CAG), and percent utilization by moose. We then regressed our systematic sample against visual estimates ($R^2 = 0.9979$) to adjust density estimates.

To assess impacts of hardwood regeneration on moose habitat carrying capacity, we used information presented by Oldemeyer and Regelin (1987) to generate curves of average stem density by forest age. Data for each of the 3 major browse species (paper birch, willow, and aspen) (Oldemeyer and Regelin, 1987: Table 3) were fitted with CurveExpert 1.22 (D. Hyams, *pers. comm.*), and then used to generate stem density estimates at 5 year intervals from 0 - 80 years. We then generated a generic diet composed of equal portions (unweighted mean) of the 3 species. This mean of the 3 major species best fit a 4th degree polynomial that generated an average generic stem density over 80 years of succession. To evaluate the effect of varying stem densities associated with different levels of regeneration following logging, we used maximum stem density from good (12,000 stems/ha), fair (2,750 stems/ha), and poor (750 stems/ha) stands. We then adjusted the fair and poor stem density curves to the initial fit of 12,000 stems by scaling them to 24% (2,750/12,000), and 6.5% (750/12,000).

We sampled 4-year-old scarified patches at 50 cm intervals from 0 - 2 m perpendicular to edge for stem density, coverage, age, height, and CAG of paper birch. We measured height and coverage of bluejoint. We noted depths of soil horizons at each interval, and we collected and froze 8 cores of the top 5 cm of soil from each interval. Samples were later analyzed for NH_4, NO_3, and total N, P, and K by the University of Alaska Agricultural and Forestry Experiment Station Laboratory. Nitrogen was determined by combustion using a LECO CHN-1000 analyzer. Phosphorus and K were measured using an elemental analysis of a nitric-perchloric (5:3 ratio) acid digest of the plant tissue using an ICP emission spectrometer. We analyzed the data using a randomized block design, where scarified patch was the blocking variable and distance from edge was the explanatory variable.

We monitored frost heave potential in different substrates by placing 0.3 x 10 cm pegs 5 cm vertically into the ground in A-horizon, B-horizon, moss and grass dominated microsites. Ten transects, each consisting of 22 pegs positioned at 10 cm intervals, were randomly located in each microsite, and heaving determined by counting the number of pegs forced out of the ground after 1 winter. We used a Pearson Chi-Square test of independence (Snedecor and Cochran 1980) to test for differences among microsites with regard to frequency of frost heaving.

Three transects perpendicular to edges of clearings were established in each of 4 clearcuts to determine seed distribution. Each transect contained 30 x 30 cm screen traps located at 25 m intervals and extended completely across clearcuts. Traps were left in place from 1 September to 1 May each year for 3 years. Seeds trapped between 1 September and 1 October and those trapped between 1 October and 1 May were counted separately.

Mechanical control of bluejoint on harvested birch-spruce sites was evaluated by determining browse density on clearcuts scarified by flat dozer blade, clearing rake, disk trencher, or whole-tree logging/skidding. We evaluated the first 3 methods in summer and in fall and the last technique only in summer. Treatment areas were reconnoitered monthly during the growing season to determine when seedlings germinated. We determined density of hardwood regeneration 3 years after treatment by counting stems in systematically placed 1 x 30 m belt plots.

We tested chemical control of bluejoint on harvested birch-spruce sites by treating 1- to 5-year-old clearcuts with glyphosate at 1.6, 3.4, and 5.0 kg/ha, 5.0 kg/ha glyphosate followed by burning, and 5.0 kg/ha glyphosate followed by scarification with disk trencher. Treatments were applied in mid-July 1990 following a randomized block design replicated 4 times; each replication covered 37.2 m^2.

RESULTS AND DISCUSSION

Logging

The best establishment of early successional hardwoods consistently occurred in logged areas with complete or nearly complete overstory removal and soil scarification. Sites which were clear cut and scarified produced an average hardwood seedling density of 18,439 (SE = 14,720) stems/ha. This is consistent with observations that overstory removal and scarification are essential components of natural disturbances—fire, windfall, and fluvial erosion—upon which the boreal forest is dependent for maintenance of early successional vegetation and wildlife habitat (Viereck and Schandelmeier 1980, Zasada *et al.* 1983, Perala 1987). With the exception of aspen sites, clearcuts not scarified either in the logging process or in postlogging site preparation supported only poor establishment of hardwoods by seed($\bar{x}$ = 1,285, SE = 1,947 stems/ha). Non-scarified sites, comprised primarily of aspen, averaged 35,540 (SE = 37,962 stems/ha) if clear cut during dormancy.

Carrying Capacity Modeling

Stem density and years since logging and scarification were strongly correlated, coefficients equaling 0.999, 0.992, and 0.775 for aspen, birch, and willow, respectively. Average stem densities for all 3 species combined best fit a 4th order polynomial (Fig. 1). The equation for the best stocking rate (12,000 stems/ha) was: $y = a+bx+cx^2+dx^3+ex^4$, where a = -62.7, b = 1484.1, c = -72.4, d = 1.2, and e = -0.007. Scaling this function to the 2,750 and 750 stems/ha changed the coefficients to a = -135.06, b = 356.2, c = -17.375, d = 0.29, and e = -0.0016, and a = -36.54, b = 97.04, c = -4.73, d = 0.079, and e = -.0.0004, for fair and poor densities, respectively (Fig. 2).

Integrating the area under each curve resulted in 286,710, 68,814, and 18, 754 stems/ha/80 years. This represents nearly 15.3 times more browse in the forest with good regeneration vs. the forest with poor regeneration. We converted these integrated values to moose days/ha by dividing by 80 years and then by 3,900 stems/day, an average consumption rate expressed in

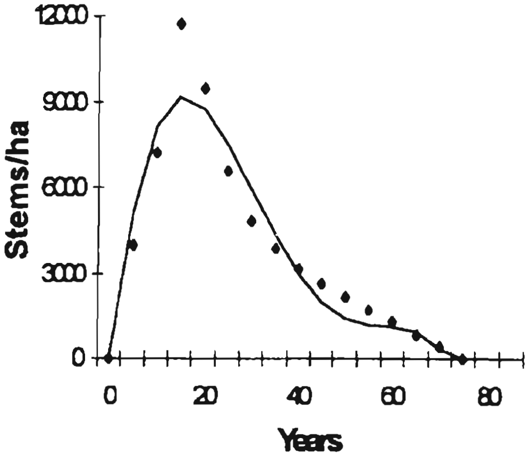

Fig. 1. Fourth order polynomial fit to mean stem density of birch, willow, and aspen. A stem density of 12,000/ha represents a good stocking following logging and ground scarification. Diamonds represent average stem densities used to fit the line.

