DEVELOPING SILVICULTURAL ALTERNATIVES FOR THE BOREAL FOREST

AN ALASKAN PERSPECTIVE ON REGENERATION OF WHITE SPRUCE

John Zasada

Forestry Sciences Laboratory
USDA Forest Service
Corvallis, Oregon

Forest Industry Lecturer

Forest Industry Lecture Series
Forestry Program
Faculty of Agriculture & Forestry
University of Alberta

7 November 1990

FOREST INDUSTRY LECTURE SERIES NO. 25

Shelterwood in 170-year-old white spruce located on an upland site in Bonanza Creek Experimental Forest near Fairbanks, Alaska.

SPONSORS

We would like to take this opportunity to express our thanks again to the sponsors of this 1990 program. We appreciate very much their willing and sustained support:

Alberta Forest Products Association — Edmonton
Blue Ridge Lumber (1981) Ltd. — Whitecourt
Canadian Forest Products Ltd. — Grande Prairie
Forestry Canada — Northern Forestry Centre — Edmonton
Grande Cache Forest Products Ltd. — Grande Cache
Procter & Gamble Cellulose Ltd. — Grande Prairie
Rocky Mountain Section — Canadian Institute *of* Forestry
Silvacom, Forestry Consultants — Edmonton
Weldwood *of* Canada Limited — Hinton Division
Weyerhaeuser Canada Ltd. — Saskatchewan Division
Alberta Forestry, Lands & Wildlife — Edmonton

JOHN ZASADA

Dr. John Zasada is a research silviculturist at the Pacific Northwest Research Station, Corvallis, Oregon.

Dr. Zasada received his BA at Macalester College in 1960, his MF degree from Yale University in 1962 and his Ph.D. from the University of Michigan in 1968. His first position (1961-65) was at the Tongass National Forest in Alaska and after completion of his Ph.D., he worked for the USDA Forest Service in Fairbanks until 1985 and then transferred to Oregon. He has travelled widely and studied population ecology with John Harper in the University College in North Wales.

Dr. Zasada is well known for his work on the silvicultural systems of the boreal forest. His pioneering work on the development of alternative practices for the regeneration of white spruce has made a major contribution to our understanding of mixedwood systems. He is also well known for his research on reproduction ecology and population biology of trees and shrubs in boreal systems, seed germination processes, aspen clonal reproduction and effects of silvicultural practices on animal populations. His present work is on the reproductive ecology and population biology of broadleaved trees and shrubs in the Oregon Coastal Range and development of non-chemical management alternatives.

We are pleased that Dr. Zasada could spend some time with us at the University of Alberta.

OPENING COMMENTS

I am pleased to talk with you today for several reasons. First, during my years in Alaska and Oregon, I became acquainted with many Canadians and being able to come to Canada and renew those acquaintances is a pleasure. In fact, our family spent a year posing as Canadians. We lived in Wales for a year, and whenever anyone asked us where we were from, we would say, with great pride, "Alaska!" — expecting immediate ooh's and aah's! Instead, the questioner would usually think for a minute as they recalled where Alaska was in relation to the rest of the world (attached to northwestern Canada, of course!) and respond with something like "Oh, you're Canadian" and proceed to tell us that they knew someone who had moved to Canada and was doing famously. At first, we vigorously denied we were Canadians and gave a minicourse on the geography of North America. Eventually, though, we accepted that we were Canadians and welcomed the good cheer that came with it!

A second reason I am happy to be here is that I grew up in northern Minnesota, about as close as to the boreal forest as one can get in the lower 48 — as Alaskans refer to the 48 contiguous smaller states — and spent almost 20 years in Alaska working, living, and raising a family in the boreal forest. My concept of what a forest is and my view of forestry developed in the boreal forest and I am happy to be able to talk about it with you. As indicated, I have been working in western Oregon for the past 5 years. During that time, I have had a chance to reflect on my view of forestry in the boreal region and relate it to forestry in Oregon and Washington. Thus, what I will talk about today is a view of silviculture and forestry in the "North" that has been influenced by recent experiences in the lower 48.

Having worked both in the land of the "big trees" and the boreal forest, I am compelled to comment briefly on the large section of a Douglas-fir so prominently displayed outside of your Dean's office. It is an impressive section and certainly must catch the Dean's attention every day. But I question that it makes a statement of any importance about Alberta's forests and particularly the boreal forest. The boreal forests of Alberta have wonderful and unique qualities of their own and, in my view, these qualities should be touted in a display in the Forestry-Agriculture building at the University of Alberta and not the growth of a coastal Douglas-fir!

There are many friend° and colleagues who have helped to shape my view of the boreal forest. I would like to acknowledge all of them for their patience and willingness to share their knowledge and experiences with me. Some who have been

particularly influential over the years — Marie and Zig Zasada, Harold Lutz, Les Viereck, John Manthei, Dean Argyle, Tony Gasbarro, Bonita Neiland, Roseann Densmore, Trish Wurtz, Alf Madson, Teri Viereck, and Jon, Inga, and Emilie Zasada. I would also like to acknowledge Andy Youngblood for his efforts to continue the studies on silvicultural alternatives that were initiated during my years in Alaska, and John Tappeiner for many fruitful discussions on the philosophy and practice of silviculture. These friends have helped me to realize that there are many values to life in the boreal forest and that we need to be conscious of all of them when we propose land use and development in the region. They believe, as I do, that the boreal forest is a special place and not simply a place to extract resources and move on.

I would also like to thank the Department of Forest Science for the opportunity to participate in this lecture series. The hospitality and reception by Faculty and students was greatly appreciated. Special thanks to Darlene Saunders for preparing my manuscript for publication.

INTRODUCTION

These are challenging, exciting, interesting, and frustrating times in forestry, as in other areas of renewable resource management. Challenging because with increasing population more wood and fiber must be produced from a shrinking land base. Exciting because of the growing realization that trees and forests are important in their own right and that they need to be grown and nurtured to sustain life on the planet, as well as for the more tangible products derived from them. Interesting because foresters are being asked to be creative in developing alternatives for managing forests. Interesting, too, because of the potential for products of tree improvement and genetic engineering programs, and new technology to be incorporated into new silvicultural systems which can help to solve some production and environmental problems. Frustrating because we are constantly being challenged to explain why we are managing lands the way we are. Frustrating, too, because our successes are often ignored and because the use of some important tools is being limited so we must shift to new methods that are less familiar and efficient.

The possibility that these pressures and conflicts will disappear soon is remote. The question seems to be "Can we satisfy the short- and long-term demands for diverse products and yet maintain a broad range of ecological conditions and future options?" There are obviously many views on how to achieve balanced use of the available forest lands. It is more apparent everyday that there are no simple answers — no magic bullets. What is needed are a variety of alternatives that include the present alternatives and a way of improving these as new information becomes available and the development of methods based on new ideas and technology.

The boreal forest is comprised of many conifer and hardwood species. One of the more difficult forest management concerns has been the regeneration of white spruce (Picea glauca) following harvesting of the extensive mixed conifer and mixed conifer-hardwood stands located in western Canada and Alaska. This paper generally describes research conducted in Alaska over about a 20-year period regarding the regeneration of white spruce and the development and testing of alternatives for natural and artificial regeneration. For a more detailed description of this work refer to the publications listed at the end of the paper.

SILVICULTURAL SYSTEMS AND ALTERNATIVES

Silvicultural systems are often viewed by foresters as the set of alternatives or practices used to grow trees for the production of wood for various uses. The description of silviculture I prefer is given by Smith (1962):

> "Silviculture is normally directed at the creation and maintenance of the kind of forest that will best fulfil the objectives of the owner. Returns from silviculture are generally thought of in terms of timber production, although it is not uncommon for owners to have other goals. The growing of wood may, in fact, have low priority among these objectives or none at all. The essential thing is that the objectives should be clearly defined and the treatment shaped to their attainment."

Key concerns in developing silvicultural alternatives are that the total cycle of forest development (a rotation or even more than one rotation) be considered and not just a portion of it, and that silvicultural methods can be used to produce a desired forest condition and not just harvestable wood. This means that, to the extent possible, we must be aware of how practices during one stage of forest development affect later development, or how practices during one rotation affect subsequent rotations. For example, much of silvicultural practice and planning in the North American boreal forest has been directed at final harvest and stand replacement. Although it goes almost without saying that we must look at these practices primarily as they affect later stand and forest development, and not as an end in themselves, we often lose sight of this reality.

The selection of appropriate silvicultural practices depends on many factors. We normally think only of the immediate concerns such as species composition, site conditions, and the technology currently available to accomplish a particular practice. But other issues, addressed either directly or indirectly, and often inadequately, are of at least equal importance (Fig. 1). First is the forest land base and status. Population pressures are directly (as in the conversion of forest land to other uses) and indirectly (for example in the potential effects of climate change and atmospheric deposition) affecting the land available for forest production and its productivity. These influences must be considered both in the long- and short-term as important to silvicultural practices. The mix of resources or benefits which we desire from the forest obviously affects the choice of silvicultural alternatives. The available silvicultural alternatives must all be evaluated in the light of various criteria that address socioeconomic as well as physical and biological concerns. Finally, efficient use and recycling of wood based products can be an important factor in determining the amount of new raw material

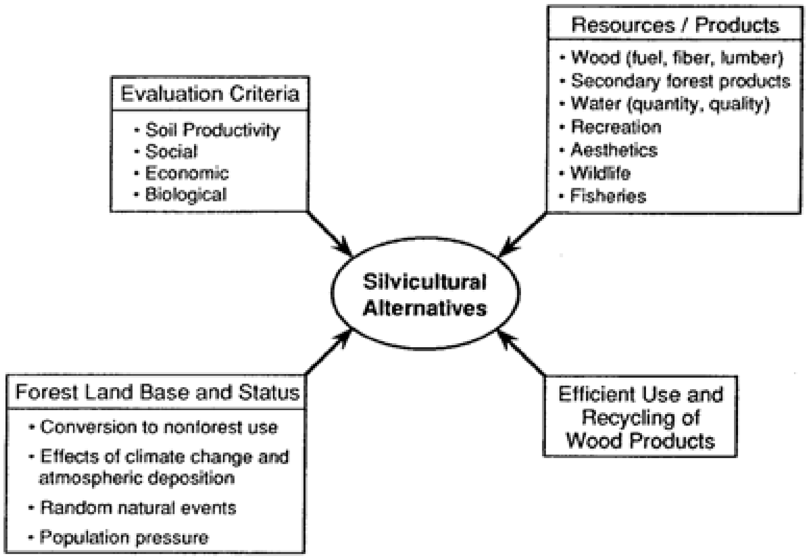


Figure 1. Factors affecting the choice of silvicultural alternatives.

