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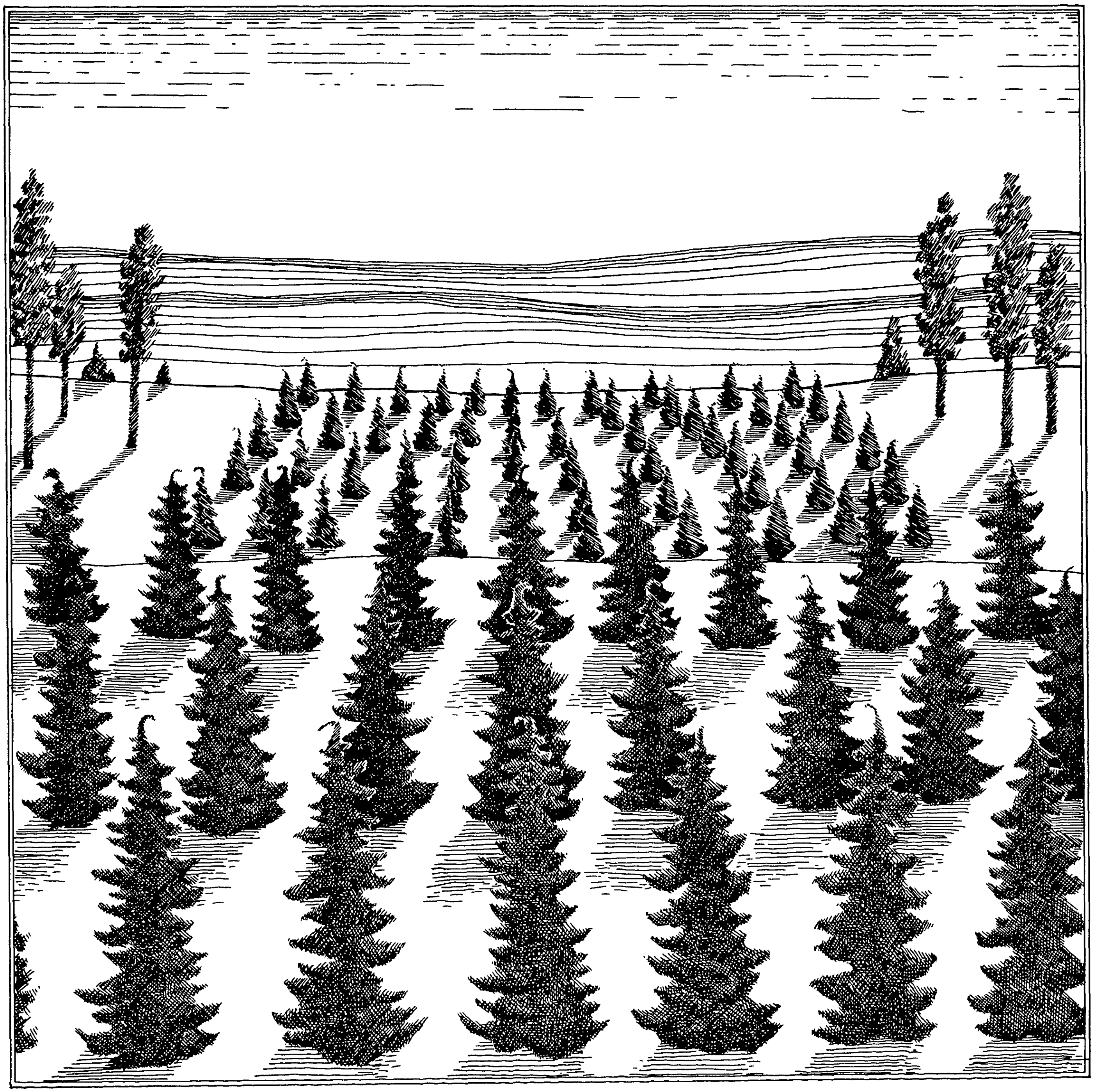
# Forest Classification at High Latitudes as an Aid to Regeneration



# FOREST CLASSIFICATION AT HIGH LATITUDES AS AN AID TO REGENERATION

Edited by

Mayo Murray

The Proceedings of a Fifth International Workshop

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CONTENTS

# INTRODUCTION

Anthony F. Gasbarro

Early in 1979, the School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks surveyed forest managers in a number of northern countries to identify topics of circumpolar interest in forest management. Responses most frequently centered on problems of forest regeneration. As a result, we initiated what was to be a series of international workshops to address the problem of obtaining adequate and economical forest regeneration at high latitudes. Our initial efforts were financed by a generous grant from the United States Department of Agriculture, U.S. Forest Service.

Since 1979, five workshops have been held, focusing on the problems of forest regeneration at high latitudes. These workshops and their respective topics were as follows:

| Year | Workshop location | Topic |
|---|---|---|
| 1979 | Fairbanks, Alaska USA | General problems related to forest regeneration in the circumpolar north |
| 1980 | Umea, Sweden | Forest regeneration problems in Sweden |
| 1981 | Prince George, British Columbia, Canada | Forest regeneration problems in northwest Canada |
| 1982 | Hinton, Alberta, Canada | Management of lodgepole pine in the boreal forest |
| 1983 | Fairbanks, Alaska USA | Forest classification at high latitudes as an aid to forest regeneration |

This report contains the papers given at the 1983 workshop. This workshop was sponsored by the School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks. The principal organizers of the workshop were Mr. Anthony F. Gasbarro and Dr. Edward Packee. The objectives of the workshop were to review systems of site classification and to identify a system or systems for aiding forest regeneration and management at northern latitudes. Sincere appreciation is expressed to the authors of the papers in this publication.

The next workshop will be held in Edmundston, New Brunswick, Canada. It will address the yield advantages of artificial regeneration at high latitudes.

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# AN ECOLOGICAL APPROACH TO FOREST MANAGEMENT

Edmond C. Packee

## INTRODUCTION

Plants are social organisms and as such form communities. Man has recognized this from the earliest times with such concepts as forests, deserts, steppe, pine forest, oak forest, and meadow. Each grouping reflects relationships among the plants in the community. Man utilized these relationships to find food and clothing items.

Today, biological classification systematically arranges living things into groups based on natural relationships; table 1 provides an example from Porter (1959) of a hierarchial classification of the grass, Poa pratensis. An ecological classification systematically arranges communities of living things into groups; it may include only the living organisms or it may include both living organisms and the abiotic environment.

An ecological classification system for forest-management purposes requires both a biological base and an abiotic base that are independent of time. The biotic base recognizes that plants are social organisms that depend upon one another as well as compete with one another for the available resources of heat, water, light, and nutrients. The abiotic base provides information on the site's capacity to provide the basic resources. The site must be classified in such a way as to eliminate the vagaries of time; events such as fire, disease, insects, wind, and harvesting activities affect the successional status of a stand, and the classification must not reflect such seral stages. Within such a classification, each unit will be uniform with respect to soil conditions and successional communities. Hence, productivity, regeneration concerns, response to fertilizer treatments, and responses to other silvicultural practices will vary only within the limits of the unit described. Such units, regardless of classification level, can be referred to as biologically valid response units.

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Table 1--The taxonomy of Poa *pratensis* (from Porter 1959)

- Kingdom—Plantae—the plant kingdom
  - Division—Embryophyta—the embryo plants
    - Subdivision—Phanaerogama—the seed plants
      - Branch—Angrospermae—seeds enclosed in an ovary
        - Class—Menocotyledoneae—the monocotyledons
          - Subclass—Glumiflorae—those with chaffy flowers
            - Order—Poales—the grasses and sedges
              - Family—Poaceae—the grass family
                - Subfamily—Festucoideae—those resembling Festuca
                  - Tribe—Festuceae—the Fescue tribe
                    - Genus—Poa—the bluegrasses
                      - Section—Prutenses—those with rhizomes
                        - Species—Poa pratensis—Kentucky bluegrass

Classification has two aims:
1. Identification of different items or units
2. Subdivision of broadly similar groups into even finer and more-specific groups (Porter 1959).

Furthermore, the classification must provide the basis for an information-storage and -retrieval system that is convenient for use. The classification is an organized index to information stored elsewhere. Finally, a good classification is an effective communication aid; the classification units provide a mental image for the parties involved.

As both an operational forester and a forest scientist, I am looking for a uniform classification of the forest ecosystems of North America and the boreal forests of the world. Josef Kostler (1956), the German forester, wrote in 1949 in Waldbau :

> As the objective of further researches, a uniform classification and standardizing of the central (and northern) European forests should be sought. That goal is still a long way off; pure plant-sociological description of forest associations has lost itself in such a multitude of types that their use for practical silvicultural problems has been rendered too difficult, apart from the fact that no uniform methods are applied.

Table 2--A classification hierarchy of ecosystems

| |
|---|
| Biome |
| Biogeoclimatic region |
| Biotic province |
| Vegetation zone |
| Vegetation series |
| Habitat type |
| Habitat-type phase |
| Ecosystem type |

Is the situation today, one-third of a century later, any different? In western North America we have two soil classifications: the Canadian and the U.S.; we use various definitions/concepts for the association; we have numerous ecological classifications: the biogeoclimatic approach using the edatopic grid of Krajina (1965, 1969) in British Columbia (Klinka et al. 1979); the habitat-type approach of Daubenmire (1952, 1968) in Washington (Daubenmire 1970), Idaho (Daubenmire and Daubenmire 1968, Pfister et al. 1977), and Montana (Pfister et al. 1977); and the biophysical land classification of Canada (Lacate 1969) in the Yukon Territory (Oswald and Senyk 1977).

With this general introduction, I will now present a preliminary classification of forest ecosystems. It is not perfect. However, the units are actual entities which can be described and mapped. The units can be used as a communication tool among land managers as well as foresters. The classification recognizes the major role of climate at the highest levels (biome, biogeoclimatic region, and biotic province), the combined effect of climate and topoedaphic features at the middle levels (vegetation zone and vegetation series), and the microenvironment at the lowest levels (habitat type, habitat-type phase, and the ecosystem type). Where appropriate, examples of the use of the classification unit in forest management are provided. In actual use, the level of the classification system required depends on the intensity of management desired.

The concepts behind the classification and the various levels are not new. Most have been used in many places, but under a variety of names. A comparison of terms used elsewhere is necessary; unfortunately, space does not permit that comparison here.

I do not pretend that this scheme is the ultimate or that it is perfect. "A 'perfect' biogeographic classification of the terrestrial world is, of course, an unattainable ideal" (Pielou 1979). I do contend that it is practicable and usable for intensive forest-management planning and prescriptions and for the extrapolation of data from elsewhere. It has been tried operationally and worked! Table 2 presents the general classification scheme.

## CLASSIFICATION HIERARCHY

### Biome

The biome is the broadest level of the taxonomy. It is the sum of the plant and animal community existing in the same geographic region (Barbour et al. 1980). Usage generally implies that the biome is a broad (continental/intercontinental) biotic community characterized by a distinctive appearance which is a response to a unique but broad range of environmental variables, especially climate (Odum 1971, Daubenmire 1978).

Table 3--Terrestrial biomes

| |
|---|
| Tundra |
| Coniferous forest |
| Deciduous forest |
| Grassland |
| Savannah |
| Tropical rain forest |
| Chaparral |
| Desert |
| Freshwater |

Table 3 lists the terrestrial biomes of the earth. Note that the boreal forests of the world are not a biome. They fall within the Coniferous Forest Biome. The hardwood forests, seral stages of boreal forests, are included within the Coniferous Forest Biome since they are time dependent and generally require disturbance for their presence.

The biomes can be mapped. In terms of intensive forestry, their usage is limited. However, in terms of ecological processes, they provide a system for identifying major differences. Factors controlling nutrient cycling in the Deciduous Forest Biome and the Grassland Biome vary considerably from the factors in the Coniferous Forest Biome. Hence, any extrapolation of data from one biome to another must be done with great care. The greatest use of the biome is for the development of general hypotheses and theories regarding ecosystem processes and functions.

### Biogeoclimatic Region

The biogeoclimatic region recognizes the regional differences in the biome. The biogeoclimatic region is a major geographic area still characterized vegetationally by a general uniformity of physiognomy, but it nevertheless recognizes differences in species composition of the overstory dominants. The difference in species composition reflects gross environmental differences, especially climate. Boundaries can be adrupt or gradual.

Within the Coniferous Forest Biome on the North American continent, there are east-west gradients and elevational gradients. Rowe's (1972) forest regions are essentially synonymous with the biogeoclimatic region and illustrate the gradients within the Canadian portions of the Coniferous Forest Biome; these are listed in table 4 along with some of their biological, geographical, and climatic characteristics.

As with the biome, the biogeoclimatic region has extremely limited utility for site-specific management interpretations. Their greatest utility is in the development of hypotheses and theories regarding ecosystem processes and structure. By recognizing the biogeoclimatic region and its characteristics, one can begin to test the validity of transferring ecosystem information from one location to another within the biome.

Data in table 4 indicate that low ambient temperatures and permafrost are characteristic features of the Northern Boreal Forest Biogeoclimatic Region; it would be difficult to transfer ecosystem-process information from there to the Coast Forest Biogeoclimatic Region. Similarly, transfer of data from the Acadian Biogeoclimatic Region to the Northern Boreal Forest should be done with great care.

### Biotic Province

The biotic province is a geographic subdivision of a biogeoclimatic region that is distinguished by a degree of flora/

Table 4—Coniferous forest biogeoclimatic regions of Canada and representative environmental characteristics (from Rowe 1972)

| | Forest Region | | | | | | |
|---|---|---|---|---|---|---|---|
| Characteristic | Acadian | Southern boreal forest | Northern boreal forest and barren | Subalpine | Montane | Columbia | Coast |
| Bio (Characteristic species) | *Picea rubens* *Picea glauca* *Picea rnariana* *Abies balsamea* | *P. glauca* *P. mariana* *A. balsamea* *Larix laricina* | *P. mariana* *P. glauca* *L. laricina* | *Abies lasiocarpa* *Picea engelmannii* *P. glauca* *Tsuga mertensiana* *Abies amabilis* | *Pseudotsuga menziesii* *Pinus ponderosa* *Pinus contorta* | *Tsuga heterophylla* *Thuja plicata* *P. menziesii* *Larix accidentalis* | *T. heterophylla* *T. plicata* *A. amabilis* *P. menziesii* *Picea sitchensis* |
| Geo (Geographic area) | Maritimes | Mid-Canada from Atlantic Ocean to Alaska | Subarctic (taiga) from Atlantic Ocean to Alaska | Higher elevations Rocky Mountains/ Coast Mountains | Interior B.C./ Southwestern Alberta | Columbia River/ Fraser River drainages | Coastal B.C. |
| Climatic (Climate) | | | | | | | |
| Mean Annual Temperature | 5 to 7°C | -6 to 6°C | -9 to 0°C | 0 to 2°C | 2 to 8°C | 7 to 8°C | 8 to 11°C |
| Mean May to September Temperature | 13 to 16°C | 9 to 15°C | 6 to 12°C | 9 to 11°C | 11 to 17°C | 16 to 17°C | 12 to 17°C |
| Number of days above 42° | 184 to 210 | 125 to 171 | 89 to 144 | 138 to 156 | 159 to 206 | 148 to 211 | 222 to 292 |
| Mean annual precipitation | 81 to 142 cm | 25 to 135 cm | 23 to 79 cm | 53 to 145 cm | 25 to 64 cm | 74 to 109 cm | 69 to 320 cm |
| Mean May-September precipitation | 36 to 53 cm | 13 to 50 cm | 15 to 41 cm | 20 to 38 cm | 13 to 38 cm | 23 to 30 cm | 13 to 81 cm |
| Potential evapotranspiration | 53 to 58 cm | 41 to 56 cm | 36 to 46 cm | 43 to 48 cm | 48 to 64 cm | 61 cm | 61 to 69 cm |
| Soil Temperature | Cool soils | Intermittent permafrost | Permafrost | Cold soils | Warm soils | Cool soils | Cool-warm soils |

fauna uniqueness. Dice **(1943)** elaborates on the uniqueness of the flora/fauna; in his definition, a biotic province "covers a considerable and continuous geographic area and is characterized by the occurrence of one or more important ecological associations that differ, at least in proportional area covered, from associations of adjacent provinces." Association, as used here, is synonymous with climax plant community. The geologic history of the flora is clearly imprinted in vegetation patterns; groups of plant species appear to "have had somewhat parallel histories of migration in recent geologic time, owing to common limitations in the configuration of land masses and climatic pressures that have induced migrations within each land mass. This is a significant point, since similar migratory patterns are evidence of a degree of similarity in the ecologies of the species" (Daubenmire **1968)**. In summary, then, a biotic province consists of biotic communities which have had a similar recent geologic and climatic history, which currently form a distinctive geographic unit, and which exhibit strong evidence of taxonomic homogeneity.