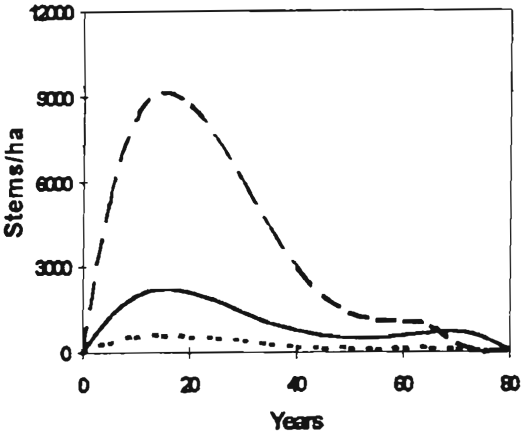

Fig. 2. Generic curves representing average stem densities following good (12,000 stems/ha) fair (2,750 stems/ha) and poor (750 stems/ha) hardwood regeneration after logging of the boreal forest.

stems/day for moose in winter (3,200 - 4,600 stems/day cited by Ricard and Joyal 1984). Values indicate that on the average each year over the 80 year life of the stand that each hectare of forest supported 0.92, 0.22, and 0.06 moose for 1 day. These values are equivalent to forage/moose/km^2 for 100 days (i.e., average winter) since there are 100 ha/km^2. Clearly, scarification and seedling regeneration are important to moose habitat enhancement, where improved carrying capacity is an integral component of forest regeneration and management.

Bluejoint

Bluejoint measured within 2 years following overstory removal by selective cutting or clear-cutting typically showed increases from 150 to 1,350 kg/ha in moist sites and from 700 to over 3,600 kg/ha in wetter sites. This grass developed dense swards and typically grew more than 1 m high by late June. By contrast, hardwood seedlings required 3 years to attain the same height, indicating why successful hardwood seedling establishment was limited primarily to individuals germinating in the absence of grass during first growing seasons following logging. Due to intense competition from bluejoint, hardwood seedling establishment was limited to mounds of mineral soil exposed by naturally upturned root wads, bare soil associated with skid trails and haul roads, or on purposely scarified soil. Overstory retained in selectively cut stands limited light and heat penetration essential for seedling development and hindered operation of machinery used for scarification.

Birch, balsam poplar, birch-spruce and balsam poplar-spruce stands not scarified during or within the first year following clear or selective cutting typically developed a herbaceous disclimax dominated by bluejoint. Above-ground biomass of bluejoint increased from approximately 167 to 1,344 kg/ha in moist sites and from 736 to over 3,600 kg/ha in wet sites. Competitive exclusion by grass and associated herbs was especially evident in stands cut when ground cover was protected by snow. Most birch, balsam poplar, birch-spruce, and balsam poplar-spruce stands not scarified had little or no hardwood seedling establishment and did not meet the reforestation requirement of 1,100 well distributed seedlings or sprouts per hectare specified by Alaska's *Forest Practices Act* (FPA) (11 AAC 95.375).

We observed 1 balsam poplar stand clear-cut in winter which had no hardwood regeneration of any kind after 32 years. Mitchell and Evans (1966) described disclimax bluejoint stands approximately 50 years old. In areas where soils are formed in volcanic ash, presence of Spodosol horizons and partly decayed or burned wood fragments immediately beneath the organic layer indicated maintenance of disclimax for 200 years or more (Simonson and Rieger 1967). Bluejoint contributes to the maintenance of disclimax by shading less competitive species and by developing a dry, decomposing mulch layer 10-20 cm thick which prevents successful seed germination (Mitchell and Evans 1966).

Scarification

Removal of overstory by logging during winter failed to mimic scarification effects of fire or natural uprooting, except on haul roads and principal skid trails. Summer logging, while better in terms of inherent scarification, typically resulted in only patchy distribution of sites favorable to hardwood seedling establishment. In any case, logging eliminated possibility for natural scarification by uprooting because it removed tree boles which otherwise enabled wind and gravity to leverage root wads from the ground. In mesic and dry sites, deliberate, prompt scarification into the soil A-horizon created microsites which favored hardwood seedling establishment. However, we did not find seedlings in wet sites, before or following scarification, except on old stumps and other natural hummocks where soil was not saturated with water.

In mesic sites, scarified patches less than approximately 60 cm wide typically became overtopped by adjacent grass. Soil shaded by grass did not support hardwood seed germination, and grass which overhung planted seedlings enabled snow press damage. Scarification which penetrated the B-horizon resulted in poor seedling nutrition, presumably because it displaced nutrient-rich O- and A-horizon soils into piles.

Availability of ammonia (NH_4), phosphorus (P), and potassium (K) in scarifications properly developed with a clearing blade decreased significantly (ANOVA's, df = 20, 4, $P < 0.0005$, $P < 0.0024$, and $P < 0.0001$ respectively) with increasing distance from edge of scarification (Table 1). NO_3 also appeared to decrease but was not significantly related to distance from edge ($P < 0.518$). Square root (SQRT) of NH_4 and P both decreased in quadratic fashion (R^2's = 0.786 and 0.678, respectively) whereas K decreased in a linear fashion ($R^2 = 0.355$) (Fig. 3). All of the above relationships were observed without blocking for possible site differences. Obviously, each of these soil nutrients was found in greater abundance at the edge of scarified patches where O- and A-horizons were deposited.