(wood and fiber) needed for various uses and the type of forests necessary to produce these materials.

Silvicultural options are often viewed by the public as universal in their applicability. That is, all options are available regardless of site conditions and species composition. In reality, however, each option needs to be evaluated on a site- and species-specific basis and related to the concerns identified in Figure 1 and to any others that relate to the particular situation. Once evaluated in this manner, every alternative is obviously not possible everywhere, and some only at great expense or high risk.

One way of viewing the silvicultural alternatives which are potentially avail-able for white spruce and other species in Alaska is shown in Fig. 2. A brief explanation of the regeneration aspects of this figure is given below. The manipulation of established regeneration to produce stands with desired characteristics is shown to emphasize where regeneration fits into the total rotation, but it is not discussed.

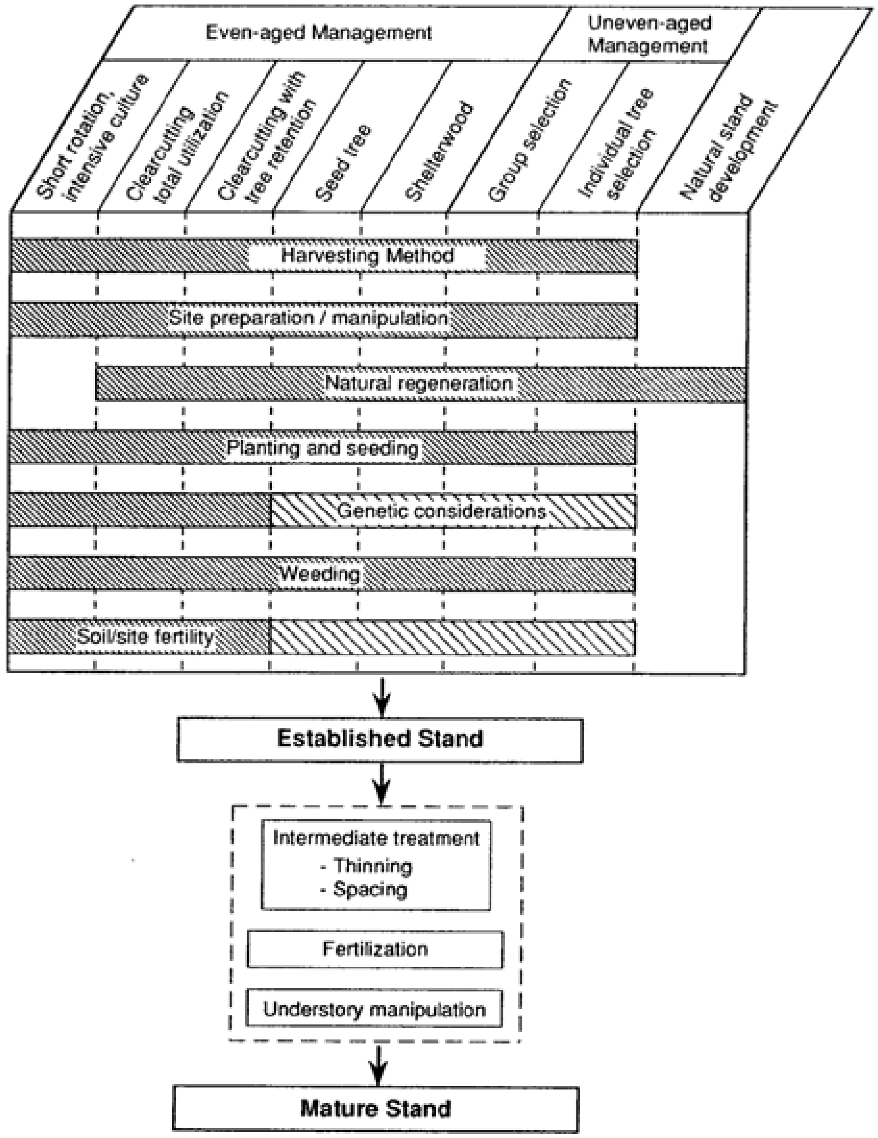


Figure 2. Silvicultural alternatives available for developing silvicultural systems for regenerating and managing white spruce in interior Alaska. Different cross-hatching suggests different considerations with regard to these treatments.

Treatment of Mature Stand.

I have chosen this as the focus of this example because harvest of the mature spruce or mixed spruce-hardwood forests and regeneration are important issues in Alaska. The first decision which is made is whether to manage even-aged or uneven-aged stands. Although even-aged management has been used exclusively, there are situations where multiple-aged stands could be created to meet some specific management objectives. In the case of even-aged management, the mature stand can be removed in one (clearcutting) or several harvests (shelterwood or seed tree). In this example, clearcutting has been separated into two types of treatments. One takes into account the retention of some living trees as recommended by advocates *of* new forestry. In some ways, this is a hybrid system in that the trees which are retained provide some shelter to regeneration. They also create a multiple-aged stand. An important distinction is that these retained trees are not meant to be removed as is the case in the shelterwood or uneven-aged methods. The second method of clearcutting is the standard practice of removing all merchantable material. Although short rotation, intensive culture is a long way from reality, it is possible on some sites and would be the most intensive form of management. The opposite end *of* the scale is represented by a natural stand development option where there would be no treatment.

This is the area of forest management where foresters in Alaska and the Canadian boreal forest have been least imaginative. In spite of the fact that white spruce, in particular, and some of the other conifers and hardwoods are suited to regeneration systems other than clearcutting, this fact has for all practical purposes been ignored. This was a mistake and it appears that we may be just beginning to realize the seriousness of this oversight. Perhaps an even sadder fact is that by ignoring the use of other methods of overstory removal, foresters have ignored an interesting and exciting part of their professional heritage.

Harvesting method.

This refers to the way in which the mature stand is removed from the site. Considerations include the type of harvesting equipment, amount of material left on the site, season of the year when harvesting occurs, location and density of skid roads and trails, and others. Harvesting has often been viewed more as an engineering operation than a silvicultural tool. However, it is an important silvicultural tool and should be used to achieve silvicultural objectives to the maximum extent possible. It is possible to create, through harvesting practices alone, a continuum of post-harvest
conditions which range from almost no disturbance of the forest floor (as would occur

in winter harvesting) and maximum amounts of logging residue, to maximum disturbance of the forest floor and minimum amounts of residue.

Site Preparation and Manipulation.

Site preparation deals with manipulation of residual forest floor material to improve seedbed conditions or planting microsites, and management of species which compete with the crop species. Because most harvesting operations do not cause enough disturbance of the forest floor to achieve regeneration goals, prescribed fire or mechanical site preparation are used to alter forest floor depth and distribution. Many machines have been developed to remove the forest floor layers and expose mineral soil. They can create a broad range of microsites depending on site conditions and other concerns (for example amount of competing vegetation and soil drainage). Controlling the distribution, abundance and vigour of non-crop vegetation can be achieved to varying degrees by mechanical site preparation, fire, herbicides, or a combination of treatments.

Natural Regeneration.

In this example, natural regeneration refers to production of seedlings from natural seedfall. Site preparation is usually used to improve seedbed conditions and utilize seed supply more efficiently. The probability of achieving successful natural regeneration varies significantly among species. In the Alaska situation, white spruce is generally more difficult to naturally regenerate than the associated hardwoods. Natural regeneration, and what would be necessary to successfully naturally regenerate a given site, should always be considered when selecting silvicultural alternatives. To achieve successful natural regeneration requires that more consideration be given to size and configuration of cutting areas, retention of residual stands and trees for seed sources. A method of predicting seed crops would increase the probability of achieving successful natural regeneration. There is less room for error in using natural regeneration systems than for artificial regeneration.

Planting and Seeding.

Artificial regeneration provides a way of overcoming much of the uncertainty of natural regeneration. However some form of site preparation is usually necessary with artificial regeneration as it is with natural regeneration. Stands established by planting or seeding are often more uniform in terms of spacing and distribution of trees than those resulting from natural regeneration. These methods can also significantly reduce regeneration time when compared to natural regeneration. White spruce is almost always regenerated artificially and usually by planting. Important variables to be considered when planting include among others time of planting, seedling size and type, choice of planting spot, protection of seedlings from animals, and planting density. Some important considerations for artificial seeding include broadcast or spot sowing, sowing density or rate, microsite selection, microsite amelioration and protection (as with plastic sowing shelters). Natural and artificial regeneration are not mutually exclusive as they can be used together to achieve regeneration goals for a given site.

Genetics Considerations.

In Alaska, there are no genetically improved seeds available and seeds are collected and used in specified seed zones. However, there are no long-term records available regarding the appropriateness of the seed zones as they are currently designated. At this point in time, the best strategy would seem to be to achieve the maximum amount of genetic diversity possible when regenerating stands. A combination of artificial and natural regeneration would probably be the best way to obtain maximum genetic diversity and not to rely solely on artificial regeneration.

Weeding.