Figure **1** is a map of the tentative biotic provinces of coastal British Columbia and adjacent Washington and Oregon. Table 5 is a distribution table of the tree species present in each of the tentative biotic provinces; no attempt has been made to place any importance values on the species. Table **6** provides Jaccard's coefficient of community similarity for the tree species in each biotic province; the larger the number, the more similar are the biotic provinces being compared. From table *6* it is apparent that, on the basis of tree species alone, the Glacier Peak and Queen Charlotte Islands are most dissimilar.

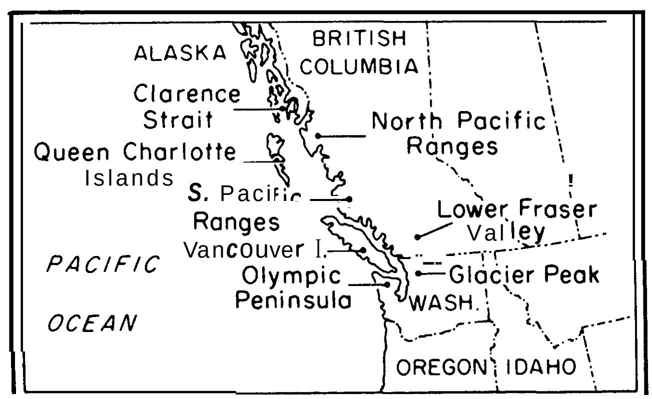



Figure 1.--Map of the biotic provinces of coastal British Columbia and adjacent Washington and Alaska.

On the other hand, Vancouver Island, South Pacific Ranges, Lower Fraser Valley, Olympic Peninsula, and Glacier Peak biotic provinces are quite similar and additional analyses using minor vegetation and/or fauna will be required to justify their continued separation.

The significance of the biotic provinces to the operational forester is often overlooked. Since there are geographical and biological differences between biotic provinces, there is a probability that environmental differences also occur. This suggests extra caution in transferring technology (e.g. planting-practice guidelines, stock type, survival/growth data) or

Table 5--Distribution of tree species by tentative biotic provinces in coastal British Columbia and adjacent Alaska and Washington

Conifers

| | Province* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ABAM | | + | | + | + | + | + | + | + |
| ABGR | | | | | + | + | + | + | + |
| ABLA2 | + | + | | + | + | + | + | + | + |
| ABPR | | | | | | | | | + |
| CHNO | + | + | + | + | + | + | + | + | + |
| JUSC | | | | | + | | | + | |
| LALY | | | | | | | | | + |
| PIEN | | | | | | + | + | + | + |
| PISI | + | + | + | + | + | + | + | + | + |
| PIAL | | | | + | | + | + | | + |
| PICO | + | + | + | + | + | + | + | + | + |
| PIMO | | | | | + | + | + | + | + |
| PIPO | | | | | | | | | + |
| PSME | | | | + | + | + | + | + | + |
| TABR | | + | + | + | + | + | + | + | + |
| THPL | | + | + | + | + | + | + | + | + |
| TSHE | + | + | + | + | + | + | + | + | + |
| TSME | + | + | + | + | + | + | + | + | + |
| | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | 6 | 9 | 7 | 11 | 13 | 14 | 14 | 14 | 17 |

Hardwoods

| | Province | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ACCI | | | | | + | + | + | + | + |
| ACGL | + | + | | + | + | + | + | + | + |
| ACMA | | | | + | + | + | + | + | + |
| ALRU | + | + | + | + | + | + | + | + | + |
| ALSI | + | + | + | + | + | + | + | + | + |
| ALTE | + | | | | | | | | |
| ARME | | | | | + | + | + | + | + |
| BEPA | + | | | + | + | + | + | | + |
| CONU | | | | | + | + | + | + | + |
| POBA2 | + | | | | | | | | |
| POTR2 | + | | | + | + | + | + | | + |
| POTR | + | + | | | + | + | + | + | + |
| PREM | | | | + | + | + | + | + | + |
| PRUI | | | | | + | + | + | + | + |
| PYFU | + | + | + | + | + | + | + | + | + |
| QUGA | | | | | + | | + | + | + |
| | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | 9 | 5 | 3 | 8 | 14 | 13 | 14 | 12 | 14 |

*1 = Chatham Strait 3 = Queen Charlotte Islands 5 = Vancouver Island 7 = Lower Fraser Valley 9 = Glacier Peak
2 = Clarence Strait 4 = North Pacific Ranges 6 = South Pacific Ranges 8 = Olympic Peninsula
**Species coding follows that of Packee (1981), first two letters of genus and first two letters of species, e.g. ABAM = Abies amabilis

Table 6--Jaccard's coefficient of community similiarity (K = c/(a + b - c) for tentative biotic provinces of coastal British Columbia and adjacent Alaska and Washington, based on the presence of tree species

| | | Biotic Province* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | (x) | 1.00 | | | | | | | | |
| | (y) | 1.00 | | | | | | | | |
| | (z) | 1.00 | | | | | | | | |
| 2 | (x) | .61 | 1.00 | | | | | | | |
| | (y) | .67 | 1.00 | | | | | | | |
| | (z) | .56 | 1.00 | | | | | | | |
| 3 | (x) | .47 | .71 | 1.00 | | | | | | |
| | (y) | .63 | .78 | 1.00 | | | | | | |
| | (z) | .33 | .60 | 1.00 | | | | | | |
| 4 | (x) | .55 | .74 | .53 | 1.00 | | | | | |
| | (y) | .55 | .82 | .63 | 1.00 | | | | | |
| | (z) | .54 | .62 | .38 | 1.00 | | | | | |
| 5 | (x) | .55 | .52 | .37 | .64 | 1.00 | | | | |
| | (y) | .46 | .69 | .54 | .71 | 1.00 | | | | |
| | (z) | .44 | .36 | .21 | .57 | 1.00 | | | | |
| 6 | (x) | .45 | .52 | .37 | .70 | .86 | 1.00 | | | |
| | (y) | .43 | .64 | .50 | .79 | .80 | 1.00 | | | |
| | (z) | .44 | .38 | .23 | .62 | .93 | 1.00 | | | |
| 7 | (x) | .43 | .50 | .36 | .68 | .90 | .96 | 1.00 | | |
| | (y) | .43 | .64 | .50 | .79 | .80 | 1.00 | 1.00 | | |
| | (z) | .44 | .36 | .21 | .57 | 1.00 | .93 | 1.00 | | |
| 8 | (x) | .35 | .54 | .38 | .61 | .89 | .83 | .86 | 1.00 | |
| | (y) | .43 | .64 | .50 | .67 | .93 | .87 | .87 | 1.00 | |
| | (z) | .31 | .42 | .25 | .47 | .86 | .79 | .86 | 1.00 | |
| 9 | (x) | .39 | .45 | .32 | .61 | .81 | .87 | .90 | .78 | 1.00 |
| | (y) | .35 | .53 | .41 | .65 | .67 | .82 | .82 | .72 | 1.00 |
| | (z) | .44 | .36 | .21 | .57 | 1.00 | .93 | 1.00 | .86 | 1.00 |

x = conifers and hardwoods
y = conifers only
z = hardwoods only

* 1 = Chatham Strait 6 = South Pacific Ranges
2 = Clarence Strait 7 = Lower Fraser Valley
3 = Queen Charlotte Islands 8 = Olympic Peninsula
4 = North Pacific Ranges 9 = Glacier Peak
5 = Vancouver Island

biological material (e.g. seed) where the coefficient of community similarity is low, below 0.75. Using Jaccard's similarity coefficients from table 6, one can note an environmental gradient along the outer coast from the Olympic Peninsula to the Chatham Strait Biotic Province: 1.00, 0.89, 0.38, 0.54, 0.35. Factors that are associated with this gradient include: temperature, day-length, and snow. In addition, factors other than those associated with the gradient appear to be involved with the Queen Charlotte Islands; one major concern is their isolation which accounts for the lack of some species, especially the heavy seed *Abies amabilis* and *Abies lasiocarpa* which also suggests genetic population differences.

## Vegetation Zone

A vegetation zone is a portion of the landscape ultimately occupied by a taxonomically closely related group of plant communities (Pfister et al. 1977). It is characterized by an individual or a distinct group of climax overstory dominants that reflects the macroclimate and are the most frequently occurring on the landscape. Since this group of overstory dominants is the most frequently occurring, the group can be considered as modal. Other overstory climax communities occur as minor components clustered around the modal climax community; these are, however, ignored in defining the vegetation zone since they reflect "abnormal" or extremes of soil, topography, or climate.

Daubenmire (1978) incorporates soil into his definition of the vegetation zone: "All the area in which zonal soils have the potentiality of supporting the same climatic climax plant association." Vegetation zones may occur as sequential belts on mountain slopes or on flat terrain. Figure 2 is a schematic representation of the vegetation zones found in the biotic provinces of south coastal British Columbia and adjacent northern Washington. The vegetation zone names are written in shorthand form: the first two letters of the genus and the first two letters of the species names; thus, ABAM-TSME

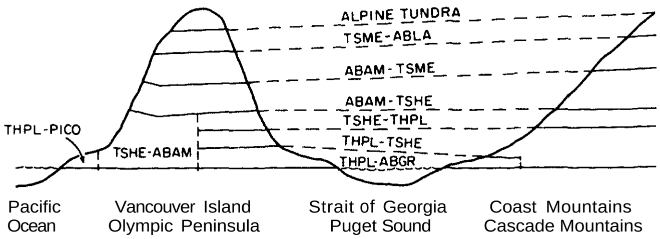



Figure 2.--Vegetation zones of south coastal British Columbia and adjacent Washington.

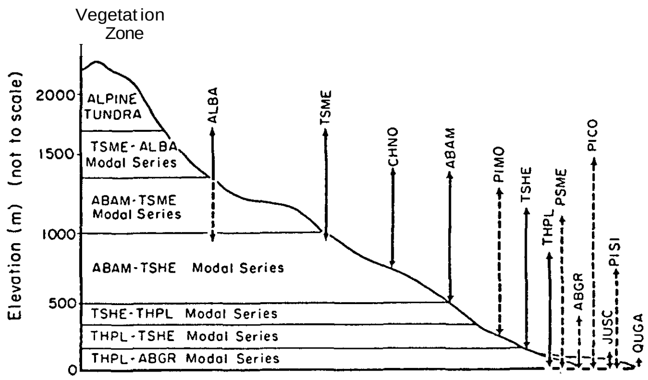



Figure 3.–Distribution of conifer trees in an area of the east coast of Vancouver Island, British Columbia. Arrows show the relative elevational range for each species; solid portion of range line indicates where a species is part of the potential climax and dashed portion where it is seral. Note that the modal vegetation identifies the vegetation zone.

stands for *Abies amabilis-Tsuga mertensiana*, and THPL-PICO stands for *Thuia plicate-Pinus contorta.*

In 1976, I published (Packee 1976) a demonstrated relationship among the vegetation zones in south coastal British Columbia based on potential soil-moisture deficits (both intensity and duration of a deficit) which reflect heat and water availability. Figure 3 is a schematic ordination of the vegetation zones along increasing moisture and decreasing temperature axes.

The vegetation zone is the broadest ecosystem unit which has site-specific implications for management. It is the first level of consideration for problem analyses, testing hypotheses, developing silvicultural guidelines, and planning. It also provides the entry into keys for determining the more specific ecosystem units (vegetation series, habitat type, and habitat-type phase).

Seed requirements should be determined for each species by vegetation zones. Generally, attempts are made to obtain a good representation (several provenances) of the site types within a vegetation zone. Sowing requests should attempt to match seed for a particular site to seed collected from a similar site of the same vegetation zone. Provenance studies should use vegetation zones as one ecological stratum for testing.

General guidelines for matching species to site should be based on vegetation-zone characteristics. For example, the two vegetation zones, ABAM-TSME and THPL-PICO, are considered to be largely unsuited for the management of *Pseudotsuga menziesii*. In the past it was planted in these vegetation zones; now that these zones can be readily identified, it is only planted on a very few specific sites.

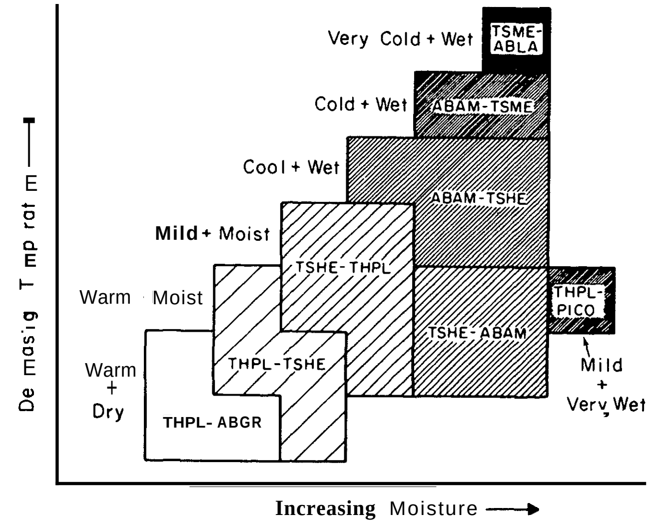



Figure 4.--Schematic ordination of vegetation zones of southern coastal British Columbia and adjacent Washington.

Vegetation zones can be used to identify potential seedling-survival hazards, time available for planting, and stock-acclimation requirements.

Vegetation Series

The vegetation series is a unit of the landscape potentially capable of supporting essentially the same overstory climax plant community. Owing to their upper-canopy position, such overstory species are strongly influenced by climate (Daubenmire 1968), however, strong topoedaphic factors also affect their occurrence. Through their effects on the understory environment of light, heat, moisture, and nutrients, to which other speices of the community must be adapted, the overstory dominants strongly determine the understory composition. Thus, the vegetation series is a hierarchial level intermediate between the macroenvironment (the vegetation zone level and the microenvironment (the habitat type) level.

An understanding of the successional role of each overstory dominant species is essential to apply the vegetation-series concept. Figure 4 provides distributional as well as successional information about the species occurring on the east coast of Vancouver Island. Note that *Pinus contorta* (PICO) and ***Pinus*** *monticolu* (PIMO), both common overstory species with a broad elevational range, are seral; therefore, since they are not climax, they do not participate in defining the vegetation series. Pfister et al. (1977) developed a key to the nine vegetation series found in Montana, which is reproduced as table 7. In both the Vancouver Island and Montana examples, relative shade tolerance is used to determine the successional status of the species.

The name of the vegetation series is based on the one or two most important climax species. In Montana, a single species was adequate; in coastal British Columbia, two species were necessary to identify the vegetation series.