Birch height, cover and CAG decreased significantly with increasing distance from edge, but no significant trend for density was observed (Fig. 4).

To test if the concentration of nutrients at edges of scarified patches favors seedling establishment (density) and growth (height and CAG), we applied a stepwise regression procedure (Neter and Wasserman 1974) to determine the best predictors of paper birch height, density and CAG from N, P, and K. Using the natural

Table 1. Mean concentrations (ppm) of phosphorus (P), potassium (K), ammonia (NH_4), and nitrate (NO_3) in upper 10 cm of scarified soil at different distances from edge. Standard deviations are given in parentheses.

Distance (cm) from edge	P	K	NH_4	NO_3
0	6.5 (3.94)	125.7 (50.89)	12.7 (9.69)	2.8 (3.54)
50	3.2 (1.17)	105.5 (45.04)	7.7 (3.72)	1.5 (0.84)
100	3.3 (1.21)	67.5 (42.45)	3.5 (1.97)	1.2 (0.41)
150	2.5 (0.55)	65.5 (21.14)	4.2 (2.79)	1.2 (0.41)
200	3.2 (0.75)	52.0 (19.72)	3.2 (0.75)	1.0 (0.00)

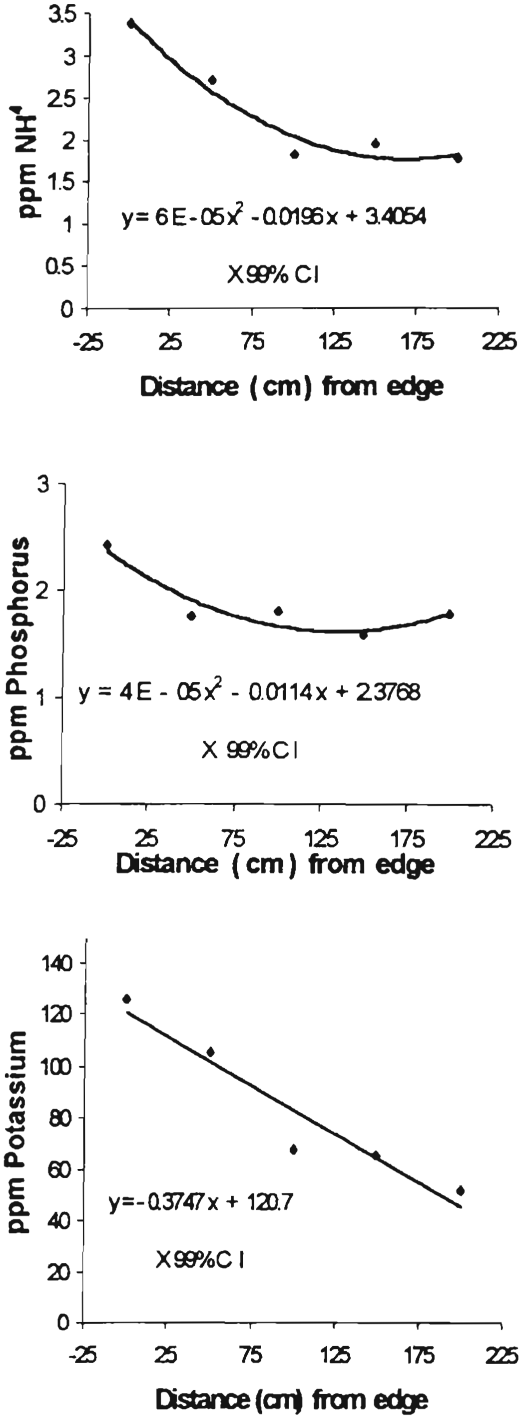

Fig. 3. Distribution of NH_4, phosphorus, and potassium from edge in scarified patch.

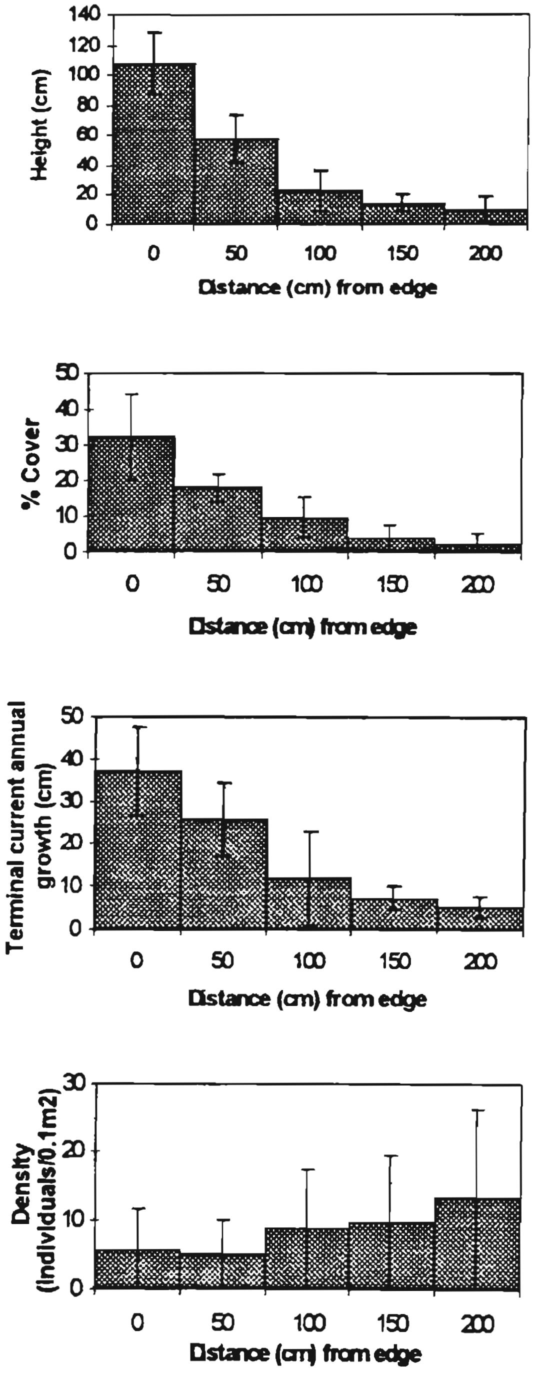

Fig. 4. Height, percent cover, terminal twig growth, and density of 3-year-old paper birch seedlings in scarified patches.

log of height, K was the only significant predictor of height ($P < 0.05$). The best predictive model was: $\ln(\text{birch height}) = 2.090054 + 0.014061 \times \text{potassium}$ ($R^2 = 0.3468$). Likewise, using the natural log of CAG, K was the only significant predictor of CAG. The best predictive model was: $\ln(\text{CAG}) = 1.475102 + 0.012223 \times \text{potassium}$ ($R^2 = 0.3751$.).