The presence of various hardwood, shrub and herbaceous species affects survival and growth. Although we usually think of these effects as negative, and there is no doubt that growth is reduced in some cases, there may be positive interactions between these species and white spruce. The methods used to control competing vegetation will depend on the species and whether plants are of seed or vegetative origin, the ability of these species to respond to the post-harvest environment and the growth characteristics and condition of the target species. Timing of regeneration is a critical consideration and strongly influences the need for weeding. Attempting to establish regeneration immediately after harvesting and before the associated vegetation has begun to develop is usually an easier task than introducing seedlings into a well-developed post-harvest plant community. Herbicides are an important and efficient tool for managing competing vegetation, but their use is controversial. There is a need to better understand how one or a combination of methods such as preharvesting treatment, partial overstorey removal, harvesting methods, site preparation, time of planting and seedling quality can be used to reduce the impact of noncrop vegetation on seedling establishment. n

Soil and Site Fertility Management.

This refers to the full spectrum of practices that can be used to reduce impacts on soils, and soil amendments that can be used to improve growth of crop species. The effect of harvest and post-harvest activities on the quantity and distribution of the nutrient capital for a site is of critical concern. With the range of options available for harvesting and site preparation, it is possible to create a variety of post-harvest conditions. The selection of a particular combination of practices will be determined by site conditions, species composition and stand characteristics. Concerns about soil organic matter and large woody materials can also be effectively dealt with by choice of season of harvest, harvest system and post-harvest treatment as can concerns about soil compaction and erosion.

There are many possible paths to produce vigorous, white spruce regeneration following harvesting (some examples are clearcutting using whole tree harvest/ site preparation/plant/weed, clearcutting with bole only removal/site preparation/artificial seeding/no weeding, shelterwood with bole only removal/site preparation/plant/weed, shelterwood with bole only removal/site preparation/natural regeneration/no weeding). The complexity of selecting alternatives is increased if more than one method of site preparation (for example mounding equipment, plows, patch scarifiers and hand scalping) or artificial regeneration (such as seeding with or without protection, planting various stock types) is available. Each individual alternative or combination of alternatives has different ecological, economic, and social consequences and these and other factors should be used to determine the best combination of alternatives for a given site. One **important point** that has to be stressed is that **there is rarely only one way to achieve a particular management objective,** even though we, as foresters, often give this impression in word and practice.

I will now describe some of the alternatives we have studied for white spruce in interior Alaska, what we have learned about their applicability, and what working with these particular systems has taught us about silviculture and about developing silvicultural alternatives in a more general sense. First, I will briefly set the stage by introducing you to Alaska because silvicultural practice cannot be considered without some idea of the forests and environment in which they grow and how forests have been or are used. For more detailed consideration of these topics, I refer you to the references listed at the end of this paper.

AN INTRODUCTION TO INTERIOR ALASKA Physical Setting and Climate

The Alaskan taiga or boreal forest is a part of the global boreal forest and has many characteristics in common with other parts of this biome. Within Alaska, the range of white spruce and the extent of the boreal forest are commonly viewed as synonymous (Fig. 3). This area lies roughly between 60 and 68° N. latitude and 140 and 156° W. longitude. The elevation of the forests range from near sea level to about 800 m. The Alaska Range, with the tallest peak in North America, cuts through the area and the Brooks Range forms the northern boundary. Major rivers are the Yukon, Tanana, and Kuskokwim, which flow west to the Bering Sea. It is, to say the least, a spectacularly beautiful region with broad vistas, snow-covered mountains and free-flowing rivers.

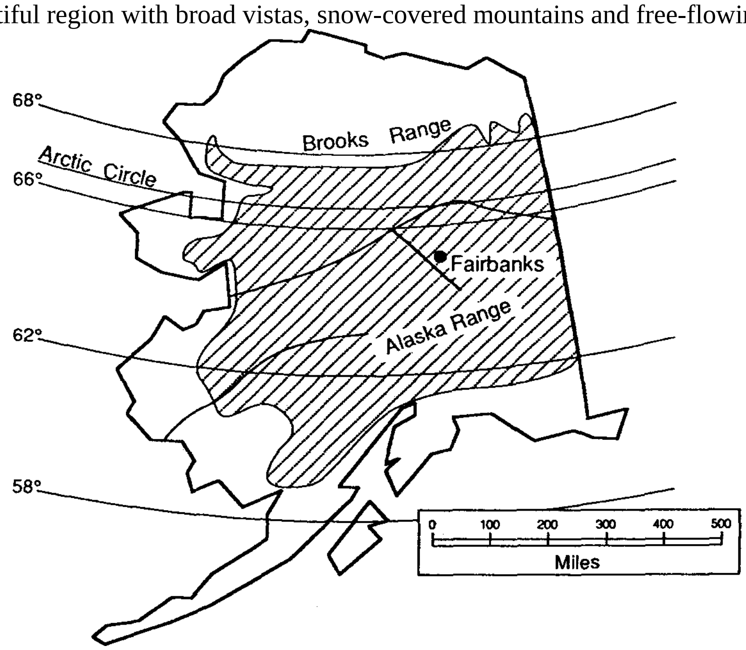


Figure 3. The distribution of white spruce in interior Alaska (adapted from Viereck and Little 1972). The range of white spruce generally describes the distribution of the boreal forest in Alaska. The research discussed in this paper was conducted on upland and floodplain sites near Fairbanks.

The portion of the Alaskan boreal forest on which I want to concentrate is north of the Alaska Range and in the vicinity of Fairbanks at about 65° N. latitude (Fig 3). The climate is continental with cold winters (lows to -60 °C or colder) and relatively warm summers (highs commonly 28 to 32 °C). Day length during the growing season is 22 to 23 hours. The frost-free period is 90 to 100 days. Precipitation averages about 30 to 40 cm per year with about two-thirds falling during the growing season. Snow accumulation is normally in the range of 50 to 100 cm.

Site Conditions and Forest Composition.

Productive forests occur on two major site types in this area — river flood-plains and generally south-facing upland sites (Fig. 4). Soils on floodplain sites are formed in silt- and sand-textured parent materials deposited to varying depths over gravel. On upland sites, soils have developed in weathered mica schist bedrock or in loess deposited over this bedrock type. This area was not glaciated during the most recent continental glaciation.

The principal tree species are white spruce (Picea glauca), aspen (Populus tremuloides), and paper birch (Betula papyrifera) on upland sites and white spruce and balsam poplar (Populus balsamifera) on floodplains. Of particular note is the absence of pine and true fir species. Lodgepole pine (Pinus contorta) and subalpine fir (Abies lasiocarpa) occur at about this latitude in neighbouring Yukon Territory, but they have not been found in the Alaskan boreal forest. The principal shrub species on the more productive sites are various willows (Salix sp.), alder (Alnus sp.), rose (Rosa acicularis), highbush cranberry (Viburnum edule) and buffaloberry (Shepherdia canadensis). Fireweed (Epilobium angustifolium), Canada reed grass (Calamagrostis canadensis), and horsetails (Equisetum sp.) are common herbaceous species. Black spruce (Picea mariana) and tamarack (Larix laricina) are common, but they occur primarily on sites of low productivity such as north slopes and poorly-drained floodplain sites. Permafrost is discontinuous in the region and is present mainly on north slopes and older floodplain sites.

Does the behaviour of the species in this part of the boreal forest differ from that in other parts of their range? A general idea of the annual phenological calendar for white spruce on more favourable sites is shown in Figure 5. Many similarities appear in the general timing of phenological events on these most favourable sites in interior Alaska and other parts of the species' range. Major differences in phenology become apparent with increasing elevation. For example, time of flowering can differ