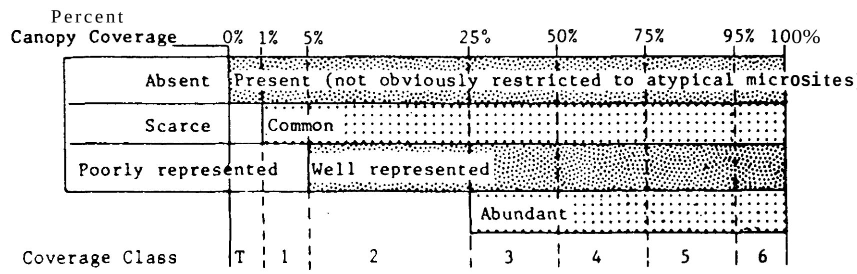
The vegetation series provides the resource manager with basic information upon which to base gross management decisions for a specific site. It also provides the researcher with an ecological framework for designing studies.

In coastal British Columbia, some vegetation series automatically limit the level of intensive management, the species suitable for management, and the harvesting options. The

Table 7.--Key to vegetation series of western Montana and habitat types and habitat-type phases of the *Pinus flexilis* vegetation series (from Pfister et al. 1977).

Read These Instructions First!

1. Use this key for stands with a mature tree canopy that are not severely disturbed by grazing, logging, forest fire, etc. (If the stand is severely disturbed or in an early successional stage, the habitat type can best be determined by extrapolating from the nearest mature stand occupying a similar site.)
2. Accurately identify and record canopy coverages for all indicator species (appendix F).
3. Check plot data in the field to verify that the plot is representative of the stand as a whole. If not, take another plot.
4. Identify the correct potential climax tree species in the SERIES key. (Generally, a tree species is considered reproducing successfully if 10 or more individuals per acre occupy or will occupy the site.)
5. Within the appropriate series, key to HABITAT TYPE by following the key literally. Determine PHASE by matching the stand conditions with the phase descriptions for the type. (The first phase description that fits the stand is the correct one.)
6. Use the definitions diagramed below for canopy coverage terms in the key. If you have difficulty deciding between types, refer to constancy and coverage data (appendix C-1) and the habitat type descriptions.
7. In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, adjust the above definitions to the next lower coverage class (e.g., well represented >1%, common >0%).
8. Remember, the key is NOT the classification! Validate the determination made using the key by checking the written description.




KEY TO **CLIMAX** SERIES (Do Not Proceed Until You Have Read the Instructions!)

1. Habitats on steep slopes (30°) composed primarily of unstable fine rock; undergrowth sparse, poorly developed and quite variable. . . . SCREE (p. 121)
1. Habitats on sites with some soil development and stability; undergrowth rather well developed and somewhat uniform. . . . . . . . . . 2

2. Tsuga heterophylla present and reproducing successfully . . . . . . . TSUGA HETEROPHYLLA SERIES (item C)
2. Tsuga heterophylla not the indicated climax . . . . . . . . . . . . . . 3

3. Thuja plicata present and reproducing successfully. . . . . . . . . . . . THUJA PLICATA SERIES (item F)
3. Thuja plicata not the indicated climax. . . . . . . . . . . . . . . . . . . 4

4. Abies grandis present and reproducing more successfully than Abies lasiocarpa. . . . . . . . . . . . . . . . . . . . . . . . . . . . ABIES GRANDIS SERIES (item E)
4. Abies grandis not the indicated climax. . . . . . . . . . . . . . . . 5

5. Abies lasiocarpa, Tsuga mertensiana, or Larix lyallii present and reproducing successfully, or Pinus albicaulis the dominant tree . . . . . ABIES LASIOCARPA SERIES (item I)
5. Not as above. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 6

6. Picea present and reproducing successfully. . . . . . . . . . . . . . . PICEA SERIES (item D)
6. Picea not the indicated climax. . . . . . . . . . . . . . . . . . . . . 7

7. Pinus flexilis a successfully reproducing dominant; often sharing that status with Pseudotsuga . . . . . . . . . . . . . . . . . . . . . . . . PINUS FLEXILIS SERIES (item A)
7. Pinus flexilis absent or clearly seral. . . . . . . . . . . . . . . . . . 8

8. Pseudotsuga menziesii present and reproducing successfully. . . . . . PSEUDOTSUGA MENZIESII SERIES (item C)
8. Pseudotsuga menziesii not the indicated climax. . . . . . . . . . . . 9

9. Pure Pinus contorta stands, with little evidence as to potential climax. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . PINUS CONTORTA SERIES (item H)
9. Pinus contorta absent; Pinus ponderosa the indicated climax . . . . . . . PINUS PONDEROSA SERIES (item B)

Key to *Pinus flexilis* Habitat Types

1. Festuca idahoensis well represented or F. scabrella common. . . . . . . . **PINUS** FLEXILIS/FESTUCA IDAHOENSIS h.t. (p. 25)
   a. Festuca scabrella common. . . . . . . . . . . . . . . . . . . . . . FESTUCA SCABRELLA phase
   b. F. scabrella scarce . . . . . . . . . . . . . . . . . . . . . . . . FESTUCA IDAHOENSIS phase
1. F. idahoensis poorly represented and F. scabrella scarce. . . . . . . . . 2

2. Agropyron spicatum well represented . . . . . . . . . . . . . . . . . PINUS FLEXILIS/AGROPYRON SPICATUM h.t. (p. 24)
2. A. spicatum poorly represented; Juniperus communis (or J. horizontalis) well represented . . . . . . . . . . . . . . . . .PINUS FLEXILIS/JUNIPERUS COMMUNIS h.t. (p. 26)

Table 8.--Key to the habitat types and habitat-type phases of the *Pinus ponderosa* and *Pseudotsuga menziesii* vegetation series in western Montana (from Pfister et al. 1977).

## Key to *Pinus ponderosa* Habitat Types

| | |
|---|---|
| 1. Prunus virginiana well represented; only in southeastern Montana . . . . . . | PINUS PONDEROSA/PRUNUS VIRGINIANA h.t. (p. 34) |
| a. Shepherdia canadensis well represented . . . . . . . . . . . . | SHEPHERDIA CANADENSIS phase |
| b. Shepherdia poorly represented . . . . . . . . . . . . . . . . | PRUNUS VIRGINIANA phase |
| 1. P. virginiana poorly represented . . . . . . . . . . . . . . . . . . . . . | 2 |
| 2. Symphoricarpos albus well represented . . . . . . . . . . . . . . . . . | PINUS PONDEROSA/SYMPHORICARPOS ALBUS h.t. (p. 33) |
| a. Berberis repens common . . . . . . . . . . . . . . . . . . . . | BERBERIS REPENS phase |
| b. Berberis scarce . . . . . . . . . . . . . . . . . . . . . . . | SYMPHORICARPOS ALBUS phase |
| 2. S. albus poorly represented . . . . . . . . . . . . . . . . . . . . | 3 |
| 3. Purshia tridentata well represented . . . . . . . . . . . . . . . . . . | PINUS PONDEROSA/PURSHIA TRIDENTATA h.t. (p. 32) |
| a. Festuca idahoensis well represented or F. scabrella common . . | FESTUCA IDAHOENSIS phase |
| b. F. idahoensis poorly represented and F. scabrella scarce . . . | AGROPYRON SPICATUM phase |
| 3. Purshia poorly represented . . . . . . . . . . . . . . . . . . . . . . . | 4 |
| 4. Festuca idahoensis well represented or F. scabrella common . . . . . . . | PINUS PONDEROSA/FESTUCA IDAHOENSIS h.t. (p. 31) |
| a. Festuca scabrella common . . . . . . . . . . . . . . . . . . . . | FESTUCA SCABRELLA phase |
| b. F. scabrella scarce . . . . . . . . . . . . . . . . . . . . . | FESTUCA IDAHOENSIS phase |
| 4. F. idahoensis poorly represented and F. scabrella scarce . . . . . . . . . | 5 |
| 5. Agropyron spicatum well represented . . . . . . . . . . . . . . . . . . . . | PINUS PONDEROSA/AGROPYRON SPICATUM h.t. (p. 30) |
| 5. A. spicatum poorly represented; Andropogon spp. well represented . . . . . . | PINUS PONDEROSA/ANDROPOGON h.t. (p. 30) |

## Key to *Pseudotsuga menziesii* Habitat Types

| | |
|---|---|
| 1. Vaccinium caespitosum present . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/VACCINIUM CAESPITOSUM h.t. (p. 39) |
| 1. V. caespitosum absent . . . . . . . . . . . . . . . . . . . . . . . | 2 |
| 2. Physocarpus malvaceus or Holodiscus discolor well represented . . | PSEUDOTSUGA MENZIESII/PHYSOCARPUS MALVACEUS h.t. (p. 41) |
| a. Calamagrostis rubescens and/or Carex geyeri are the dominant undergrowth . . . . . . . . . . . . . . . . . . . . . . | CALAMAGROSTIS RUBESCENS phase |
| b. Physocarpus and/or Holodiscus dominate the undergrowth. . . . . . | PHYSOCARPUS MALVACEUS phase |
| 2. Physocarpus and Holodiscus poorly represented . . . . . . . . . . | 3 |
| 3. Linnaea borealis common . . . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/LINNAEA BOREALIS h.t. (p. 44) |
| a. Symphoricarpos albus well represented . . . . . . . . . . . . . . . | SYMPHORICARPOS ALBUS phase |
| b. Vaccinium globulare well represented . . . . . . . . . . . . . . . | VACCINIUM GLOBULARE phase |
| c. Not as above . . . . . . . . . . . . . . . . . . . . . . . . . | CALAMAGROSTIS RUBESCENS phase |
| 3. Linnaea scarce . . . . . . . . . . . . . . . . . . . . . . . . . . | 4 |
| 4. Vaccinium globulare or Xerophyllum tenax well represented . . . . | PSEUDOTSUGA MENZIESII/VACCINIUM GLOBULARE h.t. (p. 43) |
| a. Arctostaphylos uva-ursi and Pinus ponderosa common . . . . . . . | ARCTOSTAPHYLOS UVA-URSI phase |
| b. Xerophyllum common . . . . . . . . . . . . . . . . . . . . . . | XEROPHYLLUM TENAX phase |
| c. Not as above . . . . . . . . . . . . . . . . . . . . . . . . . | VACCINIUM GLOBULARE phase |
| 4. Vaccinium globulare and Xerophyllum tenax poorly represented . . . | 5 |
| 5. Symphoricarpos albus well represented . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/SYMPHORICARPOS ALBUS h.t. (p. 45) |
| a. Bunchgrasses well represented in old-growth stands . . . . . . . | AGROPYRON SPICATUM phase |
| b. Calamagrostis rubescens well represented . . . . . . . . . . . . | CALAMAGROSTIS RUBESCENS phase |
| c. Not as above . . . . . . . . . . . . . . . . . . . . . . . . . | SYMPHORICARPOS ALBUS phase |
| 5. S. albus poorly represented . . . . . . . . . . . . . . . . . . . . | 6 |
| 6. Calamagrostis rubescens well represented . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/CALAMAGROSTIS RUBESCENS h.t. (p. 47) |
| a. Bunchgrasses well represented in old-growth stands . . . . . . . | AGROPYRON SPICATUM phase |
| b. Arctostaphylos uva-ursi common; sites capable of supporting Pinus ponderosa and not too dry for Pinus contorta (or Larix occidentalis) . . . . . . . . . . . . . | ARCTOSTAPHYLOS UVA-URSI phase |
| c. Pinus ponderosa common . . . . . . . . . . . . . . . . . . . . | PINUS PONDEROSA phase |
| d. Not as above . . . . . . . . . . . . . . . . . . . . . . . . . | CALAMAGROSTIS RUBESCENS phase |
| 6. C. rubescens poorly represented . . . . . . . . . . . . . . . . . . | |
| 7. Carex geyeri well represented . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/CAREX GEYERI h.t. (p. 51) |
| 7. C. geyeri poorly represented . . . . . . . . . . . . . . . . . . . | 8 |
| 8. Arctostaphylos uva-ursi well represented and Pinus ponderosa present . . . . . . . . . . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/ARCTOSTAPHYLOS UVA-URSI h.t. (p. 52) |
| 8. Arctostaphylos poorly represented or stands above elevational limits of Pinus ponderosa . . . . . . . . . . . . . . . . . . . | 9 |
| 9. Juniperus communis (or J. horizontalis) dominates the undergrowth . . | PSEUDOTSUGA MENZIESII/JUNIPERUS COMMUNIS h.t. (p. 53) |
| 9. J. communis not the dominant undergrowth plant . . . . . . . . . . | 10 |
| 10. Spiraea betulifolia well represented . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/SPIRAEA BETULIFOLIA h.t. (p. 52) |
| 10. S. betulifolia poorly represented . . . . . . . . . . . . . . . . . | 11 |
| 11. Arnica cordifolia or Antennaria racemosa the dominant undergrowth . . | PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t. (p. 54) |
| 11. A. cordifolia and A. racemosa not the dominant undergrowth . . . . . | 12 |
| 12. Festuca scabrella common . . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/FESTUCA SCABRELLA h.t. (p. 38) |
| 12. F. scabrella scarce . . . . . . . . . . . . . . . . . . . . . . . | 13 |
| 13. Symphoricarpos oreophilus well represented and Festuca idahoensis scarce . . . . . . . . . . . . . . . . . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS h.t. (p. 55) |
| 13. Not as above . . . . . . . . . . . . . . . . . . . . . . . . . . | 14 |
| 14. Festuca idahoensis common; Pinus ponderosa scarce . . . . . . . . | PSEUDOTSUGA MENZIESII/FESTUCA IDAHOENSIS h.t. (p. 38) |
| 14. F. idahoensis usually scarce; Agropyron spicatum well represented; Pinus ponderosa usually common . . . . . . . . . . . . | PSEUDOTSUGA MENZIESII/AGROPYRON SPICATUM h.t. (p. 37) |

Table 9--Relative resource potential ratings for northern Idaho forest-habitat types' (from Pfister 1976)

| Habitat types' | Timber[3] | Big-game forage[4] | Domestic-livestock forage[5] | Water yield[6] | Esthetic recovery rate[7] |
|---|---|---|---|---|---|
| | Resource potential ratings (1=very low to 10=very high) | | | | |
| *Pinus ponderosa/Stipa comata* | 2 | 1 | 6 | 1 | 1 |
| *Pinus ponderosa/Agropyron spicatum* | 2 | 2 | 10 | 1 | 3 |
| *Pinus ponderosa/Festuca idahoensis* | 3 | 3 | 10 | 1 | 3 |
| *Pinus ponderosa/Purshia tridentata* | 3 | 5 | 7 | 2 | 4 |
| *Pinus ponderosa/Symphoricarpos albus* | 5 | 4 | 8 | 2 | 5 |
| *Pinus ponderosa/Physocarpus malvaceus* | 6 | 7 | 7 | 3 | 7 |
| *Pseudotsuga menziesii/Symphoricarpos albus* | 6 | 5 | 7 | 3 | 6 |
| *Pseudotsuga menziesii/Physocarpus malvaceus* | 8 | 8 | 4 | 4 | 8 |
| *Pseudotsuga menziesii/Calamagrostis rubescens* | 6 | 4 | 5 | 4 | 3 |
| *Abies grandis/Pachistima myrsinites* | 9 | 10 | 3 | 5 | 10 |
| *Thuja plicata/Pachistima myrsinites* | 9 | 10 | 2 | 6 | 10 |
| *Thuja plicata/Athyrium filix-femina* | 7 | 6 | 1 | ? | 9 |
| *Thuja plicata/Oplopanax horridum* | 7 | 6 | 1 | ? | 9 |
| *Tsuga heterophylla/Pachistima myrsinites* | 10 | 10 | 2 | 7 | 10 |
| *Abies lasiocarpa/Pachistima myrsinites* | 7 | 10 | 2 | 8 | 9 |
| *Abies lasiocarpa/Xerophyllum tenax* | 4 | 4 | 1 | 6 | 4 |
| *Abies lasiocarpa/Menziesia ferruginea* | 6 | 6 | 1 | 10 | 8 |
| *Tsuga mertensiana/Xerophyllum tenax* | 3 | 4 | 1 | 10 | 8 |
| *Tsuga mertensiana/Menziesia ferruginea* | 5 | 6 | 1 | 10 | 8 |
| *Abies lasiocarpa/Vaccinium scoparium* | 4 | 4 | 3 | 8 | 2 |
| *Pinus albicaulis/Abies lasiocarpa* | 1 | 2 | 4 | 10 | 1 |

[1] Modified from Pfister, Robert; Schmautz, Jack; On, Danny, and Brown, Clarence. Management implications by habitat types. Training Manual, Mimeo, USDA For. Serv., North. Reg; 1971.30 p.
[2] Habitat types: Daubenmire and Daubenmire (1968).
[3] Estimated relative yield capability based on available site index and yield data.
[4] Estimated relative amount of desirable forage for deer and elk produced in early successional stages.
[5] Estimated relative amount of desirable forage for cattle and sheep produced in later successional stages.
[6] Estimated relative off-site water-yield production, considering relative precipitation and relative evapotranspiration loss.
[7] Based on height of common seral species and rate of secondary succession following major vegetative disturbance and minor soil disturbance.