At $\propto = 0.05$, none of the variables were significant predictors of paper birch density, suggesting that soil macronutrients are poor indicators of density or that other factors interact in the initial establishment of seedlings. However, relatively low predictive values of the above models do not lessen the importance of fertility to seedling vigor in scarified soil. Seedlings found in central portions of large scarified patches showed definite signs of poor nutrition compared to those at edges. Nevertheless, intraspecific competition among the more quickly growing seedlings at edges, combined with competition from herbaceous species immediately adjacent to scarification, may have reduced birch density near edges, masking any nutrition-related differences between edge and center.

Levels of ammonia and potassium within scarified patches remained high within 50 cm of edge, whereas phosphorus changed less with increasing distance from edge. Paper birch is particularly sensitive to P availability (Perala 1987), and any change in availability at the already low levels characteristic of Alaska soils is significant with regard to its regeneration. Phosphorus is important to development of birch roots (Hoyle 1965, 1969). Nitrogen is the second most limiting element for birch. Both limited and excessive N can reduce seedling growth (Ingestad 1977). These observations suggest that widths of scarification patches ideally should not exceed the 1- or 2-year length potential of new seedling roots, so that nutrients in displaced O- or A-horizon soils are available early in seedling development. We have observed that roots of most birch and willow seedlings extended laterally at least 30 cm by the end of their second year.

Humus, woody debris and other decaying plant materials should be incorporated into wider patches, not only as sources of nutrients, but also for moisture retention and amelioration of microclimate (Perala 1987). This practice improves nutrition, surface thermal and moisture characteristics, and possibly soil:plant mychorrizae relationships. We agree with the observations of Perala (1987) that most seedlings occurred on mineral soil, but that fastest growth occurred in seedlings established in close association with woody debris or other organic matter.

In practice it is difficult to expose A-horizon soil by stripping away overlying humus, because bluejoint rhizomes and other vegetation typically binds the two together. Consequently, some patches of B-horizon are unavoidably exposed, particularly if the grass has had a season or two to increase following logging. This is not necessarily a problem if nutrient-rich organic materials and associated micro-climatic effects are within the 2-year reach of seedling roots.

Relatively few birch seeds germinated in scarified patches more than 1 year following treatment, the reason apparently being twofold. First, the porous and open characteristic of scarified soils immediately began to "heal" as the soil became compacted by rain, covered by litter, and revegetated by mosses and competing herbaceous vegetation, greatly reducing the availability of microsites supportive of seedling establishment. Secondly, viability of residual seeds declined sharply after the first year, and seeds blown into a site following cutting experienced a rapid decrease with distance from source (Fig.5). Considering that September seedfall supplied ap-

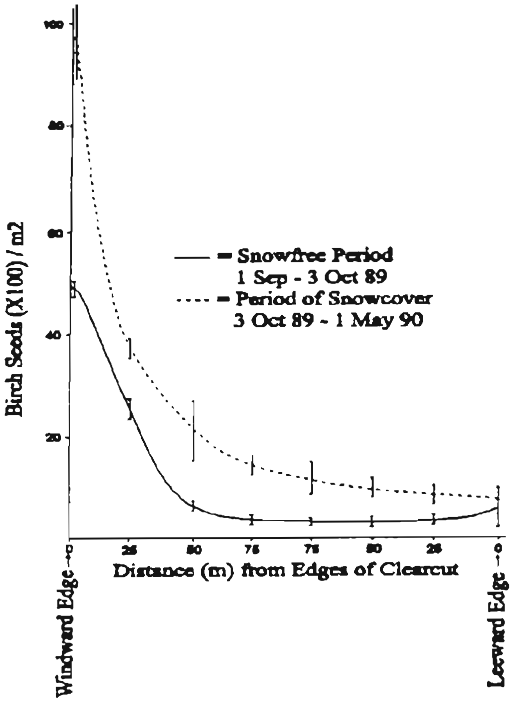

Fig. 5. Birch seed distribution into clear-cut openings of birch-spruce forest.

proximately 1,800 seeds/m^2 30 m from trees, and assuming that this seedfall was the most viable of the annual seedfall (Perala 1987), the practical seeding distance of paper birch in Alaska was approximately 30 m and equivalent to that observed elsewhere (Perala 1987). For these reasons, approximately 15 seedtrees per hectare should be retained to continue providing viable seeds to take advantage of subsequent, albeit reduced, germination opportunities, and scarification should be completed within 1 year of cutting, prior to or during the period of heaviest seed dispersal (approximately 1 September through 30 October).

Scarification to stimulate hardwood seedling establishment yielded poorest results when done by flat dozer blade ($\bar{x}$ = 3,383, SE = 1,405), because it typically exposed wide patches of B-horizon and displaced most nutrient-rich O- and A-horizon into piles where they were not readily available to those seedlings which did establish on scarified patches. Scarification by clearing blade displaced much less O- and A-horizon into piles and resulted in greater seedling densities and faster rates of growth ($\bar{x}$ = 11,857, SE = 6,363). However, scarification by clearing blade more than 1 year after overstory removal produced poor results, because, by then, bluejoint roots had consolidated A-horizon soil, making it virtually impossible to scarify without displacing that nutrient source into piles.