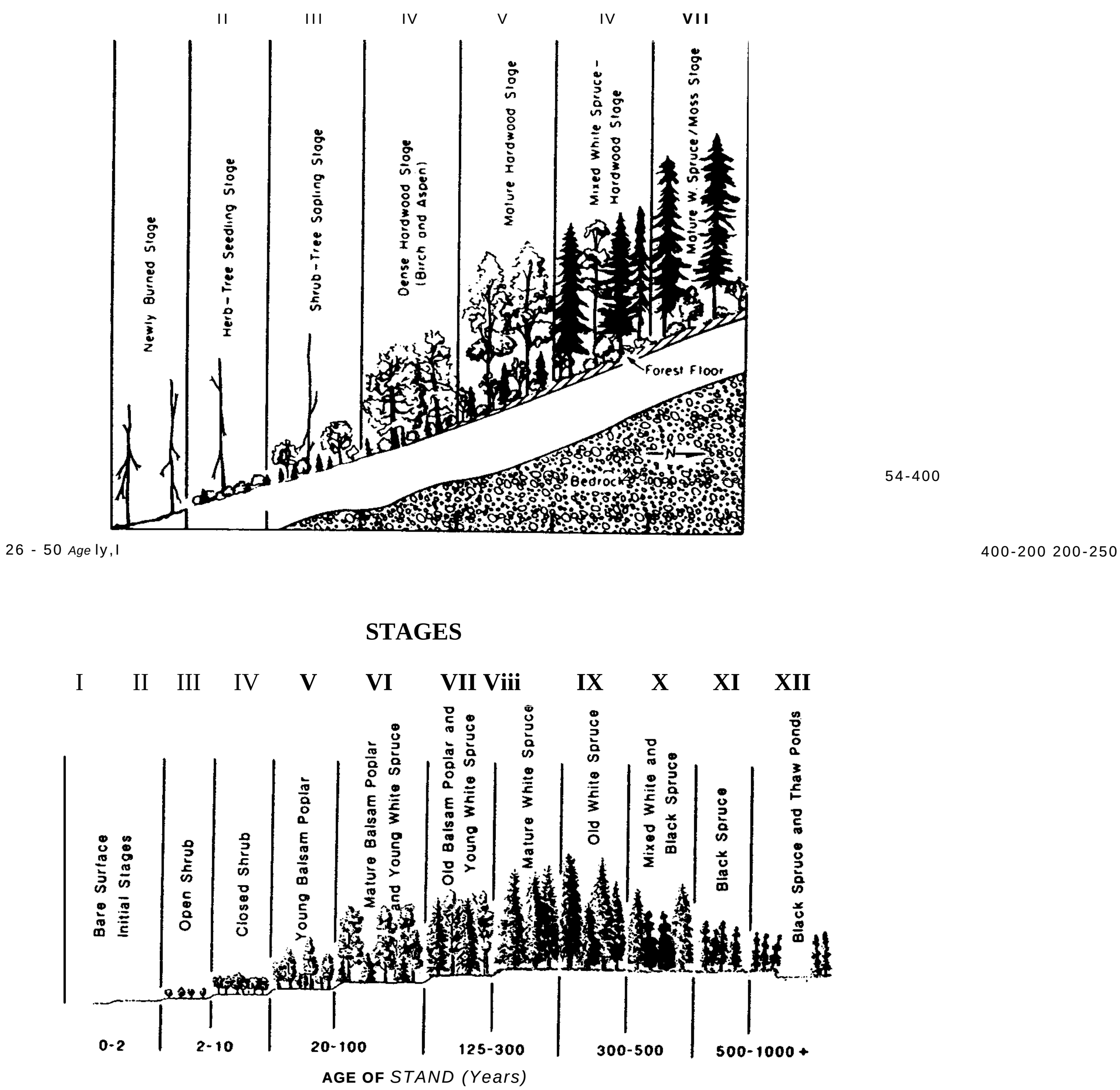
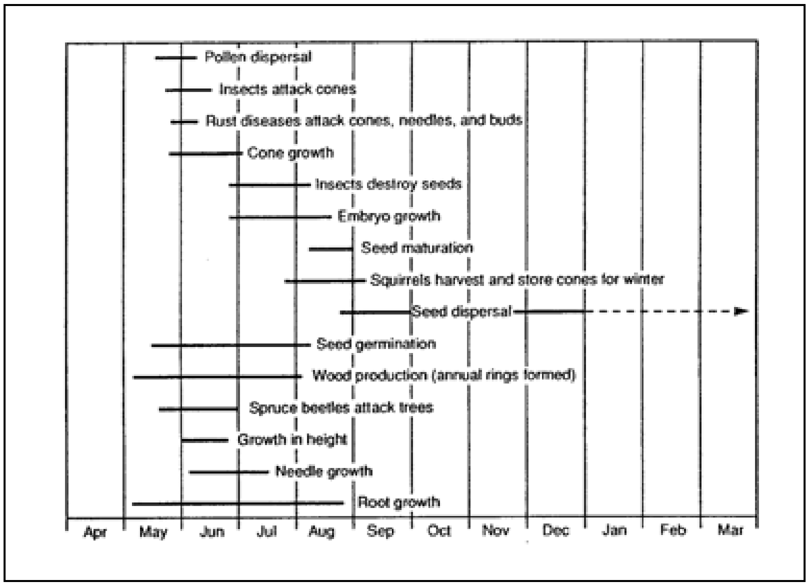


Figure 4. General successional patterns on relatively productive upland sites (a) and floodplains (b) in interior Alaska. The most productive upland sites are on the continuum of sites located oi3 west, south, and east aspects (from Van Cleve and Viereck 1981, Viereck 1989).



Yearly Cycle in the Life of an Alaskan White Spruce Tree

Figure 5. Annual phenology of white spruce on productive sites in interior Alaska.

by as much as a month within a horizontal distance of 60 to 100 km as elevation increases from about 130 to 800 m.

A particularly interesting example of regional differences in white spruce phenology comes from the work of Gregory and Wilson (1968) on cambial activity of white spruce in Alaska and New England. They found that rate of cell division in the cambium of Alaskan trees was about two times greater than for trees in Massachusetts. As a result, the Alaskan trees produced the same amount of wood in about half the time as the Massachusetts trees. This information suggests significant adaptations to the northern environment for some characteristics in white spruce, but differences for other characteristics are not as obvious.

Forest Use.

The ways in which people have used or plan to use the forest are critical to silviculturists. Past use determines the "legacy" with which we have to work. The results of past use can provide valuable insight into forest responses to some types of human disturbances. Present and future needs guide selection of alternatives that we hope produce the desired future condition and values.

Alaska's forests provide a variety of vegetation, water, wildlife, and recreational values. All of these values have been of varying degrees of importance to inhabitants of the region. The degree of importance has varied with the availability of goods and services from outside of the region. Some significant milestones in the history of this forest were the discovery of gold, construction of the railroad, and World War II with the attendant development of the Alaska Highway and air transportation to the region.

Before the gold rush, Alaska Natives had lived on and used the land for many centuries. Their dwellings, food, and clothing — indeed their total physical and spiritual well-being — were determined by what they could obtain from, and their relation to, the forest and associated lakes and rivers (Fig. 6). Nelson (1973) has

Figure 6. Alaska Natives have, historically, derived all or a significant part of their livelihood and spiritual needs from the boreal forest in interior Alaska. Although fish, meat, and fur-bearing animals are viewed as the most important parts of their subsistence life-style, trees and other plant species were extremely important for food, shelter, heating, and as food and cover for wildlife. This fish camp in interior Alaska

provided an excellent account of the relation between Native peoples and the boreal forest of Alaska.

The discovery of gold brought a wave of people and settlement to the region. The forests were heavily impacted and their exploitation has had a lasting effect on areas near settlements and along rivers which served as major transportation corridors. Wood was used for mining, construction, heating and transportation (Fig. 7). Game was an important part of the settlers' diet and furs were used for clothing. The period from the discovery of gold to the development of railroads and other more efficient transportation in the 1920's and 30's probably had as much if not more impact on forest conditions than activities since then.

Figure 7. During the 20 to 30 years following the discovery of gold, forests were heavily exploited for wood for construction, mining, production of heat and electricity, and transportation. A portion of the wood needed annually to produce heat and electricity for Fairbanks before coal or oil was available is shown here (photo from Bunnell Collection, University of Alaska-Fairbanks, Rasmuson Library, Archives and Manuscript Collection).

From the 1940's to the present time, use of the forests varied considerably. Major reasons for the decrease in the reliance on local forest products was the development of the Alaska Highway and the coming of age of air transportation. Wood has always been in demand, near settlements, for construction and heating. Export of wood products has been substantial from some areas, but because export depended on world market conditions, this demand has been cyclic (Fig. 8). Although the feasibility of pulp and particle board mills has been analyzed, no mills have been built.

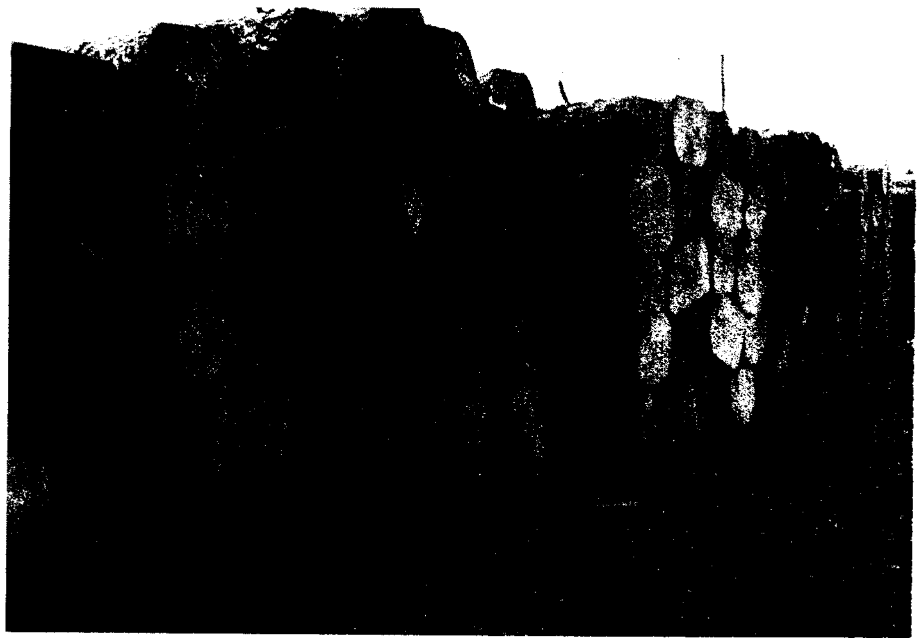


Figure 8. Present utilization of forest products is for local use such as construction and firewood, and for export in the form of round logs, lumber and squared cants. The cants shown here are for export to Japan (photo by Dean Argyle).

The secondary manufacture of lumber into furniture, cabinets and other finished products has developed slowly. The majority of these items are imported at present, but growing awareness of the usefulness and attractiveness of Alaskan woods for finished products suggests their use for these purposes could be expanded significantly (Fig. 9).

Many plant products do not require the harvest of trees (Fig. 10). Berries are important locally, and several small businesses make jams, jellies and other products. The annual harvest of berries represents only a small fraction of what is produced

Figure 9. Alaska woods can be used to produce finished products of high value and beauty. The figure shown here is carved from balsam poplar bark, the violin is made from white spruce, birch and moose horn, and the box from birch wood with fixtures such as drawer pulls fashioned from small birch burls.

Figure 10. Removal of bark from birch for making baskets. There are many potential products from trees and associated vegetation that do not require the harvesting of trees. These include berries, birch sap, cones, roots and branches used in basket making. (photo by Dean Argyle).

however. Birch sap is collected on a small scale and made into syrup. In parts of the Soviet Union, thousands of gallons of birch sap are gathered annually and used to make a bottled drink — an indication of the potential that may exist for such secondary forest products. Birch bark, spruce roots, and willow are used for making baskets that are sold for decorative more than functional use.