*Alnus rubra* vegetation series is suitable only for *Alnus rubra* or *Populus trichocarpa*, the value of the species for fiber is low, and environmental constraints and concerns strongly affect harvesting methods and accessibility. There is little justification for the investment of silvicultural resources on such marginal sites. Similarly, it is now well recognized that management €or *Pseudotsuga menziesii* is questionable on all sites within the *Abies amabilis-Tsuga martensiana* vegetation series. Within the same vegetation series, alternatives to large clearcuts should be investigated since clearcutting commonly aggravates problems associated with prompt regeneration.

For the *Thuja plicata-Pinus contorta* vegetation series, the development engineer should recognize the impacts that harvesting and roadbuilding will have on the soil-moisture regime. Of major concern are paludification and blockage of the watercourses which will result in'excess water on the site and reduced or lost productivity.

## Habitat Type

The habitat type is ''an aggregation of all land areas potentially capable of producing similar plant communities" (Pfister et al. 1977); "potentially" implies "at climax." Daubenmire (1978) defines habitat type as "a collective term for all parts of the land surface supporting or capable of supporting the same kind of climax plant association." The habitat type groups together as one unit various sites that support a particular climax plant community; although landform, soil, slope, aspect, and other site variables individually can be quite different, the sum of these variables results in essentially equivalent climax plant communities.

Because of the impact that the overstory community exerts on the understory environment, the understory plant community not only reflects topographic and edaphic conditions, but also biologically imposed conditions. One of the most obvious biological impacts of the overstory climax vegetation is its affect on the quantity and quality of light reaching the lower plant strata. The more dense the shade, the more shade tolerant must be the understory species. Yet light does not explain everything! The overstory canopy reduces the solar radiation reaching the forest floor; this reduces the amount of heat reaching the forest floor. The less the solar radiation, the cooler the soil and the longer the retention of snowpack. This favors the survival of the more cold-tolerant species over the more heat-demanding species.

The habitat type is described by the overstory climax plant community and the associated understory community. The vegetation series describes the overstory community; the understory community is described using a limited, but adequate, number of characteristic understory species. Tables 7 and 8 are keys to habitat types for three of the vegetation series in Montana as presented by Pfister et al. (1977). Note the emphasis on following instructions in spite of the apparent simplicity.

Habitat types are a primary management unit. They are reference points for evaluating the environmental setting and predicting response. They are intended for use by resource managers and scientists.

Habitat types have been used for many forest-managment activities. Table 9 provides an example from Pfister (1976) of

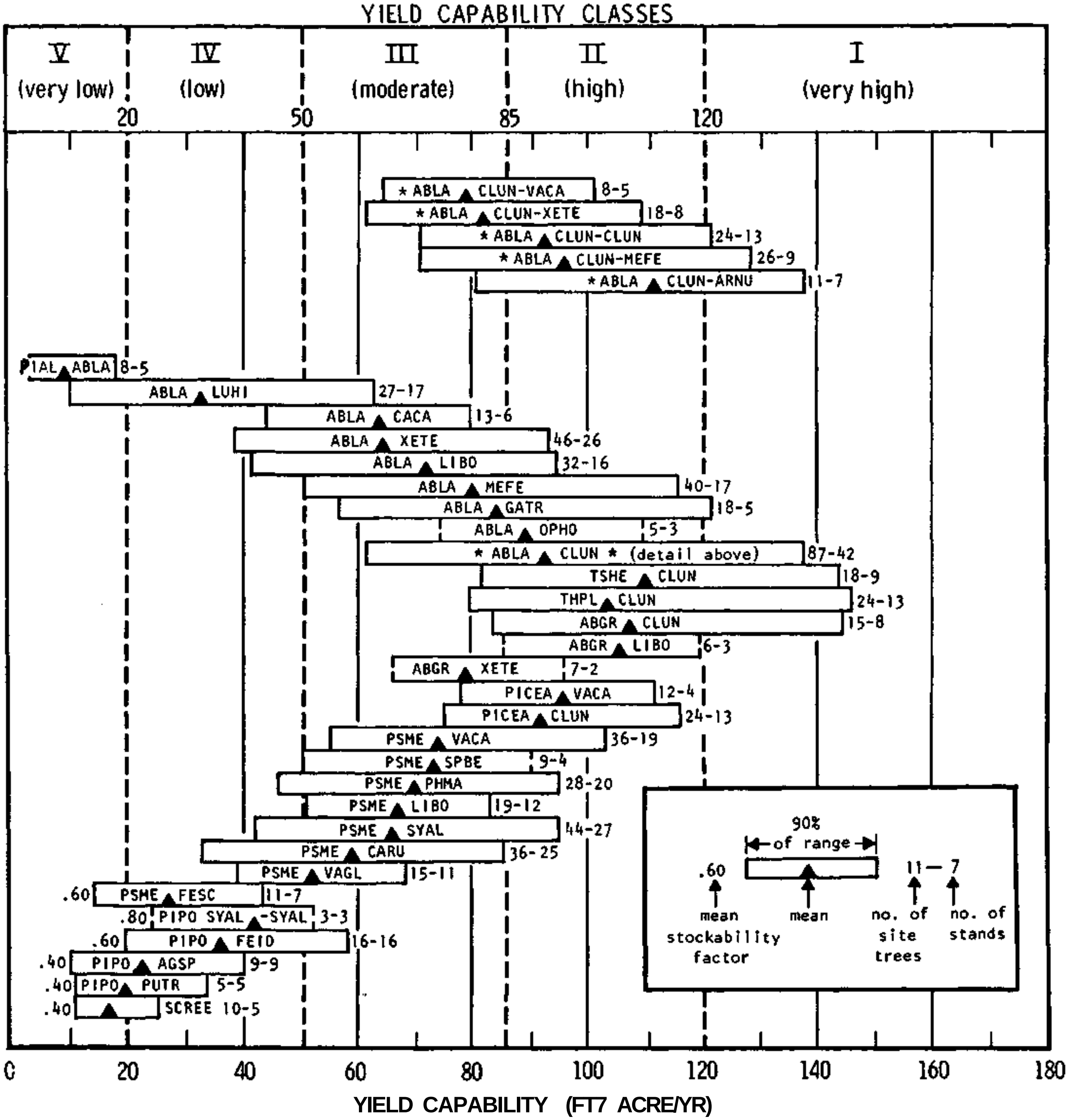



Figure 5.-Estimated yield capabilities of west-side Montana habitat types based on site-index data and stockability factors. (Kootenai, Flathead, Lolo, and Bitterroot National Forests) (from Pfister et al. 1977).

using habitat types to rate the resource potential of forest lands in northern Idaho. Figure 5 provides timber-yield capability classes for habitat types found in West-side Montana forests (Pfister et al. 1977). Habitat types are useful for identifying preferred and acceptable species for management. Obviously, it is risky to manage for a species on sites where it does not occur naturally or is under stress. Equally important is the identification of the most-appropriate species in terms of yield, value, and cost of establishment and maintenance.

The habitat type permits prediction of plant succession following disturbance. This should permit early identification of brush or grass problems and the selection of appropriate site-preparation methods and necessary stand-tending practices, The habitat type has been used to identify logging-equipment limitations, setting, boundaries, and windthrow risk,

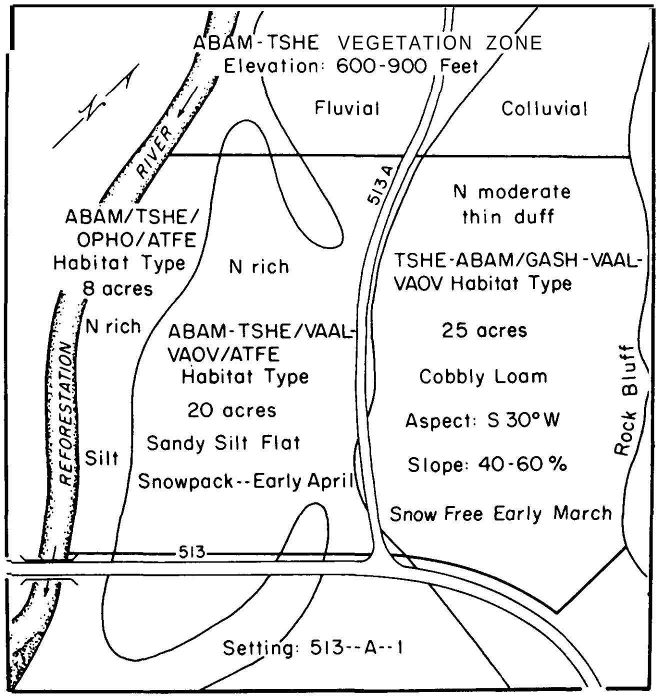
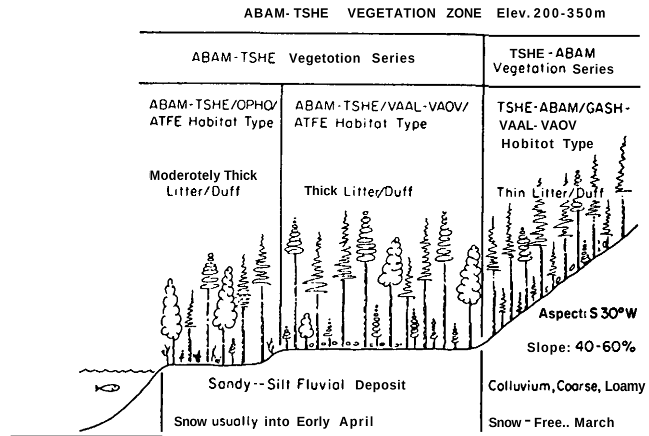



Figure 6.--Map of habitat types for a logging setting on Vancouver Island.




| | | | |
|---|---|---|---|
| Species Preference: | THPL | ABAM-TSHE | PSME |
| Regenerotion Method: | Plont 750/ocre | Plonl AEAM 450/ocre<br>TSHE Seeds noturolly | Plonl 450/ocre |
| Site Preporation: | Burn, Brush, Alder seed-tree control | Burn, Brush, Alder seed-tree control | Log clean, No fire |
| Competition: | Solmonberry Alder | Solmonberry & Huckleberry Alder | |
| Nutrition (N): | Adequote | Ureo with S | Urea ot 200 lb N/ocre |
| Logging constraints: | No Skidders Stream Core | No Skidders | |

Figure 7.--Cross-sectional sketch of logging setting of Figure 6 with prescriptions.

Figure 6 is a map of an actual logging setting on Vancouver Island. It is in a cold-air drainage corridor involving two major land-form types: fluvial and colluvial. Figure 7 is a schematic cross-sectional view of the setting. Below the sketch are the prescriptions for the three habitat types within the setting. Note the immediate regeneration-related concerns: species preference, regeneration method, desired number of stems per acre, and site-preparation requirements.

In conclusion, an ecological classification based on valid biological response is an important forest-management tool. At this time classification to the habitat-type level appears to be more than adequate in North America. Management at this level is now only beginning to be tried. Classificaton to more—specific units, the habitat-type phase, and ecosystem type (the latter incorporating specific soils information) is not warranted until operationally deemed necessary. Hence these two levels have not been discussed in this presentation. At a later date, as forest management becomes more intense, they might have an essential role.

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# DEVELOPMENT AND USE OF AN ECOLOGICAL CLASSIFICATION SYSTEM

Robert D. Pfister

## INTRODUCTION

Several classification systems have been applied to North American forests during the past century. Different purposes and scales have lead to development of forest-cover types, plant-community types, plant associations, potential natural-vegetation types, forest region, biogeocoenoses, habitat types, site types, and others. The purpose of this paper is to review the steps involved in developing an ecological site classification; from planning, to development, to application. Forest habitat-type classification efforts in Montana, (Pfister et al. 1977, Pfister and Arno 1980), will be used as a specific example of the general approach.

## USER NEEDS

If the primary justification for developing a classification system is to meet forest-management needs, then these needs must be a primary consideration in designing the approach and the ultimate product. **A** set of binary questions may help focus on these needs:

1. Do you want a vegetation classification or a site classification?
2. Do you want a user-friendly taxonomy or do you want a completed map?
3. Do you want existing vegetation types or potential (climax) vegetation types?
4. Will the system be used for field identification of types on plots and stands (large scale) or for office planning of larger areas (small scale)?

For example, Montana habitat types were developed 1) as a site-classification system, 2) with a user-friendly taxonomy, 3) based on the concept of potential (climax) vegetation types (by sampling only later successional stages), and 4) primarily as a tool for typal identification of plots and individual stands. The taxonomy then served as a foundation for operation mapping and use in area planning.

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## ECOLOGICAL PRINCIPLES

An ecological classification will only be as sound as the principles upon which it is based. The following principles are some of the important considerations in developing any ecological classification system. They are mentioned only briefly here but are elaborated on elsewhere (Daubenmire 1968, Mueller-Dombois and Ellenberg 1974).

1. The ecosystem (biogeocoenosis) concept provides a logical framework for classification concepts.

The ecosystem framework can be used to illustrate the individual structural components, their relationships, and how each component is related to a specific classification approach. In our forest habitat-type classifications, the phytocoenosis (plant-community type) is used as an integrated expression of the physical environment.

2. Different site-factor combinations provide "equivalent environments."

Two environments (sites) can be equivalent in the combined conditions for plant growth even though individual site factors may be quite different. For example, a sandy soil with 20 inches of precipitation could produce a plant community similar to that found on a loamy soil with 10 inches of precipitation. This is a logical extension of the ecological principle of "factor interaction."

3. Plant communities vary in time and space.

Most introductions to plant ecology illustrate how time and environment interact to produce different plant communities. The concept is simple but the interactions are complex as illustrated by the diversity of any landscape – a mosaic of time and space relationships. The focus of the classification exercise is to define classification boundaries in space and time. (At this point, continuum advocates are quick to point out the problems of continuous variation; ecologists with a classification goal will proceed to utilize the boundaries evident on the landscape and develop a rational approach to define operational boundaries for subdividing areas of apparent continuous variation.)

4. Climax (stable) communities are the best indicators of environment (for vegetation).

With time and space varying together, one must be held constant to examine variation in the other. Successional change is relatively slow as one approaches climax (self-perpetuating) conditions. Therefore, it is logical to begin a study of environmental variation with the study of climax vegetation.