Exposure of large patches of B-horizon by any method was detrimental to seedling establishment, because that soil was also more frost active, causing root damage and/or ejection of new seedlings from the ground where the microsite was not protected by vegetation. Most seedlings occurring in exposed B-horizon had twisted taproots and elevated root crowns. Frost heaving of pegs was not significantly different (χ^2 = 3.021, 1 df, P = 0.2483) between moss and grass covered sites. Frost heaving in A-horizon (9.1% of pegs heaved) was significantly different (χ^2 = 30.84, 1 df, P = 0.0000) from combined moss and grass sites (0.68% of pegs heaved). Frost heaving between A-horizon and B-horizon microsites was significantly different (χ^2 = 122.4, 1 df, P = 0.0000). The B-horizon heaved 5 times (42% of pegs heaved) more pegs than A-horizon.

Scarification by disk trencher produced results similar to those produced by careful use of clearing blade, but without the risk of severe displacement of nutrient rich soils. Once a disk trencher was adjusted for specific site conditions, it did not require operator attention or effort to maintain proper depth of scarification, making it ecologically safer to employ than clearing or flat blades. The disk trencher produced a great variety of microsites for hardwood seeds to find optimum conditions for germination and survival. However, delay of disk trenching more than 1 year after timber harvest typically was ineffective, because increased grass production and root mass accumulated in front of disks decreasing or preventing their penetration into soil. When used in a timely manner, effective scarification by disk trenching required 2-3 overlapping passes of the implement and approximately the same amount of time as scarification with a clearing blade.

Of those forms of timber harvest producing their own scarification, whole-tree logging during snow-free seasons was most effective. This is a form of clear-cutting, its unique feature being that dozers are used to uproot and skid trees to decking sites where stumps and limbs are removed. The processes of uprooting and dragging trees with protruding appendages produces extensive scarification. On mesic and dry sites, whole-tree logging appeared to be more effective than flat blades but was less effective than clearing blades. In terms of scarification it was about as effective as the clearing blade, but our observations of this scarification were limited to only 3 stands. Whole-tree logging had the distinct advantages that scarification was automatically completed in a timely fashion and could be accomplished without additional costs to logging.

Clearing and scarification by chaining (Vallentine 1971) was not as effective as any of the foregoing methods because downed trees kept chains from adequately contacting soil. Furthermore, the resultant jumble of trees was unattractive and dangerous to firewood cutters who retrieved the downed timber.

No form of scarification was effective on wet sites because bluejoint was well established prior to clearing and readily monopolized sites following timber harvest and/or scarification. Furthermore, use of machinery on wet sites was limited to winter when ground was frozen and capable of supporting machinery, conditions which do not occur every winter or in all wet sites within the study area. We did observe birch and willow establishment on drier mounds and rotting stumps, however, indicating that mounding and/or increased soil drainage would facilitate seedling establishment (Helm and Collins 1997, Beatty and Stone 1986).

Chemical site preparation

All 3 rates of glyphosate application resulted in 100% kill of bluejoint and all tall forbs and shrubs. Some moss and dogwood (*Cornus canadensis*) were protected from killing exposure to the herbicide by dense overhanging grass. Treatment differences in birch seed germination remained unchanged 4 years after treatment (Table 2), as there was no additional hardwood establishment in "herbicide-only" plots.

Birch seeds did not germinate in herbicide/disk plots until late July 1991. Bluejoint seeds began germinating at the same time, but they only grew 8-16 cm high before the end of the growing season and apparently did not compete with birch seedlings during their first year.

On wet sites, dense bluejoint residue continued to block re-establishment of bluejoint and other herbaceous species 4 years after treatment. While dense accumulation of killed bluejoint was effective in reducing competition with planted trees, it did not support natural regeneration by hardwoods, since bare ground was not exposed.

Fire did not penetrate the organic mat to mineral soil in sites treated with glyphosate because fuels left after logging were inadequate to support fire of adequate duration. Consequently, herbicide kill followed by burning was no more effective in supporting hardwood seed germination than was herbicide treatment alone.

Scarification of sites treated with

Table 2. Differences in birch seed germination under different site preparation treatments. Contrasts are based on a MSE of 3.772 with 41 df.

Contrast	df	MS	F	P
Low vs High Conc. Herb.	1	0.0	0.00	1.0000
Med. vs High Conc. Herb.	1	0.0	0.00	1.0000
High Herb. vs High Herb/Disk	1	1600.0	424.2	0.0001
High Herb. vs High Herb/Burn	1	0.0	0.00	1.0000
High Herb/Disk vs Disk	1	480.0	127.26	0.0001

glyphosate allowed establishment of hardwoods by seed, but also enhanced germination of residual bluejoint seed, allowing renewed dominance of the grass within 2 - 3 years. Consequently, opportunity for hardwood seedling establishment was limited to the growing season immediately following scarification. Timely scarification without glyphosate pre-treatment produced essentially the same opportunity of hardwood seedling establishment, but without the cost of herbicide treatment. Neither treatment was effective in wet sites.

MANAGEMENT RECOMMENDATIONS

The following recommendations are designed to enhance early successional moose habitat in hardwood and mixed spruce-hardwood stands in Alaska. These guidelines mutually benefit reforestation through enhanced hardwood regeneration and lessened the probability that individual hardwoods will be damaged or stunted by browsing.

(1) Clear-cutting, including personal use firewood cutting, should not be attempted without specification of site-specific requirements and guaranteed funds for post-logging site preparation and reforestation. Without site-specific reforestation effort, hardwood regeneration may not be sufficient to meet FPA guidelines and certainly will fail to meet potential browse and related wildlife habitat values. Furthermore, restocking of cutover areas at minimal FPA densities often appears inadequate, even from a forest management perspective, when poor spacing, poor form or browsing damage limit quantity and quality of regeneration.

(2) Before timber sales are advertised for bid, a preharvest inventory should be conducted to ensure that appropriate site-specific guidelines can be prescribed and employed. This inventory should minimally include the following information: basal area and density of trees by species and by height class, understory cover by dominant shrubs and herbaceous species, and general description of soils and topographic features. Such inventory will also facilitate research development of appropriate habitat/forest management practices.