Preservation of a subsistence life-style, in which people are able to obtain part or all of their livelihood from the forests and associated lakes and rivers, is an important issue. This life-style is most frequently associated with undeveloped land in remote areas of the state with few roads and less population pressure. Maintaining wildlife and fish populations is a critical aspect of subsistence and a primary goal of management activities is to provide suitable habitat for these species. The Alaska Native Claims Settlement Act attempted to address this issue by allowing Native peoples to select and retain lands adjacent to their villages that could serve as a core for subsistence purposes.

Recreational values of the land are significant. The combination of wide vistas of undeveloped land, free-flowing rivers, and large mountains make Alaska valuable for those that appreciate the aesthetics of these landscapes as well as for more active use such as skiing, dog sledding, canoeing and other outdoor activities.

Prior to passage of the Alaska Native Claims Settlement Act in the 1970's, virtually all of the land was in federal or state ownership. This Act gave the Alaska Natives title to 40 million acres. This has had a significant effect on land use and will continue to affect the way land is managed and utilized.

This brief summary was intended to indicate the range of benefits people derive from the forests of interior Alaska. The absence of a major wood manufacturing facility is a key difference when Alaska is compared to other parts of the boreal forest — although the export of wood as chips, round logs, cants, or rough lumber has significantly affected some lands in the region. Silvicultural options and systems need to be developed with all of these values in mind. This means that options are needed for a range of intensities of management and at the scale of individual trees, stands, and landscapes. Coordinating uses within a given area will be difficult, as it has been everywhere else. If a range of alternatives can be developed, however, and their consequences evaluated and communicated to all interested groups, then satisfying demands for the production of multiple values from a given stand or area has a chance of becoming a reality. However, if the status quo continues conflicts among competing resources will increase as forest harvesting activities impact larger areas.

SILVICULTURAL EXPERIENCE IN INTERIOR ALASKA

In the late 1960's, we started to consider the silvicultural alternatives that might be applicable to the forests of interior Alaska — in particular, those available for regenerating white spruce. At that time little biological, ecological, or silvicultural information was available, and operational experience was limited in our specific area. No clear idea had been expressed about desired future forest conditions, and although harvesting was occurring, it was sporadic and strictly exploitive. Furthermore, no forestry infrastructure, such as nurseries or specialized equipment existed for conducting forestry operations as they were being practiced in other regions. We believed that we needed to obtain basic ecological and biological information that could be used in formulating and comparing the alternatives we developed or that others were using.

Although white spruce was the target species, we soon recognized that we needed information for all species of trees, shrubs, herbs, and nonvascular plants if we were going to do a reasonable job of developing silvicultural alternatives for these sites and truly develop an understanding of the impacts of harvesting on forest succession, and future forest composition and productivity. Furthermore, we had no guarantee that artificial regeneration methods would be readily available. This meant that alternatives were needed for obtaining natural regeneration. As time passed and forest practices evolved, studies of artificial regeneration were initiated so that these practices could be used alone or in conjunction with natural regeneration in meeting regeneration goals.

The basic requirements for developing silvicultural options were some form of site classification system, information on forest succession, and information on the population biology, autecology, and effects of disturbance on individual species and a framework for organizing this information and determining additional needs. From the early 1960's to the present much of the research has been more or less aimed at developing this type of information. Les Viereck, Keith Van Cleve, Terry Chapin, Ted Dyrness, Joan Foote, John Yarie, and others have done much of the work on the relationship of forest productivity to site factors and how these relationships vary in space and time, and I refer you to their publications for a discussion of these issues. The silvicultural work attempted to utilize this basic ecological information in developing, understanding, and assessing silvicultural alternatives.

We obviously were not operating in an information vacuum. We drew heavily on the basic principles of silviculture, and from experience from Canada and other parts of the boreal forest. The work we started in Alaska was viewed by some as "unique" to the boreal forest in western North America. This may have been true to some extent, particularly in view of the fact that during this time (late 1960's to the 1980's) clearcutting and planting became the only prescription for regenerating white spruce after harvesting — a trend which was in a significantly different direction than the way our research was headed. However, the initial treatments which we established were based on studies of spruce in Alberta and Manitoba. Our work drew on papers by Waldron, Lees, Jarvis, Steneker, Ackerman and Rowe — all working with the Canadian Forest Service — to name but a few. We also drew heavily on observations made from past forest harvesting as it related to the most desirable seedbed conditions and potential response of trees retained in shelterwoods or other partial cutting systems.

FOREST SUCCESSION

The sites most affected by harvesting are the more productive sites on uplands; generally the continuum of sites with west, south and east aspects; and floodplain sites (Fig. 4). These sites differ significantly in the factors influencing forest development. On upland sites, fire has been the most important disturbance in terms of landscape scale forest distribution. The fire return interval on these sites is about 150 to 200 years. Forest development after harvesting appears to follow successional patterns that occur following fire. Some major differences are obvious between areas disturbed by harvesting and those disturbed by fire (for example, in the amount of residual large woody material and forest floor, microsite conditions, and quantity and quality of nutrient availability after disturbance), but the effects of these differences, if any, on long-term forest ecosystem productivity are not known.

On floodplains, forest development is directly related to the interaction between processes associated with the river and the assemblage of plant species available to colonize these sites. The river directly affects the development of vegetation in the early stages of forest succession through frequent flooding, depth to water table, condition of the substrate available for colonization, and other abiotic variables. As the elevation of a surface or terrace increases with respect to the river level or as the river changes course, the frequency of flooding decreases and the direct influence of the river decreases. Fire may play a role in late succession when white or black spruce dominate the site. In the absence of disturbance, the productivity on these sites decreases substantially and thF' end point of the successional sequence is an open black spruce forest with a continuous layer of permafrost (Fig. 4b).

Harvesting on floodplains initiates a secondary successional pattern which is very different from the primary successional process that produced the harvested forest. For example, regeneration of white spruce in primary succession occurs under various broadleaved tree and shrub species. Litter depths are usually shallow and consist mostly of leaf litter from these species. While in secondary succession as would occur after harvesting, white spruce would regenerate in forest floor layers comprised of mosses and undecomposed litter from spruce and other species. The soil temperature regime would be significantly different in the two cases due to overstory and forest floor differences, as would the soil water regime due to terrace height and forest floor condition.

An interesting and somewhat perplexing problem on floodplain sites is the long-term stability of any given area. Changes in river level or the channel can result in site destruction over short or long periods. Thus predicting what sites will be available in 50 to 100 years is difficult as is determining if investments in forest management will literally be washed down the river.

Population Biology.

Forest succession provides the general plan of forest development for a given site, but it gives little or no insight as to the conditions at the time of forest establishment and how they influenced the composition and productivity of the forest. To fully understand successional patterns in the context of silvicultural practice, we must have information such as seed availability and dispersal, effect of seedbed conditions on establishment, influence of associated vegetation on establishment of the crop species, and other similar information that is not usually available from community level studies of forest succession.

Plant population biology provides a useful framework for gathering and evaluating this type of information. Conceptual models for organizing and assessing information are illustrated in Figs. 11 and 12. Regeneration from seed is a complex process which can be considered as a sequence of interrelated steps (Fig. 11). Al-though controlling each of these steps by silvicultural practices is impossible, placing regeneration in this context forces us to consider the whole process of natural regeneration and where the most critical points are in the process, as opposed to considering only those factors over which we have relatively more control. This model can also be used to evaluate the potential for seed regeneration of the species associated with white spruce or other crop species.

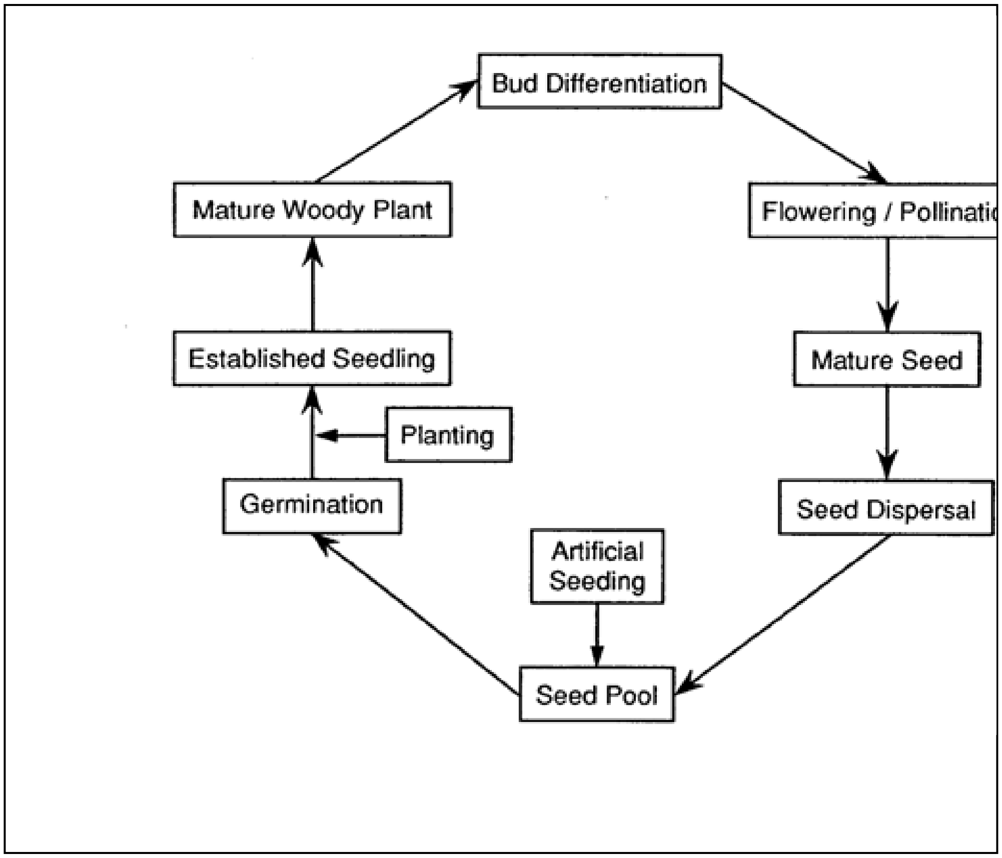


Figure 11. Conceptual model for assessing seed reproduction. Seed reproduction can be viewed as a number of discrete but interrelated steps which are of varying degrees of importance depending on species and biotic and abiotic site factors. Artificial regeneration removes some of the uncertainty in the regeneration process by assuring an adequate seed pool or seedlings.