5. The climax concept must be defined for the study area. Daubenmire (1952) searched diligently for climax and near-climax stands. In Montana (Pfister and Arno 1980) we were able to relax stand-selection criteria to include late-seral stands, thereby greatly increasing efficiency. Therefore, our data base provides a less-precise documentation of potential climax, but still meets the criteria of a relatively stable stage of development along the successional (time) gradient. The undergrowth vegetation stabilizes quite rapidly under the forest canopy, and the successional direction of the tree component can be predicted quite confidently from a stand table and current knowledge of the autecology of the tree species. Thus, the operational definition of climax for classification purposes in Montana was about 300 to 500 years.

6. The plant association (climax) provides the basis for the site classification.

Daubenmire built upon the foundation of the definition of plant association "agreed" upon at the 1910 International Botanical Congress – a kind of "plant community of definite composition, presenting a uniform physiognomy and growing on uniform habitat conditions." Recognizing that this definition does not mention variation due to succession (time), Daubenmire used "association" only in reference to climax community types. (Many ecologists have not been that restrictive in their usage of the term "association" – hence, confusion.) From this definition, we see the logical derivation of the term "habitat type" from the 1910 definition. If the 1910 Congress had substituted the word "site" for "habitat," the logical term should have been "site type" as used by scientists with a stronger forestry background vs. a plant-ecology background. To avoid some of this confusion, we (Pfister et al. 1977) define "association" as "climax plant community type" and point out that habitat types are site-typing taxonomy based on classification of potential climax communities.

## OBJECTIVES

Objectives must be clearly specified for an ecological classification study because of the numerous possible directions that are possible. For instance, should one pursue a natural classification or a technical one? Is the immediate objective a taxonomic system or a mapping system? Should the classification address all existing vegetation types or focus on potential climax? Who will use the classification and for what purposes? Fundamental differences among numerous possible approaches are discussed by Bailey et al. (1978).

When we started the Montana efforts in 1970, we had the benefit of experience in using the Daubenmires' (1952, 1968) classification for several years. Primary funding was provided to produce a similar, compatible system for Montana. Therefore our objectives were to:

1. Develop a habitat type classification for the forests of Montana (a taxonomy of "site types" called habitat types for conformity with previous terminology in the Northern Rocky Mountains).
2. Describe the vegetation of later successional stages of the habitat types.
3. Describe the physical environments (site factors) of the habitat types.
4. Provide management implications for the habitat types.

In effect, this called for a natural, taxonomic classification based on potential climax vegetation for use by field foresters in the process of site identification, habitat-type mapping, and application of available management implications.

## DATA BASE

The data base (along with principles) provides the foundation for developing the classification. Details are provided by Pfister and Arno (1980). Briefly, our goal was to objectively and efficiently sample the oldest available successional communities from a full range of environments. Sampling theory was predicated on a philosophy discussed in Mueller-Dombois and Ellenberg (1974) as "subjective without bias." This translates to first recognizing homogeneous stands in the field (stratification) and sampling them to avoid any bias related to preconceived notions about the outcome of the classification system. Replication was achieved by sampling transects in different geographic areas, with different crews, prior to grouping stands into classes. Sample size for each type is therefore not known until the classification is completed. Plot size was 375 $m^2$ (ca. 1/10 acre). Stand data included tree species, diameter, age, and structure. Coverage data for all undergrowth species was collected. Physical site variables and a minimal soils description were recorded. Data and observations pertinent to management implications were also recorded. The plant-community data are essential to developing the taxonomy. Site data are useful in testing the classification and describing the physical environment. Other data collection is somewhat flexible depending on intended uses and feasibility.

## SELECTING APPROPRIATE ANALYSIS TECHNIQUES

With the advent of computers and "mathematical ecology," there are numerous ways to analyze the data, but the final classification still must reflect the judgement of the ecologist. First, in selection of analytical tools; second, in weighting the data; and third, in fine-tuning the classification to reflect the combination of all important variables. We used the following techniques in building the classification (Pfister and Arno 1977):

1. Initial subjective groupings based on classification from adjoining areas and field observations.
2. Successive synthesis tables (computer generated) to display all species by all stands at each approximation of the classification.
3. Indirect ordinations to display and evaluate species distributions.
4. Indirect ordinations to display and evaluate type distributions.
5. Collective judgement of team members.
6. Scientific method of "successive approximations."

## DEVELOPING, TESTING, AND REFINING TAXONOMY

Using the above techniques, the classification progressed through at least four approximations based on analysis of vegetation data. At that point, the physical-site data were analyzed for each type to examine relationships and anomalies. The "fifth approximation" became the "preliminary" classification and was released, to field foresters for field testing and feedback to the classification team. The essential components of the preliminary classification include: 1) a list of types, 2) descriptions of vegetation types, 3) descriptions of physical environments, 4) a key for identification, and 5) management implications. Following this testing, and with inclusion of additional data from problem areas, the review draft of the "final" classification was prepared for operational use and for peer review as a formal publication. Although labelled "final" publication, the "successive" approximation philosophy suggests future revision may be appropriate. However, a point of diminishing return is reached rapidly when the classifier becomes trapped in a continuous revision cycle.

## DESCRIPTION OF VEGETATION TYPES

The description of the vegetation is readily accomplished from the synthesis tables used in the analyses. An average or modal description and appendix table provide the user with a summary of species occurrence and quantities sampled in the type. Successional interpretations are also provided. Thus, one obtains a vegetation classification of later successional stages as a spin-off from a site-classification objective.

## DESCRIPTION OF PHYSICAL ENVIRONMENT

This description includes elevations, aspects, slope configurations, geographic area, and soils information from the original data base, summarized for each type. As other inventories are conducted using the defined types, additional data become available for an expanded site description.

## DEVELOP A KEY FOR IDENTIFICATION

Have you ever tried to use a classification system (list of types) that doesn't have a key? The key is a crucial element for obtaining use of the taxonomy by a wide audience of potential users. Developing an efficient, accurate key is a demanding task, but well worth the effort to prevent user frustration and numerous questions. It is usually defined for application throughout all but the very earliest stage of secondary succession.

## PROVIDING MANAGEMENT IMPLICATIONS

A site taxonomy without management implications will gather dust on the shelf of a manager's library. It is not enough to be able merely to put the "proper" name on a unit of land. In Montana, we collected enough site-index data and multiresource observations to provide some direct-management implications as part of the taxonomy package. These have been a key to wide acceptance and provide a foundation for continual improvement of management implications based on additional research and management experience tied to the taxonomic classification.

## TRAIN USERS OF TAXONOMY

The normal lag time for acceptance and use of new knowledge is 10 to 20 years. Without training, a new system is often misapplied and rejected for the wrong reasons. Formal training sessions (annual week-long sessions of 40-60 foresters and biologists) have been conducted since the advent of the first preliminary classification (1971-western Montana). The need continues as foresters transfer and new foresters are hired. People completing the training are usually qualified to use the system appropriately for their own management activities, to map habitat types, and to train field crews in the basics of habitat-type identification.

We soon learned that a major stumbling block was the inability of foresters to identify undergrowth species. The major instructional objectives of current training sessions are to provide:

1. Ability to identify all indicator species.
2. Understanding of ecological principles pertinent to habitat types.
3. Ability to identify habitat types accurately through proper use of the key, descriptions, and appendix information.
4. Introduction to habitat-type mapping methodology.
5. Ability to make appropriate use of direct management implications.
6. Introduction to use of the classification document for deriving indirect management implications.

Widespread acceptance, enthusiastic use, and continued demand for training new people demonstrate the utility of the classification for forest multiple-use management. Few other mangement tools are as readily transferable to the potential users.

## CONCLUSION

I have used the Montana examples to illustrate development and use of a site-classification system called "habitat types." Credit for the concept goes to Daubenmire for his pioneering work in northern Idaho and adjacent Washington. He demonstrated the approach and defended the concepts, although it took forestry organizations 18 years to get serious about using the system.

Development of a system for a new area requires recognition of the major work involved. Full-time ecologists are essential to direct the field and lab activities and to wrestle with the anomalies of ecological theory. Computer-assisted analyses provide good efficiency for developing the taxonomy. Management implications – present and future – provide the payoff for land-manager involvement.

Training is the key to ensuring use of the classification by managers. Developers of the classification must commit the time and energy to transfering their knowledge. The system is well adapted to user application, thereby freeing the ecologist for working on further management implications and knowledge of succession in relation to management treatments.

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# THE IMPORTANCE OF PREDICTIVE MODELS OF FOREST SUCCESSION TO SILVICULTURE MANAGEMENT

Dale A. Draper and Evelyn H. Hamilton

## INTRODUCTION

The Prince George Forest Region (P.G.F.R.), nearly 30 million hectares in total area, is one of six administrative units within the British Columbia Ministry of Forests. The region is situated in the northeast corner of the province, bounded by Alberta and the Yukon and Northwest Territories to the east and north, and by other administrative units within the province to the south and west (fig. 1).

Main physiographic features in the region are the Alberta Plateau to the east of the Rocky Mountains and the northern portion of the Interior Plateau west of the same range. The area as a whole is characterized by a continental climate with cold to very cold winters and short, cool to relatively warm summers.

The forests in the northern part of the P.G.F.R. include the Boreal White and Black Spruce (BWBS) Zone, which extends from the Alberta Plateau in the northeast corner of the province into valley bottoms at elevations below about 1000 m. The subalpine Spruce-Willow-Birch (SWB) Zone occurs at elevations above the BWBS and below the Alpine Tundra Zone north of about 57° N latitude. The Sub-Boreal Spruce (SBS) Zone is found between 500 and 1300 m elevation on the Nechako and Fraser Plateaus and in the Fraser Basin in the central part of the region. The Engelmann Spruce-Sub-Alpine Fir (ESSF) Zone occurs at elevations above the SBS in the mountainous regions south of about 57° N latitude. Finally, the Interior-Cedar-Hemlock (ICH) Zone extends up the Rocky Mountain Trench into the southern part of the region (Pojar 1983).

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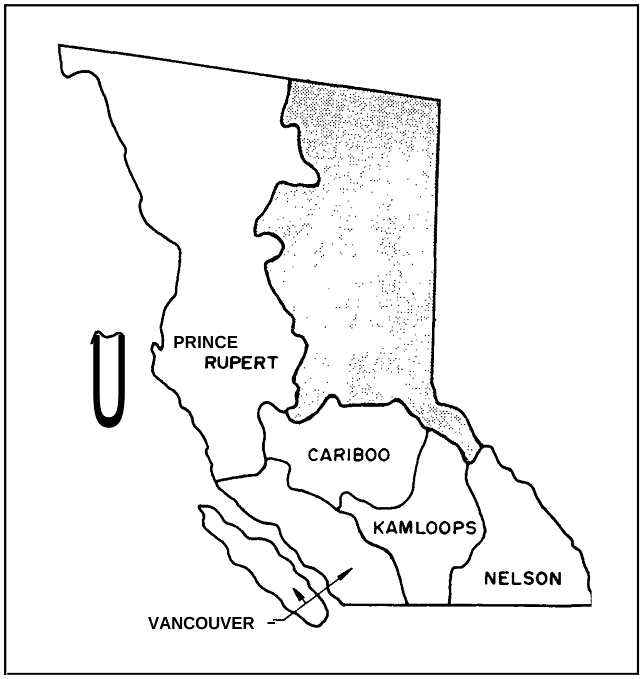


Figure 1—Prince George Forest Region.

The 17 million hectares of productive forest land in the region are divided approximately equally into mature forest (7.8 million ha) and immature forest (8.2 million ha); the remainder (1.3 million ha) is classed as noncommercial brush species, nonsatisfactorally stocked or other.

## EXISTING ECOLOGICAL CLASSIFICATION

The Research Branch of the Ministry of Forests has developed an ecological classification of lands under the ministry's

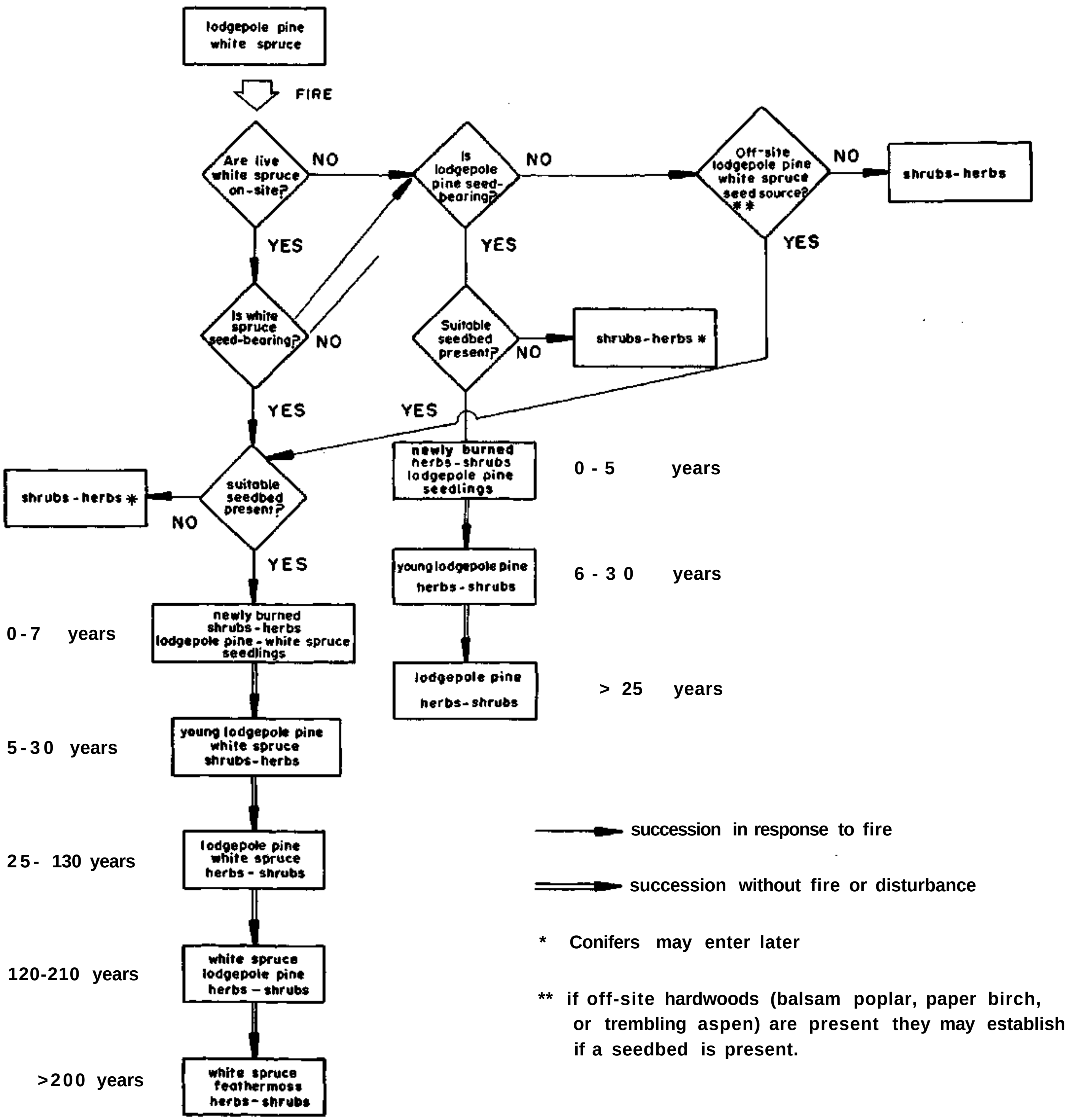


Figure 2.-Successional pathways in a Boreal White and Black Spruce Biogeoclimatic Zone and Northern White and Black Spruce Subzone (from Parminter, 1983).