(3) To improve understanding of harvest/scarification results, histories of timber harvests should be recorded. This should include mapped location and layout, total size, dates and methods of harvest, slash disposal/accumulation, and prevailing weather and soil conditions during harvest.

(4) Site preparation should be described in terms of method, date, percent coverage by each exposed soil horizon, and prevailing soil conditions (moisture, frost). Information on seed availability is useful for evalu-

ation of site preparation methods and resultant regeneration.

(5) All clear-cutting (including personal-use firewood cutting) and scarification or other site preparations should be completed within 1 year to take advantage of stored seed, to ensure optimal synchronization with seed fall, and to reduce the lag period in which competing grass cover has time to monopolize sites. Consequently, geographic units of actual cutting (whether they are complete cutting units or portions thereof) should not exceed that size for which the harvester is capable of completing site preparations within 1 year of cutting.

(6) "Selective" cutting should not be conducted unless immediately followed by firewood cutting or some other means of essentially removing all overstory except seed trees.

(7) Aspen harvests should encompass entire clones to ensure maximum release of root sprouts.

(8) All aspen stems exceeding 1.5 m height should be cut to ensure that dormant buds within clonal root systems are released for root sprouting.

(9) Aspen sites should only be harvested during tree dormancy to ensure maximum root reserves for resprouting.

(10) All aspen occurring in clear-cut stands of predominately birch or spruce should be felled, regardless if they have a market. This minimal effort more efficiently and reliably enhances moose habitat than any other single practice.

(11) Balsam poplar and cottonwood should be clear-cut during dormancy to ensure maximum stump and root sprouting.

(12) Sites having soils and understory vegetation indicative of poor drainage or high water table should not be harvested unless appropriate site preparation techniques have been demonstrated for those conditions.

(13) All downed stems greater than 10 cm diameter should be piled or removed from sites in order to allow efficient scarification.

(14) All stems smaller than 10 cm diameter should be scattered for eventual incorporation into soil by scarification and decomposition.

(15) Stumps should not exceed heights which will impede operation of scarification equipment.

(16) A sufficient number of well distributed birch seed trees should be retained in clear-cuts at least until regeneration objectives have been met. In most cases, 15 well-formed birch trees per hectare provides an adequate seed source. Left uncut, the trees will add to the structural diversity of the site, enhance bird habitat, and eventually become material for cavity nesting birds and small mammals. Seed-tree groups represent an attractive alternative to scattered individual seed trees. Retention of groups rather than individuals reduces seed tree mortality commonly caused by sudden crown exposure, root or bole damage by logging, and wind throw.

(17) Tall shrub or tree-sized willows should be left intact for seed and browse production wherever they do not impede logging. Tipping or crushing by logging activities is not necessarily harmful as long as the willows are not completely uprooted.

(18) When contracts to cut hardwoods are advertised for bid, they should include performance clauses requiring scarification of 50 - 60 % of the site according to the following specifications:

(a) Scarification should remove O-horizon material from patches or strips, leaving displaced organics distributed as uniformly as possible among strips or patches. Distribution of these nutrient-rich materials should not be limited by pushing them into large piles. This means that equipment must be operated at the shallowest depth which will allow displacement of O-horizon without excessive displacement of A-horizon. Patches or strips of B-horizon which unavoidably become exposed should not exceed 1.5 m width.

(b) All harvested sites must be scarified within 1 year of harvest, when snow will not hamper scarification and when soils are dry or frozen enough to support equipment without becoming compacted.

(c) Unless better methods or equipment are identified, scarification should be done by disk trencher, by whole-tree logging in summer, or by clearing blade. Use of the clearing blade should be limited to skilled operators who will maintain proper scarification depth.

(d) Tall willows should not be completely uprooted by scarification.

(e) Swales, potholes, or other treeless sites occurring as inclusions within the cutting unit should not be scarified or included in the determination of percent coverage by scarification.

(f) Operators of scarification equipment should be trained to comply with scarification guidelines. Improper scarification can seriously retard site recovery.

(19) Requirements outlined in timber harvest contracts should be closely monitored to ensure that successful bidders comply with stipulations concerning times and methods of cutting, site cleanup, and scarification procedures. Slack enforcement of requirements not only allows damage to the resource and future productivity, but it diminishes the credibility of resource managers, leading to reduction of future use and management opportunities.

(20) Sale requirements and specifications must also address the short and long-term implications of temporary and permanent roads to fisheries and wildlife, especially species vulnerable to increased disturbance or hunting pressure.

ACKNOWLEDGEMENTS

We would like to thank K. B. Schneider for initial assistance with program development and procurement of project funding. We thank J. Hansen, A. Collins, E. Collins, and M. Collins for field assistance. We also thank E. F. Becker for providing statistical advice. This project was a contribution of Federal Aid in Wildlife Restoration Projects W-23-5, W-24-1, W-24-2, and W-24-3.

REFERENCES

AHLGREN, C. E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. Ecology 41:431-445.

ALDRIDGE, J. W. C. 1967. The durability of scarified seedbeds for spruce regeneration. B. C. For. Serv. Res. Note 42. 20 pp.

APPELROTH, S-E. 1981. Latest developments in site preparation in Finland. Paper No. 7-32, Symp. Engineering Systems For. Regen. Am. Soc. Agric. Engineers, Raleigh, North Carolina. 8 p.

ARGUS, G. W. 1978. The genus *Salix* in Alaska and the Yukon. Publ. Bot. No. 2. Nat. Museum Nat. Sci., Ottawa, Canada. 192 pp.

BEATTY, S. W. and E. L. STONE. 1986. The variety of soil microsites created by tree falls. Can. J. For. Res. 16:539-548.

BJORKBORN, J. C. 1971. Production and germination of paper birch seed and its dispersal into a forest opening. USDA For. Serv. Res. Pap. NE-209. Northeast For. Exp. Sta., Upper Darby, PA. 14 pp.

BLACKMORE, D. G. and W. G. CORNS. 1979. Lodgepole pine and white spruce establishment after glyphosate and fertilizer treatments of grassy cutover forest land. For. Chron. 55:102-105.