Regrowth from vegetative materials is not a consideration in the regeneration of white spruce per se on productive sites. However, it is of great significance when considering recovery of the vegetation complex and the development of species competing with white spruce for growing space. The type of bud bank (Fig. 12) present and a knowledge of its potential for growth following disturbance can be used to design practices which eliminate or retard development.

(Note: I use population biology as the context in which to evaluate this aspect of silviculture because I believe that it forces us to expand our view to more than just the tree component of the forest vegetation. Furthermore, the field of plant population biology has a literature rich witliexamples from which foresters and silviculturists can benefit.).

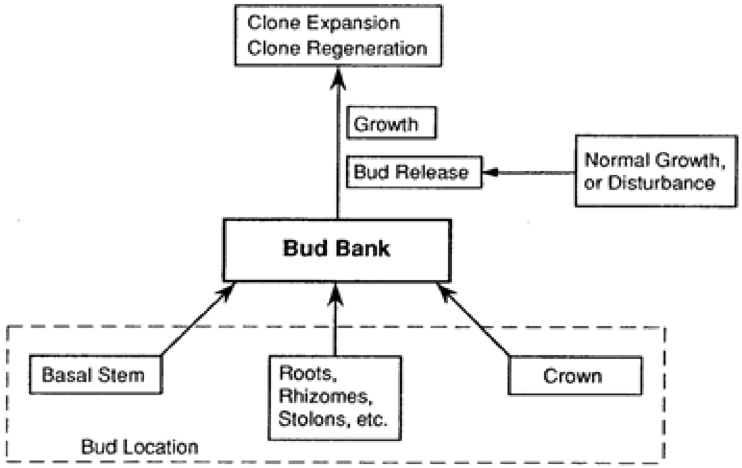


Figure 12. Conceptual model for assessing vegetative reproduction. Development of the bud bank provides the basis for vegetative reproduction of broadleaved trees, shrubs, herbaceous species. Examples of Alaskan species with bud banks of each type are: roots — aspen; rhizomes — wild rose; basal buds — virtually all trees and shrubs with the exception of aspen which loses this ability as it ages; layering of branches — blueberry, black spruce; rooting of broken branches — balsam poplar.

Silvicultural Alternatives.

The main limits to the range of silvicultural alternatives that one might consider are the biology of the species, site conditions, impacts on future productivity and the imagination. Economic and social limits, and conflicts with other resources need to be considered, but they should not limit what is biologically possible in an ideal sense.

The alternatives I will discuss are best categorized as those that alter composition or regulate growth rates but within the context of the successional framework (Fig. 4) and using the complement of species present on a given site. This approach differs from one that has the goal of eliminating or greatly altering the successional pattern — for example use of intensive vegetation management practices that incorporate chemical control and other practices designed to significantly restrict development of early successional species; planting of exotic species such as lodgepole pine to improve production; moving species to sites where they are not normally found — for example planting tamarack on upland sites; or short rotation intensive culture of early successional species such as willow or poplar. These alternatives are viable for wood and fiber production on these sites and incorporating them may become important as management intensifies. Their consideration is beyond the scope of this paper, how-ever.

Altering Composition or Growth Rate.

Stand composition and rate of growth of natural stands may not be desirable because of composition, stocking, or spacing. Natural development may solve some of these problems, but the time necessary for natural development may be unacceptable. By using such practices as artificial seeding and underplanting, the rate of invasion may be increased and at the same time, the spacing and density of the desired species controlled so that future operations to remove the overstory will have a minimal effect on trees developing in the understory. Density reduction also occurs naturally through density-dependent mortality; the rate of this natural process can be increased by commercial and precommercial thinning. Two examples, for which some information is available for these sites, are given below.

On floodplain sites, the white spruce stands that develop during primary succession can vary significantly in density and stem distribution because of the variation in factors affecting invasion. Assuring establishment of a minimum density and better distribution of white spruce may sometimes have an advantage. In one study, we investigated the early dynamics of seedling populations of white spruce and other species established from artificially sown seed in different successional stages on floodplains. Successional stage and seedbed condition had a significant effect on germination and survival, and the study indicated that this practice was feasible. Use of devices (for example, plastic shelters) to protect seeds and modify the microenvironment for germination and early seedling growth affects the seed-to-seedling ratios and may produce more reliable results. Underplanting would also achieve the same objective.

Thinning is a common tool used to alter stand structure and concentrate growth on desired trees. Thinning is normally viewed as a means to improve wood production or quality, but it can also alter stand development for wildlife. In pure young white spruce stands, we observed rapid response of individual trees to thinning alone and thinning combined with fertilization. Additional studies by Alan Richmond at the University of Alaska and Frances Herman of the Institute of Northern Forestry generally substantiated these results. Their work pointed out, however, that some significant problems related to snow breakage and mortality followed the drastic change in conditions resulting from thinning.

Regeneration

Harvesting of mature white spruce stands and their replacement is the practice that causes the greatest conflict with other resources and is most questioned by the public. In Alaska, as well as in other parts of the North American boreal forest, clearcutting has been used to the exclusion of other alternatives to harvest the mature forest. Regeneration practices have varied, but the trend was always toward larger clearcuts and some type of artificial regeneration, usually planting. This "prescription" has been uniformly applied regardless of site or stand conditions, or evidence that other systems are as good or better for regenerating white spruce and associated hardwoods and perhaps achieving other management objectives at the same time.

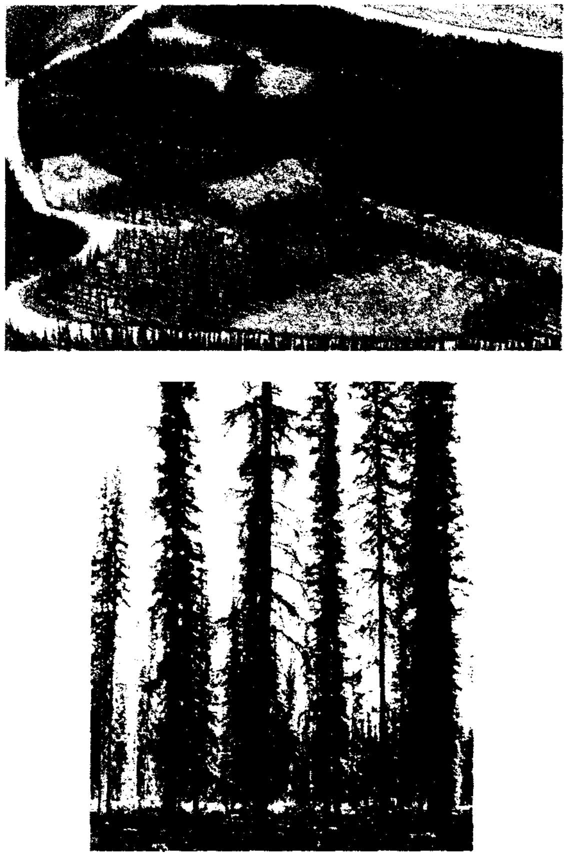


Figure 13. Research with shelterwoods on upland and floodplain sites has shown that they can be used to successfully regenerate white spruce from natural seedfall or by artificial seeding or planting. (a) Floodplain study site showing clearcuts, shelter-woods and uncut forest. (b) Shelterwood in about 120-year-old white spruce on floodplain site in (a).

We initiated two fairly detailed studies, one on an upland and one on a floodplain site, and several less-formal studies to compare regeneration of white spruce in clearcuts, shelterwoods and other methods of partial overstory removal (Fig. 13). The following briefly summarizes some of the results and experience from these ongoing studies and more information can be obtained from the references listed at the end of the paper.

Effect on site conditions.

On upland sites, solar radiation was increased by about 440 percent in clearcuts and 300 percent in shelterwoods when compared to uncut stands. These increased levels of radiation resulted in substantially higher temperatures in the surface organic layers but had less effect on the temperature of the surface of mineral soil seedbeds. Soil water content increased in clearcuts and shelterwoods when compared to uncut areas but did not differ between the two treatments at least during the 3 years following harvesting. Pattern of snowmelt was also affected to some degree with snow being retained longer in the shelterwoods.

White Spruce Seedling Survival and Growth.

The methods used in the study on the upland site (small clearcuts of 1 to 2 ha to assure adequate seedfall and shelterwoods with residuals at a spacing of about 12 to 15 m) demonstrated that abundant natural regeneration could be attained in both clearcuts and shelterwoods. Growth tended to be a little better in clearcuts, but the difference was not great after about 13 growing seasons. Abundant natural regeneration in small clearcuts (0.5 to 2 ha) with suitable seedbed conditions has been observed on similar sites in other years. These findings contrast with the poor stocking of natural
regeneration in larger clearcuts under operational conditions.

Density and frequency of seedlings from natural seedfall or artificial seeding is much lower on organic mattef seedbeds than on mineral seedbeds created by some type of mechanical site preparation (e.g., blade scarification, or patch scarification with a Brakke type scarifier). The survival of planted seedlings on floodplain sites after 5 years, however, was similar on mineral soil and organic substrates. Early growth of natural and planted seedlings originating from seed tended to be better on mineral soil surfaces. But in our oldest study on an upland site, there was little difference between natural seedlings growing on the two surfaces after 13 years.