Table 1. Successional classification of a white spruce *(Piceaglauca* [Moench] Voss) ecosystem association

| Condition or Treatment | Pioneer Seral | Young Seral | Maturing Seral | Over mature Seral | Climax |
|---|---|---|---|---|---|
| Natural Succession | PS1[1]→PS2[2] → | YS1[3] → | MS1[4] → | OMS1[5] → | C[6] |
| Severe Fire | PS2 → | YS1 → | MS1 → | OMS1 → | C |
| Logging | PS1 → | YS1 → | MS1 → | OMS1 → | C |
| Light-Medium Fire | | YS1 → | MS1 → | OMS1 → | C |
| Approximate Stand Ages (Years) | 0-15 | 15-60 | 60-140 | 140-200 | 250+ |

[1] Pioneer shrub and herb stage occurring immediately after disturbance.
[2] Pioneer shrub and herb stage including *Populus tremuloides* Michx., *P. balsamifera* L., *Salix* spp., *Rosa acicularis* Lindl., *Epilobium angustifolium* L., and *Aster conspicuous* Lindl.
[3] Young seral stand dominated by *Populus tremuloides, P. balsamifera* with sparse *Picea glauca,* and including *Salix* spp., *Calamogrostis canadensis* (Michx.) Nutt., and *Rosa acicularis* Lindl.
[4] Maturing seral stand dominated by *Populus tremuloides,* with *Picea glauca* regeneration, *Populus balsamifera, Betula papyrifera* Marsh. and *Cornus sericea* L. also present.
[5] Overmature seral stand with *Populus tremuloides, P. balsamifera,* and *Picea glauca* . Persistent seral species remain. Snags and deadfalls are abundant. *Picea glauca* is regenerating.
[6] Climatic climax stand of *Picea glauca.*

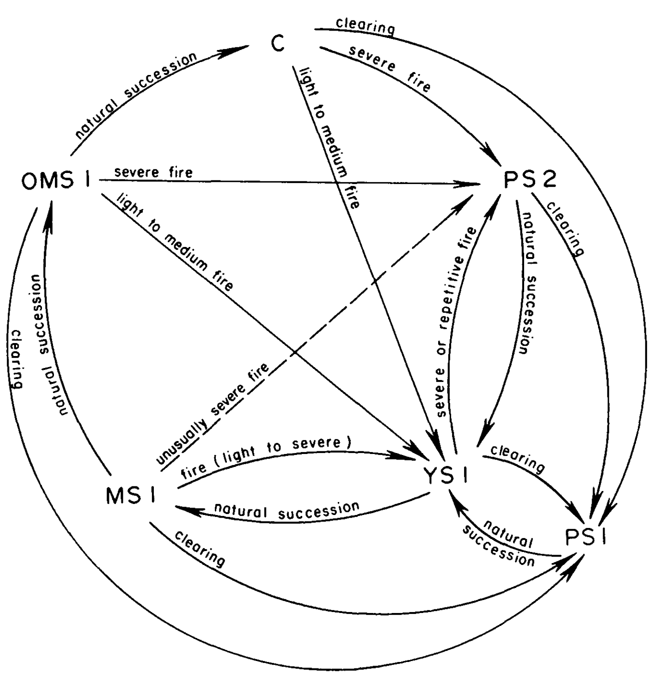


Figure 3.--Successional Pathways in a White Spruce Ecosystem Association (adapted from Harcombe et al. 1980).

jurisdiction to provide an information system to assist in the improvement of forest and range management. A modification of the Biogeoclimatic system developed by V. J. Krajina and his associates (Krajina 1969, 1972), is used as a basis for this classification (Pojar 1983).

Classifications are made at two levels: first, at the biogeoclimatic level where the land base is divided into regions which have homogeneous climatic conditions; and second, at the ecosystem level where units similar in terms of their vegetation, soil, and function are identified.

The classification of ecosystems is based upon sampling of climax or near-climax forests. Once classification is completed the ecosystems will be examined in greater detail to evaluate ecological change over time and under differing silvicultural management. Methods for the identification and classification of stages in the successional process are under development.

## STATUS OF SUCCESSIONAL RESEARCH

Although there are many studies of forest succession in North America, few are specific to northern British Columbia.

Generalized postwildfire successional sequences in the boreal forests of western Canada and Alaska can be found in Lutz (1956), Kershaw et al. (1975), Viereck (1970), Maikawa and Kershaw (1976), and Foote (1983). Summaries of existing knowledge of boreal succession are provided by Kelsall et al. (1977), Johnson and Rowe (1977), Larson (1980), and Viereck and Schandelmeier (1980).

Forest successional studies in northern British Columbia include Parminter (1983 a, b), who examined sequences arising after wild-fire in the Fort Nelson and Cassiar Timber Supply Area. Here successional pathways were explained in terms of presence or absence of a seed source and suitable seed bed (fig. 2). Harcombe (1978) described the seral and climax plant communities of the Northeast Coal Area, between Prince George and Fort St. John, and briefly outlined seral pathways on different landforms. Vegetation succession following logging and fires of various frequency and intensity near Fort St. John are descried in more detail by Harcombe et al. (1980). Figure 3 is adapted from this source and gives an example of successional pathways identified in a white spruce ecosystem association. Table 1 provides the description and definition of terms used in this figure.

An initial classification of ecosystems in the BWBS zone in the P.G.F.R. has been completed and ecosystem-specific silvicultural prescriptions, reflecting the current understanding of seral processes, are under development (L. Jang, pers. comm., March, 1983).

Successional sequences in other forest zones in the P.G.F.R. are not well documented. Revel (1972) provides brief descriptions of some seral ecosystems in the SBS, and Harcombe (1978) has outlined some seral pathways in the same zone. Descriptive accounts of forest succession in the eastern Rocky Mountains (likely to be classified as ESSF in British Columbia) are given by Cormack (1953), Day (1972), and Corns and LaRoi (1976). In the United States, ESSF-like ecosystems have been described in some detail by Stickney (1980), Davis et al. (1980), and Arno (1982).

No published description of seral ecosystems in the ICH is available, although work by Habeck (1968), Wittinger et al. (1977), Irwin and Peek (1979), Davis et al. (1980), Stickney (1980), Antos and Habeck (1981), and Zamora (1982) has relevance in this zone. Climax ecosystems in the ICH have been described and silvicultural prescriptions made which reflect the current understanding of seral processes.

Studies in northern British Columbia confirm the importance of successional pathways and identify some biotic and cultural factors of influence. Further information on successional ecosystems is essential for improved management. Pfister (1982) pointed out some of the informational needs which can be satisfied, at least in part, by descriptions and predictions of secondary plant succession. Important informational needs in northern British Columbia are considered here with emphasis on general silvicultural requirements and related forest-management needs.

## SILVICULTURAL IMPLICATIONS

The harvesting of forest growth emphasizes the importance of mature or overmature forest age-classes. However, silvicultural practice in British Columbia, and elsewhere (Arno 1982), is focused primarily upon activities in the 20-30-year period following disturbance. Smith (1982) observed that it is the occupational disease of the forester to deal more with regenerating forest stages than final ones. The majority of silviculture expenditures – and thus the priority for silviculture-management information – is in the first 20 years following disturbance. This equates with early successional vegetation complexes.

A major consequence of regeneration delay in the P.G.F.R. is the development of competitive vegetation. This vegetative development is, in part, attributable to site characteristics recognized by the late-successional or climax classificaton. There are, however, a variety of factors, independent of site, which may also be important. These include season and method of harvest, residual species eradication policy, and method of site preparation. A more comprehensive knowledge of successional pathways arising from treatments on a given site is a prerequisite to setting priorities for vegetation management. While the scale of vegetative competition problems exceeds our operational capacity to address them, this need for site- and treatment-specific priority assessment will remain high.

The immediate goal of site preparation is the production of a suitable number of accessible, well-spaced, biologically acceptable planting spots at an appropriate cost. This goal satisfies immediate needs but largely ignores the long-term consequences of site preparation which include effects upon:

1. the development and duration of successional vegetation complexes,
2. soil physical properties influencing in turn soil-development processes and mechanical and hydrologic soil characteristics,
3. site productivity.

Short-term site-preparation effects are generally well known. The middle- and long-term effects can only be evaluated if we have an understanding of expected successional development on the site. A key part of any artificial regeneration program is the monitoring of post-planting survival and growth. Free-to-grow status of planted trees is assessed by surveying plantations and associated competitive vegetation at a single point in time. The timing of these surveys is critical if we are to avoid:

1. costly survey duplication if free-to-grow status has not yet been achieved,
2. assessment errors arising from conferring free-to-grow status to a plantation which subsequently "brushes in," and
3. excessive delay in assigning free-to-grow status.

Plantation surveys to determine free-togrow status must be timed in accordance to tree- and competitive vegetation-growth dynamics. An improved knowledge of early successional trends on important ecosystems is a valuable tool in this regard.

Predictive models of forest succession allow for integrated long-term forest-management planning. Management activities can be selected and scheduled so as to optimize forest values including those related to timber production, wildlife habitat, range, recreation, and soil and hydrology management. These values can be assessed only if we can predict forest type, floristic composition, stand and community structure and their changes over time.

The risks and effects of soil erosion can be predicted through information or post-disturbance succession. Hydrologists benefit from improved predictions of stand structure, which in turn facilitate assessment of snow and water interception and water use as well as snow accumulation.

Range managers require data on the successional development of forested and nonforested rangeland. This includes the information on changes in stand structure and diversity, species composition, species vigour, and productivity required to predict and assess the quality and quantity of forage.

Information on stand structure, species composition, and areal and spatial diversity over time on different sites allows wildlife managers to evaluate and predict habitat suitability. Major informational needs include stand and layer structure, presence and condition of dead standing and fallen trees, and species composition. These are critical in evaluating thermal cover, hiding cover, nesting habitat, and forage availability.

## SUMMARY

The classification of forest ecosystems is a fundamental step in improving the understanding and management of our forest lands. The extension of existing climax-oriented classifications to include predictive models of forest succession is a logical and important development from this classification base. Management decision-making in early successional stages can be referenced to this predictive framework, and a greater confidence and consistency in forest-management decisions generated as a result.

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# POTENTIAL USE OF THE ALASKA VEGETATION SYSTEM AS AN INDICATOR OF FOREST SITE PRODUCTIVITY IN INTERIOR ALASKA

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ABSTRACT: Four basic forest site types in interior Alaska are differentiated on the basis of successional and mature vegetation, soil temperature and moisture, and topographic position: (1) upland white spruce (2) floodplain white spruce (3) upland black spruce and (4) lowland black spruce. A number of site factors, including a typical soil profile and biomass accumulation and productivity, are given for each type. Forest productivity is high (238 to 950 $g \cdot m^{-2} \cdot yr^{-1}$) on the two white spruce types and low (72 to 148 $g \cdot m^{-2} \cdot yr^{-1}$) in the black spruce types.

## INTRODUCTION

In 1980 "A Preliminary Classification System for Vegetation of Alaska" (Viereck and Dyrness, 1980) was published to meet the need for a statewide vegetation classification system that could be correlated with several other systems used by various agencies and groups in Alaska for inventorying and mapping of vegetation. The classification was developed by aggregating plant communities as the basic unit, it was hierarchical in nature, and it was based primarily on the characteristics of the vegetation. Information on the plant communities was obtained from a complete literature review of published and unpublished descriptions of Alaska vegetation types. The system had five levels with the plant communities as the lowest level. The highest level consisted of five formation classes: forest, tundra, shrubland, herbaceous, and .aquatic vegetation.

The classification system has been' reviewed by field workers and needed changes made. A revision of the classification was distributed to field workers in May 1981. This revision contained two major changes from the published 1980 version: (1) tundra as a level I formation was discontinued and incorporated into the shrubland and herbaceous vegetation formations and (2) the wetland units were developed more fully and were clearly identified at level IV.

At the Workshop for Alaska Vegetation held in Anchorage in December 1981, the classification was revised to level III, definitions were agreed upon which helped to delineate the major units, and criteria for determining the various levels were discussed. As a result of this meeting, the classification was again revised in May 1982 and widely redistributed to field workers in Federal and state agencies (Viereck, et al. 1981).[1] The present classification has three categories at level I, (table 1) forest, scrub, and herbaceous vegetation, and more closely follows both the UNESCO classification (UNESCO 1973) and that of the resource-evaluation techniques (RET) group in Ft. Collins, Colorado (Driscoll et al. 1983). Level II of the classification further subdivides the vegetation on a number of different criteria including size (i.e., tall, low, and dwarf shrub); broadleaf vs. needleleaf for trees; and graminoid, forb, bryoid, and aquatic for the herbaceous vegetation. For level III, the forest and shrub vegetation is divided primarily by the per cent cover of the canopy with the following classes:

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[1] Unpublished report by L.A. Viereck, C.T. Dyrness and A.R. Batten. 1982 Revision of Preliminary Classification for Vegetation of Alaska. On file at Institute of Northern Forestry, Fairbanks, Alaska. 1982; 72 p.

Table 1--1982 revision of classification system for Alaskan vegetation of level III

| Level I | Level II | Level III |
|---|---|---|
| 1. Forest | A. Needleleaf (conifer) forest | 1) Closed needleleaf (conifer) forest<br>2) Open needleleaf (conifer) forest<br>3) Needleleaf (conifer) woodland |
| | B. Broadleaf forest | 1) Closed broadleaf forest<br>2) Open broadleaf forest<br>3) Broadleaf woodland |
| | C. Mixed forest | 1) Closed mixed forest<br>2) Open mixed forest<br>3) Mixed woodland |
| 2. Scrub | A. Dwarf tree scrub | 1) Closed dwarf tree scrub<br>2) Open dwarf tree scrub<br>3) Dwarf tree scrub woodland |
| | B. Tall shrub | 1) Closed tall shrub scrub<br>2) Open tall shrub scrub |
| | C. Low shrub scrub | 1) Closed low shrub scrub<br>2) Open low shrub scrub |
| | D. Dwarf shrub | 1) Closed dwarf shrub scrub<br>2) Open dwarf shrub scrub |
| 3. Herbaceous | A. Graminoid herbaceous | 1) Dry graminoid herbaceous<br>2) Mesic graminoid herbaceous<br>3) Wet graminoid herbaceous (emergent) |
| | B. Forb herbaceous | 1) Dry forbs herbaceous<br>2) Mesic forbs herbaceous<br>3) Wet forbs herbaceous |
| | C. Bryoid herbaceous | 1) Mosses<br>2) Lichens |
| | D. Aquatic (non-emergent) herbaceous | 1) Freshwater aquatic herbaceous<br>2) Brackish water aquatic herbaceous<br>3) Marine aquatic herbaceous |

| | Trees | Scrub |
|---|---|---|
| | ------ Per cent ------ | |
| Closed | 60-100 | 70-100 |
| Open | 25-60 | 25-75 |
| Woodland | 10-25 | -- |

Level IV of the classification is based primarily on dominant plant species or a combination of two or more species.

The lowest level, Level V, corresponds to the basic plant community and is named by the dominant or most common or conspicuous species in each of the main layers in the community ; for example, *Picea mariana/Betula glandulosa-Ledum groenlandicum/Sphagnum* spp. for an open black spruce type with a shrub understory of resin birch and Labrador-tea and with one or more species of sphagnum as an abundant moss in the forest floor. In most cases, the types are based on published accounts of descriptions of the stands.

This paper will concentrate on only the major forest types from the Fairbanks area of the taiga of interior Alaska. This represents only a fraction of the communities in the area, but reflects the present lack of published descriptions of types in the area. At present, the Institute of Northern Forestry has a data base of over 600 stands – mostly forest stands from interior Alaska, and a synthesis and summary of these data will add greatly to the understanding of forest types in interior Alaska. A paper by Foote (1983) utilizes some of these data in descriptions of plant communities following fire in interior Alaska. A large number of interior Alaska forest types have been described by Yarie (1983). These types are not discussed in this paper.