BLISS, L. C., editor. 1973. Botanical Studies of Natural and Man-modified

Habitats in the MacKenzie Valley, Eastern MacKenzie Delta Region and Arctic Islands. Rep. No. 73-43. Environmental-Social Committee, Northern Pipelines Task Force on Northern Oil Development.

CEDERLUND, G. and G. MARKGREN. 1987. The development of the Swedish moose population. Swedish Wildl. Res. Suppl. 1:55-62.

COATES, D. and S. HAEUSSLER. 1987. A guide to the use of mechanical site preparation equipment in north central British Columbia. B. C. Ministry of Forest and Lands, Government of Canada, British Columbia. 64 pp.

CONN, J. S. 1990. Seed viability and dormancy of 17 weed species after burial for 4.7 years in Alaska. Weed Sci. 38:134-138.

CROUCH, G. L. 1986. Effects of thinning pole-sized lodgepole pine on understory vegetation and large herbivore activity in central Colorado. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Res. Pap. 268.

DANIEL, T. W., J. A. HELMS, and F. S. BAKER. 1979. Principles of Sylviculture. McGraw-Hill. 500 pp.

DENSMORE, R. V. 1988. Regeneration of paper birch and willow following scarification of logged areas in southcentral Alaska. Unpubl. Report, Inst. Northern Forestry, U.S. For. Serv. Fairbanks, Alaska. 21 pp.

FRANZMANN, A. W. 1978. Moose. Pages 67-81. *in* J. L Schmidt and D. L. Gilbert (eds.) Big Game of North America, ecology and management. Stackpole Books, Harrisburg, PA.

GREGORY, R. A. and P. M. HAACK. 1965. Growth and yield of well-stocked aspen and birch stands in Alaska. Res. Pap. NOR-2, USDA For. Serv., Northern For. Exp. Sta. Juneau, Alaska. 28 pp.

HAMILTON, C. D., P. D. DRYSDALE, and D. EULER. 1980. Moose winter browsing patterns in northern Ontario. Can. J. Zool. 58:1412-1416.

HEILMAN, P. E. 1968. Relationship of availability of phosphorus and cations to forest succession and bog formation in interior Alaska. Ecology. 49:331-336.

HELM, D. J. and W. B. COLLINS. 1997. Vegetation succession and disturbance on boreal forest floodplain. Can. Field-Nat. 111:553-566.

HERNANDEZ, H. 1972. Surficial disturbance and natural plant recolonization in the Tuktoyaktuk Peninsula Region, N.W.T. M. S. Thesis, Univ. Alberta, Edmonton.

HOGG, E. H. and V. J. LIEFFERS. 1991. Seasonal changes in shoot regrowth potential in *Calamagrostis canadensis*. Oecologia 85:596-602.

HOYLE, M. C. 1965. Addition of phosphorus to subsoil promotes root development of yellow birch. USDA For. Serv., Northeast For. Range Exp. Sta., Res. Note NE-42. 7 pp.

______. 1969. Response of yellow birch in acid subsoil to macronutrient additions. Soil Sci. 108:354-358.

INGESTAD, T. 1977. Nitrogen and plant growth; maximum efficiency of nitrogen fertilizers. Ambio 6:146-151.

JANNSON, P. E. 1987. Simulated soil temperature and moisture at a clearcutting in central Sweden. Scand. J. For. Res. 2:127-140.

KELSALL, J. P., E. S. TELFER, and T. D. WRIGHT. 1977. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian north: a review and selected bibliography. Can. Wildl. Serv. Occasional Pap. No. 32. Ottawa, Ontario. 58 pp.

LAUGHLIN, W. M. 1969. N. P. K. influence on yield and chemical composition of bluejoint forage. Agronomy J.

61:961-964.

LAUTENSCHLAGER, R. A., H. S. CRAWFORD, M. R. STOKES, and T. L. STONE. 1997. Forest disturbance type differentially affects seasonal moose forage. Alces 33:49-73.

LERESCHE, R. E., R. H. BISHOP, and J. W. COADY. 1975. Distribution and habitats of moose in Alaska. Naturaliste can. 101:143-178.

LIEFFERS, V. J., S. E. MACDONALD, and E. H. HOGG. 1993. Ecology and control strategies for *Calamagrostis canadensis* in boreal forest sites. Can. J. For. Res. 23:2070-2077.

______ and K. J. STADT. 1993. Growth of understory *Picea glauca, Calamagrostis canadensis,* and *Epilobium angustifolium* in relation to overstory light transmission. Can. J. For. Res. 24:1193-1198.

LORANGER, A. J., T. N. BAILEY, and W. W. LARNED. 1991. Effects of forest succession after fire in moose wintering habitats on the Kenai Peninsula, Alaska. Alces 27:100-109.

LYKKE, J. and I. M. COWAN. 1968. Moose management and population dynamics on the Scandinavian Peninsula, with special reference to Norway. Proc. N. Am. Moose Conf. Workshop 5:1-22.

MACDONALD, S. E. and V. J. LIEFFERS. 1993. Rhizome plasticity and clonal foraging of *Calamagrostis canadensis* in response to habitat heterogeneity. J. Ecol. 81:769-776.

MARGOLIS, H. A. and D. G. BRAND. 1990. An ecophysiological basis for understanding plantation establishment. Can. J. For. Res. 20:375-390.

MCKENDRICK, J. D. 1983. Alaska's rangelands. Pages 125-156 *in* H. L. McNicholas (ed.) Alaska's Agriculture and Forestry. Alaska Rural Development Council, Pub. No. 3. Univ. Alaska, Fairbanks. 220 pp.

______. 1984. Range management boreal zone Alaska. Cooperative Extension Service Bull. A-00145. Univ. Alaska, Fairbanks. 14 pp.

MCNICOL, J. C. and F. F. GILBERT. 1980. Late winter use of upland cutovers by moose. J. Wildl. Manage. 44:363-371.