One general result from these two studies was that performance on organic surfaces was much better than what was expected based on operational experience in the area and information from elsewhere. These results led me to conclude that knowing more about the relation between organic substrates and survival and growth of seedlings of white spruce and other species was essential.

An important factor in regeneration efficiency (seed-to-seedling ratio in the case of natural or artificial seeding and survival of planted seedlings) seems to be the length of time elapsing between completion of site preparation and the availability of seed or planting. Seedbed receptivity declines fairly rapidly because of the growth of other vegetation and litter fall; after 3 years seed-to-seedling ratios are substantially higher than those for newly prepared seedbeds and survival and growth of planted seedlings with no subsequent weeding treatment was poorer than planting immediately after treatment.

The overstory can be removed with minimal effect on the regeneration. Time of year, size of seedlings and method of log removal all affect seedling damage.

Residual Stand.

The residual trees in shelterwoods on both upland and floodplain sites have survived well. Harvesting was closely administered and damage to the shelterwood was not great. We did observe that skidding when temperatures were below -10 to 15°C resulted in less damage than when temperatures were at 0 °C or above. Mortality has been less than 15 percent. Most of the mortality occurred soon after harvesting and was caused by the combination of release and subsequent insect attack.

An important factor in the survival of the residual trees was that dominants and codominants were retained. These trees have better crowns and root systems and are better able to withstand release and the post-harvest environment, and damage resulting from harvesting. The general experience has been that intermediate and suppressed trees have lower survival on similar sites. Methods that leave a residual stand always cause some mortality regardless of how carefully they are conducted.

The residual trees on the upland site responded to cutting with an increase in diameter growth. The increased growth was indicative of the vigour of these trees in spite of the fact that they were 150- to 180-years-old. Seed production in the shelterwoods followed the same pattern as that in uncut stands in the study conducted on the upland site.

Development of Associated Vegetation.

Most of the discussion has been concerned with regeneration of white spruce because of the economic importance of the species. In addition, white spruce is the most difficult tree to regenerate on these sites and is generally not as well-adapted for rapid recovery under post-harvest conditions. Without particular attention given to the species, it is possible that the occurrence of white spruce could be greatly reduced or, in the extreme case, eliminated from large areas as a result of harvesting, removal of seed source and rapid regrowth of the associated trees, shrubs and herbs. The other potentially important species, all hardwoods, regenerate vegetatively, and have a great advantage over white spruce in producing seeds, which are easily dispersed over long distances, at more frequent intervals and in larger quantities and are thus much better adapted for rapid recovery following harvesting or other disturbances. Generally speaking, anything done to improve conditions for natural regeneration of spruce also creates favourable conditions for seed regeneration of aspen, birch, alder and willow. Thus it is rare not to have vegetative or seed regeneration of these species present when regenerating white spruce.

The tendency is to view the broadleaved trees and shrubs as detrimental to spruce regeneration. There is no doubt that their presence affects the growth of spruce. However, white spruce is relatively shade tolerant and can develop under hardwoods, particularly when it becomes established at the same time as the faster growing hardwoods. Thus it is possible to take advantage of some of the positive benefits of aspen, birch, willows and alder, such as wood production, wildlife habitat, and soil fertility, and have an adequate spruce component in mixed stands. There are ecological and economic reasons for creation and management of mixed stands. The experience gained from studies on the upland sites indicated that these tree and shrub species regenerate reasonably well over the range of conditions — clearcuts of various sizes and shelterwoods — observed in our research on upland sites. The presence of a mineral soil seedbed was more important than condition of the overstory in our studies. More experience is negded in regenerating and growing mixed stands.

Other Considerations.

The retention of a residual stand has obvious implications to wildlife habitat management. Although our observations of wildlife were limited in scope, some were made. Red squirrels continued to use the shelterwoods, but not all middens (cone storage areas) present before harvest remained active after harvest. Red-backed voles continued to use both clearcuts and shelterwoods. Larger mammals, moose for example, frequented the area utilizing the willow and other browse that developed from seed and vegetative reproduction.

Harvesting removes biomass and nutrients from sites and thus has the potential of reducing long-term site productivity. In our studies, we used whole tree harvesting to have sites with as little debris as possible. Even with these systems however most of the branches broke off during the skidding operation — this was particularly true on the floodplain sites which were harvested in the winter. Site preparation can have a significant impact on availability and distribution of nutrients. The methods used in this study resulted in the displacement of the forest floor and nutrients over short distances but did not remove them from the site. As mentioned earlier, the conditions resulting from harvesting and site preparation can vary greatly depending on stand conditions, method of harvesting, and site preparation; the latter two can be adjusted to create conditions necessary to satisfy cumulative effects or long-term site and ecosystem productivity concerns.

The reaction of people to the shelterwood was generally favourable. Most often, the comments were that it looked like a park or showed some other indication that it was aesthetically appealing.

General Observations and Preliminary Conclusions Regarding

Silvicultural Options in Interior Alaska

1. The forests of interior Alaska can provide many tangible and intangible benefits. They should be managed to produce the broadest array of products and conditions possible and to meet a variety of life-styles. These forests are often viewed as being of low productivity when compared with forests further south. To some extent this is true, but the fact is that these forests do produce benefits ranging from firewood to house logs, birch bark to birch sap, berries to meat, passive to active recreational use, and others. People depend on these products and there is no reason why the forest resource should not be managed for their continued production.

2. In order to produce these products and conditions, a variety of silvicultural alternatives (Fig. 2) must be available to create forests of varying composition and structure. These alternatives should address various levels of management intensity and management at the tree, stand and landscape levels of resolution. Clearcutting has been used exclusively to harvest mature white spruce stands. This method can conflict with other resource values. The work briefly summarized here suggests that there are more options to regenerating white spruce and associated hardwoods than are currently used. Fig. 14 illustrates several options which appear to be viable for both upland and floodplain sites. Systems which incorporate some degree of overstorey retention, whether used to create even-aged or uneven-aged stands, provide more flexibility and opportunity for meeting multiple resource management objectives. Similarly, management of mixed spruce-hardwood stands provides more flexibility in terms of products and ecosystem condition. Forest managers have been innovative and quick to adopt alternatives for creating more suitable conditions for regeneration, and for providing more suitable seedlings for regeneration — but all in the context of clearcutting. Often, too, these practices have limited research and operational experience to support them. It is time to become innovative and more progressive in the way mature stands are treated and harvested. Without this innovation, harvesting activities may be greatly reduced or prohibited in some areas.

3. Although the shelterwood system used in the classical sense is a method for creating even-aged st4tids, the stability of the stands, positive growth response of residual trees, and continued seed production observed to date in our studies indicated that residual trees can be retained for 15 to 20 years. A key to successful
if

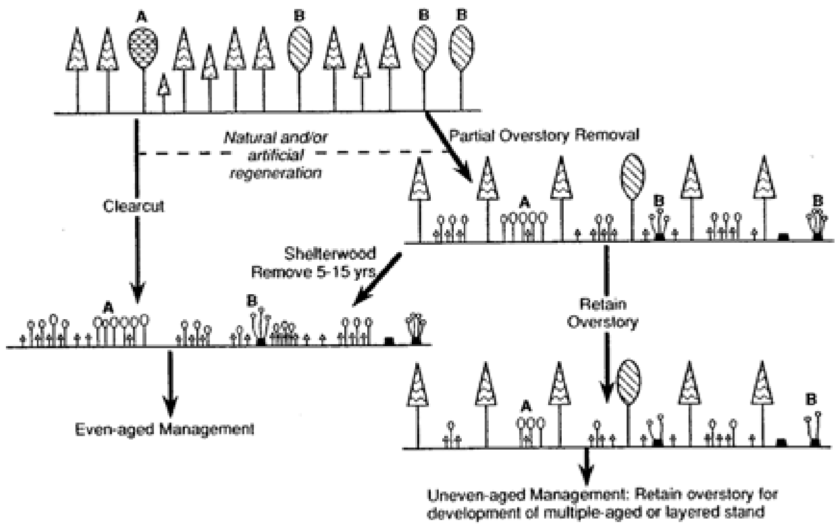


Figure 14. Some silvicultural alternatives for upland sites in interior Alaska. Evenaged stands can be created by clearcutting or with shelterwoods where the overstory is removed in one or more stages. Regeneration can be either natural or artificial (planting or seeding). Although shelterwoods are typically used to create evenaged stands, partial overstory removal which occurs in shelterwoods can be used to create multiple-aged or -storied stands. Dominant and codominant mature white spruce in the 150 to 180 year age class survive partial cutting and show a positive growth response. Residual trees can be harvested or left to meet wildlife or other management goals.

retention of residuals is to retain vigorous dominants and codominants and not intermediate and suppressed trees. The results suggest that multiple-aged or layered stands can be produced on both upland and floodplain sites. We need more information on the impacts of insects and diseases in these residual stands to fully evaluate long-term retention.

4. Management of organic layers is an important consideration in boreal forests. Disturbance of the organic layers appears to be essential for rapid establishment of white spruce as well as hardwood species. However the results of our studies suggest that regeneration on organic seedbeds was more successful than it is in other parts of the boreal forest. Further study of the role of organic layers in

regeneration and the regeneration response of all species to organic layer conditions (such as depth, type of material, effects of disturbance and change of conditions with time) is needed.

5. Harvesting must be considered as an integral part of any silvicultural system or prescription and not simply as an engineering or technical problem. Some important considerations are season of logging and choice of a logging system as they relate to site and stand conditions and management objectives. Using the proper combination of methods it is possible to clearcut or partially cut stands in a variety of configurations and achieve some conditions necessary for efficient regeneration. Loggers are important to the successful use of silvicultural systems which incorporate partial overstory removal. They should be consulted regarding the best way to accomplish a job. In short, they should be partners in accomplishing the silviculture job and not adversaries.