At present, the following fifty-three communities from the Fairbanks area have been described:

| General forest types (level II) | Number of level IV communities |
|---|---|
| Closed needleleaf forest | 6 |
| Open needleleaf forest | 10 |
| Woodland needleleaf forest | 13 |
| Closed broadleaf forest | 9 |
| Open broadleaf forest | 4 |
| Mixed closed forest | 7 |
| Mixed open forest | 4 |
| | 53 |

The total of fifty-three forest communities includes both successional and climax (mature) forest stands. Information from fifteen forest communities is used to characterize the sites described in this paper (table 2). Although the Alaska vegetation classification is based as closely as possible on the vegetation itself, we look upon it as a way to eventually develop a site-type or ecosystem-type (habitat type) classification of an ecological nature that will include important factors of the ecosystem such as soil type and environmental factors.

We have begun to develop the necessary information for such a site-type classification as part of a National Science Foundation funded multidisciplinary study in interior Alaska on the structure and function of black spruce *(Picea mariana* [Mill.] B.S.P.) forest in relation to other fire-effected taiga ecosystems.

## STUDY SITES

In addition to the description of a large number of forest stands in the "extensive sites," we designated twenty-one widely scattered sites in this study as "semiintensive sites" and included two transects at the intensive site in our analysis. These sites, all within 50 km of Fairbanks, were selected to represent a spectrum from the coldest sites at tree line and on north-facing slopes to the warmest and driest sites that support tree growth. Stands for which data were available from previous studies were selected whenever possible. The geographic locations of these stands are shown in figure 1, and the relative positions of the stands along a cross section of the floodplain and uplands are shown in figure 2.

In the upland, the warmest, driest, south-facing site is represented by an Aspen/buffaloberry/grass stand on a south-facing bluff above the Tanana River. A young aspen stand and two birch stands represent the deciduous forest successional stage after fire on productive sites. Two white spruce stands 70 and 165 years in age represent later stages in this successional sequence.

Table 2--Forest types of the Fairbanks area discussed in this paper

| Level I | Level II | Level III | Level IV | Level V |
|---|---|---|---|---|
| Forest | A. Needleleaf forest | 1. Closed needleleaf forest | a. White spruce | 1. *Picea glauca/Rosa acicularis-Viburnum edule/ Hylocomium splendens* community |
| | | | | 2. *Picea glauca/Rosa acicularis-Viburnum edule/ Linnaea borealis/Hylocomium splendens* community |
| | | | | 3. *Picea glauca/Rosa acicularis/Rhytidiadelphus triquetrus* community |
| | | | b. Black spruce | 1. *Picea mariana/Pleurozium schreberi-Hylocomium splendens* community |
| | | | c. Mixed black and white spruce | 1. *Picea glauca-Picea mariana/Alnus crispa/ Rhytidiadelphus triquetrus* community |
| | | 2. Open needleleaf forest | a. Black spruce | 1. *Picea mariana/Ledum groenlandicum-Vaccinium uliginosum/Pleurozium schreberi* community |
| | | | | 2. *Picea mariana/Ledum groenlandicurn-Vaccinium uliginosum/ Sphagnum* spp. community |
| | | | | 3. *Picea mariana/Ledum groenlandicum/ Hylocomium splendens* community |
| | | | | 4. *Picea mariana/Ledum groenlandicum/Pleurozium schreberi* community |
| | | | | 5. *Picea mariana/Salix planifolia/Ledum groenlandicum/Sphagnum* spp. community |
| | | 3. Needleleaf woodland | a. Mixed spruce | 1. *Picea glauca-P. mariana/Alnus crispa-Betula glandulosa/ Pleurozium schreberi* community |
| | B. Broadleaf forest | 1. Closed broadleaf forest | a. Quaking aspen | 1. *Populus tremuloides/Viburnum edule/Linnaea borealis* community |
| | | | b. Paper birch | 1. *Betula papyrifera/Alnus crispa/Calamagrostis canadensis* community |
| | | | c. Balsam poplar | 1. *Populus balsamifera/Alnus tenuifolia/ Rosa acicularis/ Equisetum* spp. community |
| | | 2. Open broadleaf forest | a. Quaking aspen | 1. *Populus tremuloides/Shepherdia canadensis/ Calamagrostis purpurescens* community |

The series of floodplain stands represents mid to late stages of a successional sequence developing on newly exposed silt on both the Chena and the Tanana Rivers. Younger forest stages include balsam poplar stands of varying ages. The mature, productive white spruce stands include two 100-120- year-old stands and one 250-year-old stand. Older stages on terraces underlain by permafrost include a mixed black and white spruce stand and three black spruce stands. Open and closed stands of black spruce with feathermosses or sphagnum, most of which are underlain by permafrost, are representative of the colder upland sites. The coldest site was a white spruce-black spruce/alder-shrub birch/feathermoss type at tree line at an elevation of 750 m.

METHODS

The methods used in this study of twenty-three stands are reported by Viereck et al. (1983) who describe the vegetation and soils in detail. Biomass and productivity were determined for selected stands only (a total of fifteen for this paper). Microclimate measurements were concentrated in soil temperatures at most of the sites. Soil moisture was determined by weekly gravimetric samples and averaged for the growing season. We found that soil temperature was a better indicator of site than air temperature. As a comparison index, we developed a soil degree-day accumulation index for each stand based on a 10-cm depth, 0°C as a base, and the period from May 20 to September 10. The index ranged from 2200 for the aspen stand on the south-facing bluff to 483 for a north slope, black spruce stand underlain by permafrost.

DESCRIPTION OF SITE TYPES

The forest sites separated into two distinct groups along the environmental gradient of soil moisture and soil tempera-

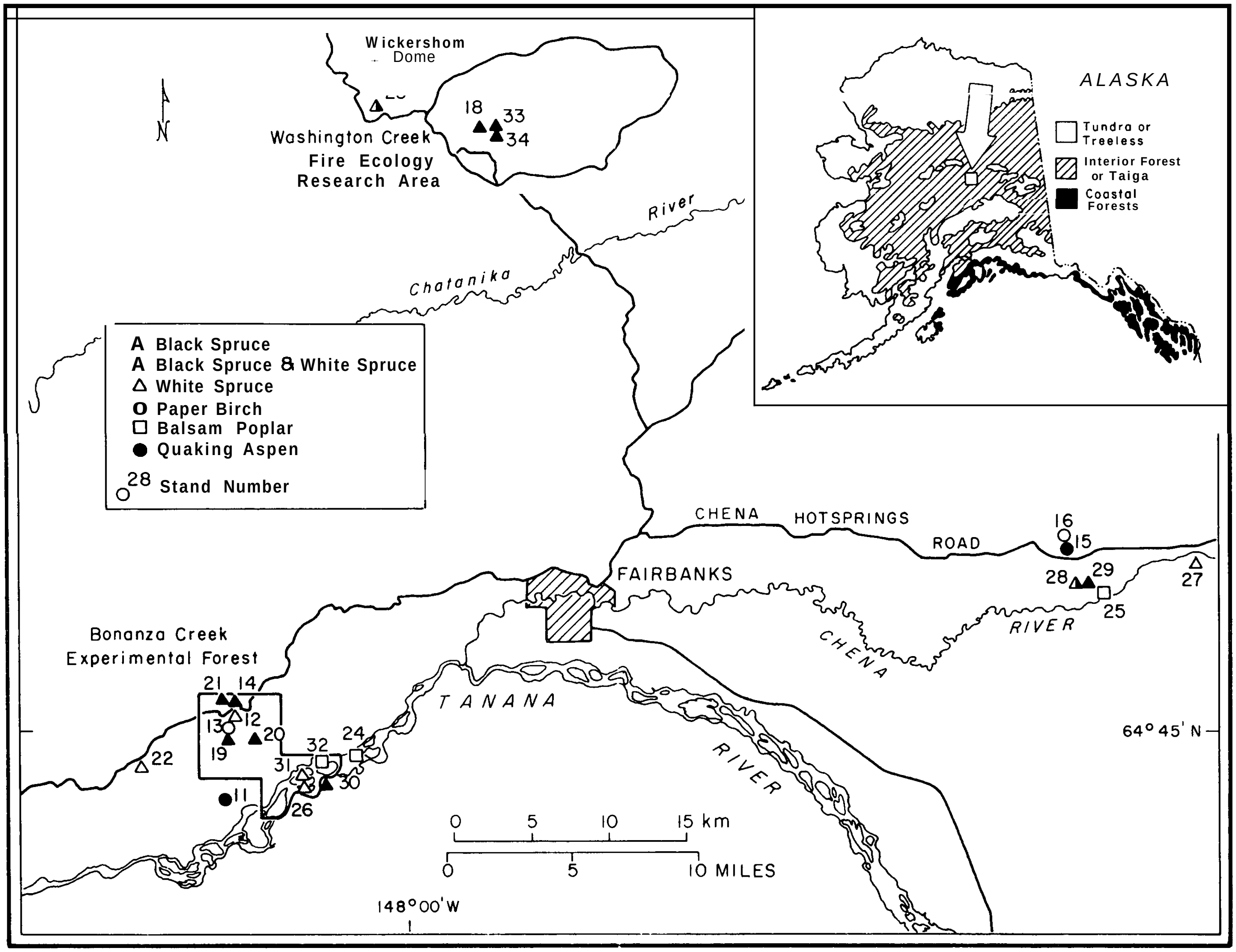


Figure 1.–Location of twenty-one semiintensive sites (stands 11-16 and 18-22) and the intensive site (stands 33 and **34)** in the Fairbanks area of interior Alaska (from Viereck et al. 1983).

ture (fig. 3). The group of stands on warm mesic sites has an aboveground tree productivity of over 200 $g{\cdot}m^{-2} \cdot yr^{-1}$ and is dominated by white spruce in the mature stages. The group of stands on cold, wet sites has a low productivity of under 200 $g{\cdot}m^{-2}{\cdot}yr^{-1}$, is usually underlain by permafrost, and is dominated by black spruce in later stages of succession (fig. 4). The productive forest sites can be further subdivided into two forest site types based on parent material and topographic position: (1) upland sites with thick loess deposits on slopes that tend to be south-facing, and (2) floodplain sites adjacent to the rivers that have developed on recently formed alluvium (fig. 3). The successional sequences in these two site types leads to white spruce stands but are different in vegetation components and developmental processes.

The low-production, black spruce sites are also found in two topographic settings: (1) upland, north-facing slopes on loess and coluvium or any slope at higher elevations or on shallow soils, and (2) lowland sites on old river terraces and in valley bottoms. Although a number of distinct black spruce forest types are found on these two site types, we could determine no distinct separation by vegetation type. Successional stages leading to mature black spruce stands can be similar on both upland and lowland sites. Because of these similarities, we have separated these two types primarily on the basis of topographic position rather than vegetation composition, although analysis of a larger number of stands may show distinct differences in the communities on the two sites.

Upland Mesic White Spruce Site

Description of the site type.--This site type occupies the mesic, south-facing, loess-covered slopes adjacent to the Tanana River to an elevation of at least 400 m. In our study, it was represented by two successional, closed broadleaf forest communities and one closed white spruce forest community.

1. Closed *Populus tremuloides/Viburnum edule/Linnaea borealis* community,
2. Closed *Betula papyrifera/Alnus crispa/Calamagrostis canadensis* community and one spruce type, and
3. Closed *Picea glauca/Rosa acicularis- Viburnum edule/ Hylocomium splendens* community.

The type is represented by three soil series: Gilmore, Steese, and Fairbanks, all of which are classified as Alfic cryochrepts. Soils supporting upland white spruce were found to be among the warmest and best drained soils in the area. The following is a generalized description of a profile typical of Fairbanks silt loam:

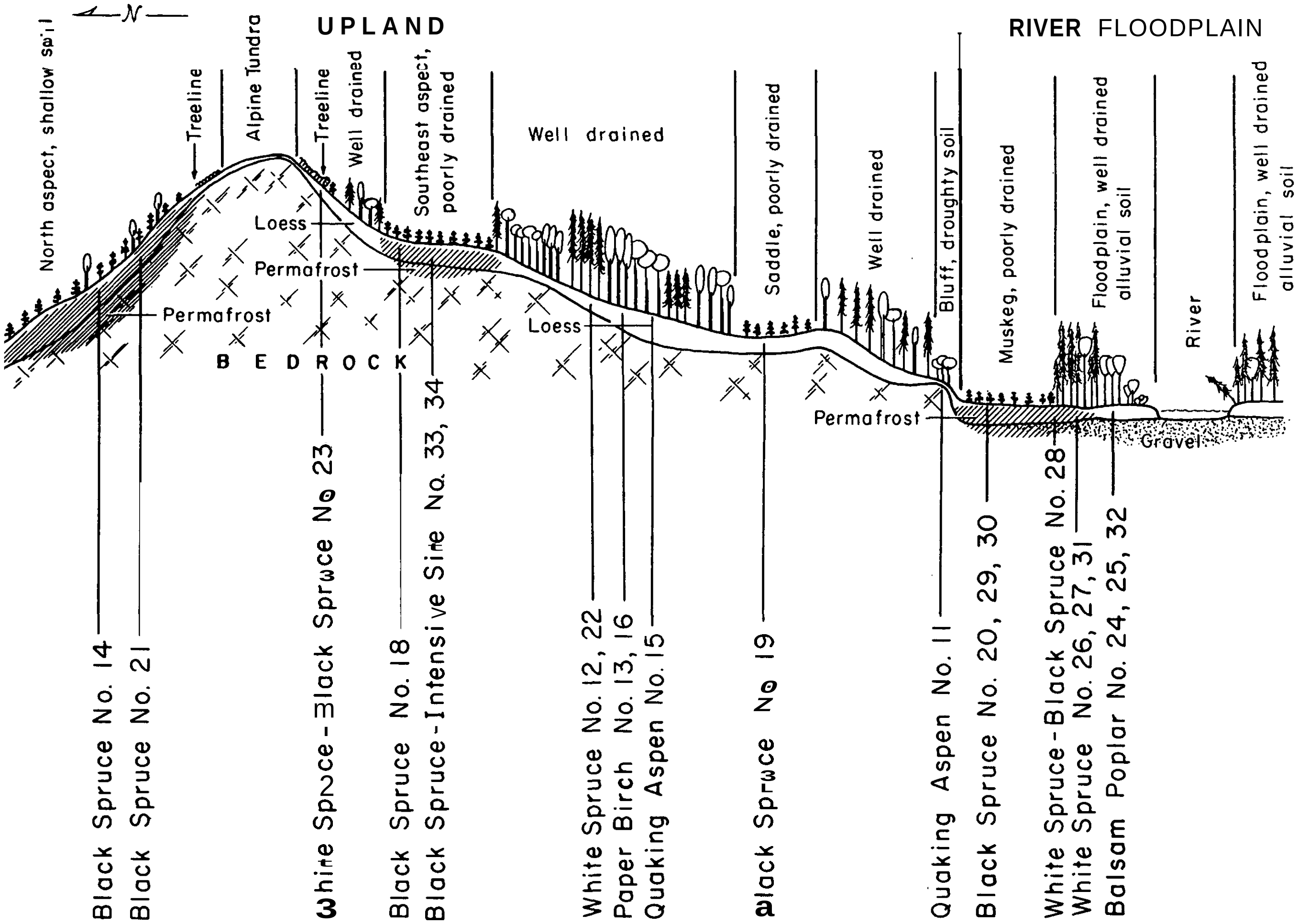


Figure 2.--Generalized cross-section of topography, landforms, vegetation, and parent material in the Fairbanks area with locations of the semiintensive sites (stands 11-16 and 18-32) and the intensive site (stands 33 and 34) (from Viereck et al. 1983).