MITCHELL, W. W. 1968. Taxonomy, variation, and chronology of three chromosome races of the *Calamagrostis canadensis* complex in Alaska. Madronon 19:235-245.

______ and J. EVANS. 1966. Composition of two disclimax bluejoint stands in southcentral Alaska. J. Range Manage. 19:65-68.

MUELLER, D. and H. P. SIMS. 1966. Response of three grasses to two soils and a water table depth gradient. Ecology 47:644-648.

MURPHY, D. A. and J. H. EHRENREICH. 1965. Effects of timber harvest and stand improvement on forage production. Missouri Fed. Aid Rep., W-013-R 29/4/734-749.

NETER, J. and W. WASSERMAN. 1974. Applied linear statistical models. Irwin Inc., Homewood, IL. 842 p.

NEU, C. L., C. R. BYERS, and J. M. PEEK. 1974. A technical analysis of utilization-availability data. J. Wildl. Manage. 38:541-545.

OLDEMEYER, J. L. 1977. Impact of LeTourneau tree crushers on moose habitat on the Kenai National Moose Range. 28th Annual Conference, Northwest Section of The Wildlife Society, Feb 17-18, 1977, Kalispell, MT.

______ and W. L. REGELIN. 1980. Response of vegetation to tree crushing in Alaska. Proc. N. Am. Moose Conf. Workshop 16:429-443.

______ and ______. 1987. Forest succession, habitat management, and moose on the Kenai National Wildlife Refuge.

Swedish Wildl. Res. Suppl. 1:163-180.

ORLANDER, G., P. GEMMEL, and J. HUNT. 1990. Site preparation: a Swedish overview. B.C. Ministry of Forests and Lands, Victoria. FRDA Rep. 105.

PEEK, J. M., D. L. URICH, and R. J. MACKIE. 1976. Moose habitat selection and relationships to forest management in northeastern Minnesota. Wildl. Monogr. 48. 65 pp.

PERALA, D. A. 1987. Regenerating birches: ecology and cultural requirements. Ph.D. Dissertation, Univ. Minn. 215 pp.

PETERSON, R. L. 1955. North American Moose. Univ. Toronto Press, Toronto. 280 pp.

POWELSON, R. A. and V. J. LIEFFERS. 1991. Growth of dormant buds on severed rhizomes of *Calamagrostis canadensis*. Can. J. Plant Sci. 71:1093-1099.

RENECKER, L. A. and R. J. HUDSON. 1986. Seasonal energy expenditures and thermoregulatory responses of moose. Can. J. Zool. 64:322-327.

RICARD, JEAN-GUY and R. JOYAL. 1984. Technique pour calculer la biomasse ingeree quotidiennement en Hiver par l-orignal en Liberte. Alces 20:245-258

SAFFORD, L. O. 1983. Silvicultural guide for paper birch in the Northeast (revised). U.S. Dept. Agric, For. Serv., Northeastern For. Exp. Sta. Broomall, PA. Res. Pap. NE-535. 29 pp.

SCHWAB, F. E. and M. D. PITT. 1991. Moose selection of canopy cover types related to operative temperature, forage, and snow depth. Can. J. Zool. 69:3071-3077.

SIMONSON, R. W. and S. RIEGER. 1967. Soils of the Andept suborder in Alaska. Soil Sci Soc. Amer. Proc. 31:692-699.

SNEDECOR, G. W. and W. G. COCHRAN. 1980. Statistical Methods. Seventh ed. The Iowa State University Press, Ames, IA. 507 pp.

STELFOX, J. G., G. M. LYNCH, and J. R. McGILLIS. 1976. Effects of clearcut logging on wild ungulates in the central Albertan foothills. For. Chron. 52:65 - 70.

STONE, T. L. 1977. Production and utilization by deer and moose of woody and herbaceous vegetation on areas commercially clearcut in northern Maine. M.S. Thesis, Univ. Maine, Orono. 52 pp.

TEIKMANIS, A. 1956. Om den naturligaforyngringen efter markberedningar I Norrland. Norrlands SkogsvForb. Tidsdr. 3:385-442

THORSEN, A., editor. 1978. Scarification. Forskningsstiftelsen Skogsarbeten. Tryckeri AB Knappen, Karlstad.

TODESCO, C. J., H. G. CUMMING, and J. G. MCNICOL. 1985. Winter moose utilization of alternate strip cuts and clearcuts in northwestern Ontario: Preliminary results. Alces 21:447-474.

TOLMOCHEV, A. I., editor. 1964. The Flora of the USSR II. Graminae. Moscow. 172 pp.

VALLENTINE, J. F. 1971. Range Developments and Improvements. Brigham Young Univ. Press, Provo, UT. 516 pp.

VAN CLEVE, K. and C. T. DYRNESS. 1983. Effects of forest floor disturbance on soil-solution nutrient composition in a black spruce ecosystem. Can. J. For. Res. 13:894-902.

VIERECK, L. A. and L. A. SCHANDELMEIER. 1980. Effects of fire in Alaska and adjacent Canada - a literature review. Bur. Land Manage. Tech.Rep. 6. 124 pp.

WILM, H. G. D. F. COSTELLO, and G. E. KLIPPLE. 1944. Estimating forage yield by the double-sampling method. J. Am. Soc. Agron. 36:194-203.

ZASADA, J. C. and R. A. GREGORY.

1972. Paper birch seed production in the Tanana Valley, Alaska. USDA For. Serv. Res. Note, PNW-177. Inst. Northern Forestry. 7 pp.

______, K. VAN CLEVE, R. A. WERNER, J. A. MCQUEEN, and E. NYLAND. 1977. Forest biology and management in high-latitude North American forests. Pages 137-195 *in* M. Murray and R. M VanVeldhuizen (eds.) Symposium Proceedings, North American Forest Lands at Latitudes North of 60 Degrees. Univ. Alaska, Fairbanks.

______, R. M. VAN VELDHUIZEN, and C. E. TEUTSCH. 1983. Artificial regeneration of trees and tall shrubs in experimentally burned upland black spruce/feather moss stands in Alaska. Can. J. For. Res. 13:903-913.