6. If forest managers are going to successfully use silvicultural systems which include partial overstory removal, they have to be fully involved in the whole process of harvesting and regeneration — this includes the full spectrum of activity from pre-harvest planning to pre-commercial thinning. There is no substitute for well-designed and supervised silvicultural operations.

7. Forest managers and silviculturists need to be competent ecologists. They must understand the response characteristics of the species they are managing plus all of the associated species, and they must be aware of the impacts which harvesting and site preparation have on site conditions, long-term forest productivity, and other components of the forest ecosystem.

Selected References

Canadian Journal of Forest Research-Special Issue. 1983. The structure and function of a black spruce forest in relation to other fire-affected taiga ecosystems. Can. J. For. Res. 13(5): iii - 916.

Densmore, R. 1979. Aspects of the seed ecology of woody plants of the Alaskan taiga and tundra. Ph.D. dissertation. Duke University, Durham, NC. 285p.

Dyrness, C.T., L.A. Viereck, M.J. Foote, and J.C. Zasada. 1988. The effect on vegetation and soil temperature of logging flood-plain white spruce. USDA Forest Service Res. Pap. PNW-RP-392. 45 p.

Foote, M. J. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of interior Alaska. USDA Forest Service Res. Pap. PNW-307. Pacific Northwest Forest and Range Experiment Station, Portland OR. 45 p.

Fox, J., J. Zasada, A. Gasbarro, R. Van Veldhuizen. 1984. Monte carlo simulation of white spruce regeneration after logging in interior Alaska. Can. J. For. Res. 14: 617-622.

Gregory, R. and B. Wilson. 1968. A comparison of cambial activity of white spruce in Alaska and New England. Can. J. Bot. 46: 733-734.

Hard, J. and E. Holsten. 1985. Managing white and Lutz spruce in south-central Alaska for increased resistance to spruce beetle. USDA Forest Service Gen. Tech. Rep. PNW-188. Pacific Northwest Forest and Range Experiment Station. Portland OR. 21 p.

Juday, G. and C. Dyrness (eds). 1985. Early results of the Rosie Creek fire research project, 1984. Agriculture and Forestry Experiment Station, University of Alaska-Fairbanks. Misc. Pub. 85-2. 46 p.

Krasny, M., K. Vogt, and J. Zasada. 1984. Root and shoot biomass and mycorrhizal development of white spruce seedlings naturally regenerating in interior Alaska floodplain communities. Can. J. For. Res. 14: 554-558.

Mowrey, R. and J. Zasada. 1984. Den tree use and movements of northern flying squirrels in interior Alaska and implications for forest management. In: Meehan, R., T. Merrell, and T. Hanley (eds.). Fish and wildlife relationships in old-growth forests: proceedings of a symposium held in Juneau, Ak, 12-15 April 1982. Amer. Inst. Fish. Res. Biol. 425 p.

Nelson, R. 1973. Hunters of the northern forest. University of Chicago Press. 339 p.

Putman, W. and J. Zasada. 1986. Direct seeding techniques to regenerate white spruce in interior Alaska. Can. J. For. Res. 16: 660-664.

Shugart, H.H., R. Leemans, and G.B. Bonan (eds.). 1991. A systems analysis of the global boreal forest. Cambridge University Press. Cambridge. in press.

University of Alaska, School of Agriculture and Natural Resources Management. 1977. North American forest lands at latitudes north of 60 degrees. Proceedings of a symposium held at the University of Alaska, Fairbanks, Sept. 19-22, 1977. Published and distributed by University of Alaska, School of Agriculture and Natural Resources Management, Fairbanks, Alaska. 331 p.

Van Cleve, K. and J. Zasada. 1976. Response of 70-year-old white spruce to thinning and fertilization in interior Alaska. Can. J. For. Res. 6: 145-152.

Van Cleve, K., F.S. Chapin III, P.W. Flanagan, L.A. Viereck, and C.T. Dyrness (editors). 1986. Forest ecosystems in the Alaskan taiga — a synthesis of structure and function. Ecological Studies 57. Springer-Verlag. New York. 230 p.

Van Cleve, K. and L.A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. pp. 185-211. In: D.C. West, H. Shugart, and D.B. Botkin (eds). Forest Succession: Concepts and Application. Springer-Verlag, New York. 517 p.

Viereck, E.G. 1987. Alaska's wilderness medicines — healthful plants of the North. Alaska Publishing Company, Edmonds, WA. 107 p.

Viereck, L.A. and E.L. Little. 1972. Alaska trees and shrubs. USDA Forest Service Agriculture Handbook No. 410. 265 p.

Viereck, L.A. 1989. Floodplain succession and vegetation classification in interior Alaska. In: Ferguson, D. E.; Morgan, P. ; Johnson, F. D. (compilers). Proceedings, land classification based on vegetation applications for resource management. November 17-19, 1987, Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 197-203.

Walker, L.; J. Zasada, F. Chapin. 1986. The role of life history processes in primary succession on an Alaskan floodplain. Ecology 67: 1243-1253.

Walker, L. aid F. Chapin. 1986. Physiological controls over seedling growth in primary succession on an Alaskan floodplain. Ecology 67: 1508-1523.

West, S., R. Ford, J. Zasada. 1980. Population response of the northern red-backed vole to differentially cut white spruce forest. USDA Forest Serv. Res. Note PNW-362. 15 p.

Wolff, J. and J. Zasada. 1976. Red squirrel response to clearcut and shelterwood silvicultural systems in interior Alaska. USDA Forest Service Res. Note PNW-225. 7 p.

Wurtz, T. and J. Zasada. 1986. An exceptional case of natural regeneration of white spruce in interior Alaska. In: Current topics in forest research: emphasis on contributions by women scientists. Proc. National Symp. Gainesville, FL. Nov. 4-6, 1986. USDA Forest Service Gen. Tech. Report SE-46.

Youngblood, A. and J. Zasada. 1991. White spruce regeneration options on river floodplains in interior Alaska. Can. J. For. Res. 21: 423-433.

Youngblood, A. 1990. Effect of shelterwood and removal methods on established regeneration in an interior Alaska white spruce stand. Can. J. For. Res. 20: 1378-1381.

Youngblood, A. 1990. Radial growth after a shelterwood seed cut in a mature white spruce stand in interior Alaska. Can. J. For. Res. 21: 410-413.

Zasada, J., M.J. Foote, F.J. Deneke and R.H. Parkerson. 1978. Case history of an excellent white spruce cone and seed crop in interior Alaska: cone and seed production, germination, and seedling survival. USDA Forest Service General Tech. Report PNW-65. 53 p.

Zasada, J. and D. Grigal. 1980. The effects of silvicultural system and seedbed preparation on natural regeneration of white spruce and associated species in interior Alaska. Proceedings 5th North American Forest Biology Workshop 1978. p. 213-220.

Zasada, J., C. Slaughter, C. Teutsch, J. Argyle, and W. Hill. 1987. Winter logging on the Tanana River floodplain in interior Alaska. Northern J. Applied Forestry 3: 16-18.

FOREST INDUSTRY LECTURE SERIES

1. Industrial Forestry in a Changing Canada. C. Ross Silversides. 17 November 1977.
2. The Role of Integrated Companies in Western Canada. W. Gerald Burch. 15 March 1978.
3. Premises of Energy Forestry in Sweden. Gustaf Siren. 7 March 1979.
4. Agro-Forestry – Prospects and Problems. K. F. S. King. 27 September 1979.
5. The Role of the Federal Government in Forestry. F. L. C. Reed. 5 March 1980.
6. Breeding for Variable Environments. Gene Namkoong. 14 August 1980.
7. Federal Forestry Commitments in the 1980's. Roger Simmons. 5 December 1980.
8. Space, Time, and Perspectives in Forestry. Kenneth A. Armson. 26 November 1981.
9. Labour's Role in Forest Resource Management. John J. (Jack) Munro. 25 March 1982.
10. Stocking Control and Its Effect on Yields. Dr. Peder Braathe. 4 November 1982.
11. Timber Management Scheduling on Public Lands – Why the Future is Not Like the Past. Dr. K. N. Johnson. 29 March 1983. Talk only – paper not available.
12. The Canadian Schools of Forestry – Retrospect and Prospect. Dr. V. J. Nordin. 19 January 1984.
13. Increasing the Land Base and Yield Through Drainage. Dr. J. Paivanen. 15 March 1984.
14. Forestry Productivity Limits: Real, Imagined and Potential. Dr. Conor Boyd. 24 January 1985.
15. Air Pollution and Forest Resources - The Nature of the Threat. Dr. Peter Rennie. March 28, 1985. Paper not yet available.
16. Land Use Planning for Forest Harvesting and Environmental Concerns. John A. Marlow. November 28, 1985.
17. Northern Forest Management for Wildlife. Gordon W. Gullion. October 16, 1986.
18. From NSR to Intensive Forest Management. Hugo Von Sydow. 12 March 1987.
19. People - Managing Trees: Understanding Today’s Environment for Natural Resource Management. Mary Jo Lavin. 19 November 1987.
20. The Social Renewability of Forestry. Harold R. Walt. 30 March 1988.
21. Forest Policies: Public Duty and Private Action. Adam H. Zimmerman. 1 November 1988.
22. New Dimensions in the Development of Forest Policy: A View From the Trenches. T.M. (Mike) Apsey. 16 March 1989.
23. Vision and Reality - The View From Sweden. Bjorn Hagglund. 17 October 1989.
24. The Contribution of Old Growth to the New Forestry. Jerry F. Franklin. 4 April 1990.
25. Developing Silvicultural Alternatives for the Boreal Forests: An Alaskan Perspective on Regeneration of White Spruce. John Zasada. 7 November 1990.