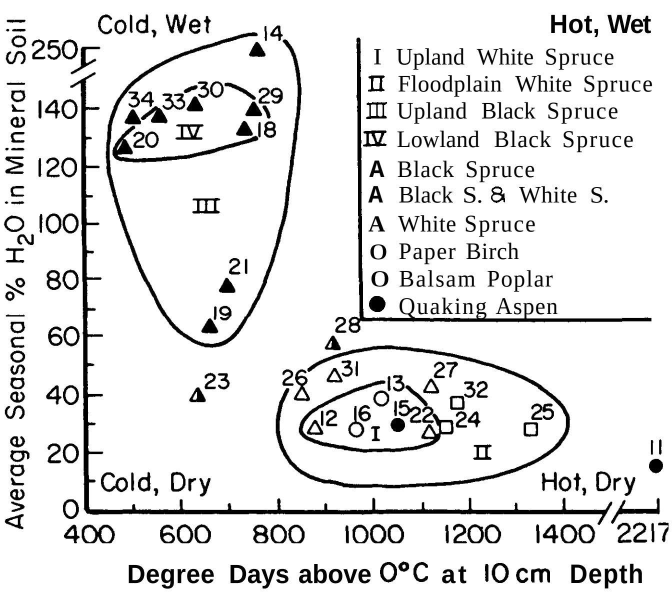


Figure 3.–Location of site and forest types along an environmental gradient determined by accumulated soildegree days and average seasonal moisture in the mineral soil (from Viereck et al. **1983,** modified).

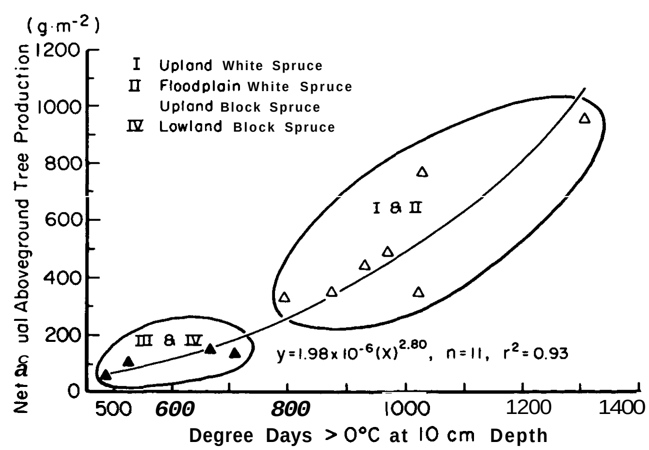


Figure 4.–Net, annual, above-ground, tree-biomass production as related to degree-day accumulations of black spruce and white spruce sites in interior Alaska (from Viereck and Van Cleve 1984, modified).

| | | |
|---|---|---|
| 01 | 8 to 5 cm | Live moss and recently deposited litter. |
| 021 | 5 to 0 cm | Dark brown mat of coarse fibrous moss remains and forest litter; roots abundant. |
| A1 | 0 to 4 cm | Dark brown (lOYR 3/3) silt loam; weak granular structure; friable; roots abundant. |
| A3 | 4 to 10 cm | Brown (10YR 4/3) silt loam; moderate subangular blocky structure; friable; roots abundant. |
| B1 | 10 to 25 cm | Brown (10YR 4/3) silt loam; weak subangular blocky structure; friable; roots common. |
| B2 | 25 to 30 cm | Dark yellowish brown (10YR 3/4) silty clay loam; weak platy structure; firm; roots common. |
| C1 | 30 to 39 cm | Brown (10YR 4/3) silt loam; platy structure; slightly firm; roots common. |
| C2 | 39 to 100 cm+ | Dark grayish brown (2.5YR 4/2) silt loam; weak platy structure; friable; roots common, decreasing with depth. |

During the period of our study, the average soil degree accumulation ranged from 876 to 1117, and the average soil moisture in the upper 15 cm of mineral soil ranged from 25 to 40 per cent, The average soil temperature for the growing season at 10 cm ranged from 8 to 10°C. Forest-floor thickness on the sites ranged from 2 cm in the aspen stands to 9 cm in the spruce stands. The pH of the forest floor ranged from 5.8 and 5.6 for the aspen and birch stand to 6.0 for the white spruce stand. The sites were all free of Permafrost.

On this site type, tree development and productivity are high. Aspen and birch reach heights of 20 m and diameters of 25 cm in 80 to 100 years. Basal area of aspen and birch stands is approximately 30 to 35 $m^2 \cdot ha^{-1}$ in the mature stands. In mature spruce stands, which usually have a closed canopy, trees may reach heights of 25 to 30 m and diameters of 25 to 35 cm. Basal areas range from 40 to 60 $m^2 \cdot ha^{-1}$.

Standing above-ground tree biomass ranged from 9,200 to 18,300 $g \cdot m^{-2} \cdot yr^{-1}$ for the hardwood stands and 24,900 $g \cdot m^{-2}$ for one spruce stand. Annual above-ground tree biomass productivity ranged from 343 to 760 $g \cdot m^{-2} \cdot yr^{-1}$ for the hardwood stands and was 353 $g \cdot m^{-2} \cdot yr^{-1}$ for the spruce stand.

The main shrub species in the mature spruce stands are scattered alders *(Alnus crispa* [Ait.] Pursh.), prickly rose *(Rosa acicularis* Lindl.), and highbush cranberry *(Viburnum edule* [Michx.] Raf.). Low shrubs and herbs are sparse to occasional, depending on overstory canopy, and consist primarily of twinflower *(Linnaea borealis* L.), horsetails *(Equisetum* spp.), and northern comandra *(Geocaulon lividum* [Richards.] Fern.). The forest floor has a nearly continuous mat of *Hylocomium splendens* (Hedw.) B.S.G.

Successional sequence.-- Following fire, the usual pattern of plant invasion is by species with light, wind blown seed, such as fireweed *(Epilobium angustifolium* L.) and willow shrubs, especially *Salix bebbiana* Sarg. and *S. scouleriana* Barratt. A number of species resprout from stumps or roots, especially highbush cranberry, rose, willows, alder, aspen, and birch. A few species develop from seed apparently left unburned in the soil – *Geranium bicknellii* Britt., *Corydalis sempervirens* (L.) Pers., and *Rubus idaeus* L. The next stage in the developing vegetation is dominated by shrubs, primarily willows, and by deciduous tree saplings. Spruce seedlings may be present at this time but their slow growth makes them relatively inconspicuous in the stand.

In the dense hardwood stage, young aspen and birch trees form a dense canopy that tends to shade out the understory that develops following fire. Heavy litterfall prevents the development of a moss layer, but moss species of the mature forest stages, such as *Hylocomium splendens* and *Pleurozium schreberi* (Brid.) Mitt., become scattered on elevated areas such as fallen logs. This stage usually occurs during the period of 25 to 50 years following the fire. For the next 50-100 years, deciduous trees dominate the site, although white spruce may become conspicuous in the understory. Both the aspen and birch stands become more open with age, and the density drops to about 700 trees per ha for aspen and 300 to birch. At about 100 years after a fire, white spruce becomes dominant, often with a component of birch and aspen. As the stands become older, the hardwoods are less abundant. The greatest change is the development of a continuous mat of feathermoss, primarily *Hylocomium splendens.* The mature spruce stage, with scattered remnants of birch and a well-developed moss mat and organic layer, is reached at about 200 years following a fire.

### Floodplain White Spruce Site

Description of the site type.--This site type occupies the floodplains adjacent to the major rivers of interior Alaska. We examined forest stands along both the Chena River and the Tanana River between 120 and 180 m elevations. In our study, the site type was represented by one successional community and two white spruce communities:

1. Closed *Populus balsamifera/Alnus tenuifolia-Rosa acicularis/Equisetum* community,
2. Closed *Picea glauca/Rosa acicuiaris-Viburnum edule/Linnaea borealis/Hylocomium splendens* community, and
3. Closed *Picea glauca/Rosa acicularis/Rhytidiadelphus triquetrus* community.

The young soils on floodplains immediately adjacent to the rivers are of the Salchaket series and are classified as Typic Cryfluvents. Soils supporting floodplain white spruce are formed in alluvium that is well drained and free of permafrost. The soils occur on level floodplains and terraces adjacent to the major rivers, and profiles often reflect the effects of repeated flooding episodes. The following is a typical profile in the Salchaket series (Typic Cryofluvent) supporting a mature stand of white spruce:

| | | |
|---|---|---|
| 01 | 13 to 9 cm | Live feathermoss, moss remains, and recently deposited litter; lower portion is mixed light gray silt from recent flooding. |
| 021 | 9 to 3 cm | Partially decomposed moss remains; mixed with small amounts of light gray silt; roots abundant. |
| 022 | 3 to 0 cm | Black (10YR 2/1) humus; roots abundant. |
| C1 | 0 to 9 cm | Dark grayish-brown (10YR 4/2) very fine sandy loam; distinct medium and fine gray (lOYR 5/1) and yellowish-brown (lOYR 5/6) mottles; weak subangular block structure; friable; roots common. |
| C2 | 9 to 16 cm | Dark grayish brown (2.5YR 4/2) silt loam; weak subangular blocky structure; friable, roots common; horizon contains many lenses and pockets of organic material as a result of past flooding. |
| C3 | 16 to 32 cm | Olive brown (2.5Y 4/4) very fine sandy loam; weak fine platy structure; friable; roots few. |
| C4 | 32 to 90 cm | Grayish brown (2.5Y 5/2) medium sand; single grained; loose; very few roots; water-worn gravels at about 180 cm. |

During the period of our study, average soil moisture ranged from 30 to 50 per cent and soil degree sums from 800 to 1310, giving an average soil temperature at 10 cm for the growing season of 7.0°C to 11.6°C. Forest-floor thickness varied from 5 to 7 cm in the balsam poplar stands to 18 cm in the white spruce stands. The pH of the forest floor was 6.2 for the balsam poplar stands and 5.6 for the white spruce stands.

Tree productivity is highest on these floodplain sites. Balsam poplar may reach heights of 25 m and diameters of 25 cm in 60 years. Because of the low densities of the trees, about 650 stems per ha in older stands, basal area is usually under 40 $m^2 \cdot ha^{-1}$. In the mature white spruce stands, tree heights of 30 m are common, and diameters at 120 years average 30 cm. Basal area of the floodplain stands of white spruce ranged from 40 to $58^{2} \cdot ha^{-1}$.

Standing crop of above-ground tree biomass ranged from 4,000 to 18,000 $g \cdot m^{-2}$ for balsam poplar stands to 6,000 to 24,500 for white spruce stands. Annual, aboveground tree biomass productivity ranged from 264 to 952 $g \cdot m^{-2} \cdot yr$ for the balsam poplar stands and 240 to 540 $g \cdot m^{-2} \cdot yr$ for the white spruce stands.

The main shrub species in this site type are alders *(Alnus* tenuifolia Nutt.) and willows (primarily Salix alaxensis [Anderss.] Cov.) in the early successional stages, but, in the mature stands, *Alnus* crispa may replace *Alnus tenuifolia*, and the willows are largely replaced by Viburnum edule and Rosa acicularis. A wide variety of herbs occurs in the earlier successional stages but are replaced largely by orchids and Pyrola species in the mature stands. Low and dwarf shrubs are lacking in early stages but Linnaea borealis, *Empetrum nigrum* L., and Vaccinium vitis-idaea L. are common in the mature spruce stands. The feathermoss, Hylocomium splendens, is the typical forest floor moss, but in some stands it is largely replaced by Rhytidiadelphus triquetrus (Hedw.) Wornst., perhaps as a result of occasional flooding.

Successional Sequence.–Succession on recently deposited alluvium on the floodplains of the major rivers in interior Alaska is a primary succession sequence. Succession begins with the invasion of willow species, which are usually followed by alder, and eventually develop into a closed shrub stage. A number of physical, chemical, and biological factors, including frequency of flooding, seed source, height above the river, are all important in these early successional stages. Balsam poplar, a fastgrowing, floodplain species forms the next successional stage. During this stage, forest productivity is high, litterfall large, and soil temperatures relatively warm. Willows and alders persist into the balsam poplar stage as a well-developed shrub layer but gradually thin out as the tree canopy closes. Other shrubs, especially *Rosa* acicularis and Viburnum edule, develop under the poplar canopy. The herbaceous layer, well developed in early successional stages, continues in the poplar stage primarily as a thin mat of Equisetum *pratense* Ehrh. Establishment of white spruce may occur during the shrub stage or during the balsam poplar stage. The stands next develop into mixed white spruce-balsam poplar stands and finally into well developed spruce stands.

Following the initial white spruce stands, succession is somewhat variable and poorly documented. The white spruce stands may persist through several generations or may be replaced by black spruce after the first generation. Eventually, on the older terraces, soil temperatures become colder, permafrost is established, and the white spruce stands are replaced by black spruce.

Upland Black Spruce Site Type

Description of the Site Type.--The site type we have designated as the upland black spruce site type is variable and will undoubtedly be further subdivided as more detailed information becomes available. The sites were primarily on ridge tops or north-facing slopes from elevations of from 385 to 470 m. Two stands at the intensive site at Washington Creek had a 10 per cent slope with a southeast aspect.

The forest communities on the sites are generally open to closed black spruce stands that were subdivided into a number of community types but which seem to fit into three broad community types:

1. Closed Picea *mariana/Pleurozuim schreberi-Hylocomium* splendens community,
2. Open Picea *mariana/Ledum* groenlandicum-Vaccinium *uliginosum/Pleurozium* schreberi community, and
3. Open Picea *mariana/Ledum groenlandicurn-Vaccinium uliginosum/Sphagnum* community.

On some slopes the Pleurozium-dominated community on the upper slopes gradually grades into the Sphagnum type on the lower slopes (Dyrness and Grigal 1979).

The upland black spruce type was found on four soil series: the Ester, Fairplay, Gilmore, and Saulich, which are classified as Histic Pergelic Cryaquepts, Aquic Cryorthents, or Alfic Cryochrepts. Of the six stands that we studied in this type, three were underlain by permafrost, and three were classified as permafrost-free although the bedrock beneath the shallow soil mantle may have been frozen.

The soils supporting upland black spruce were found to be the wettest and coldest of all those soils supporting tree growth. Although these conditions may generally be attributed to very thick forest floors and the consequent appearance of shallow permafrost, they also exist in certain soils on upper slopes and ridgetops that lack permafrost. The following is a generalized profile description from the intensive study site at Washington Creek and is representative of the Saulich soil series:

| | | |
|---|---|---|
| 01 | 25 to 18 cm | Live moss and recently deposited litter. |
| 021 | 18 to 5 cm | Dark reddish-brown (5YR 3/2) mat of coarse, fibrous moss remains and forest litter; roots abundant. |
| 022 | 5 to 0 cm | Black (5YR 2.5/1) humus; roots abundant. |
| A1 | 0 to 7 cm | Very dark grayish-brown (10YR 3/2) silt loam; weak subangular blocky structure; friable; roots common. |
| C | 7 to 25 cm | Dark grayish-brown (2.5YR 4/2) saturated silt loam; many distinct dark yellowish-brown (10YR 4/4) mottles; massive, sticky and plastic; roots scattered. |
| | 25 cm+ | Permafrost. |

Soil moisture in the mineral soil varied from 60 per cent in the permafrost-free sites to 250 per cent in one site with a shallow active layer. At 10 cm, soil degree-day sums ranged from 490 to 760, giving an average temperature at 10 cm during the growing season of 4.4 to 6.7°C. The organic layer is thick in all of the stands in this type but varied from 17 to 38 cm. The pH of the forest floor was 4.2. In the stands underlain by permafrost, the thickness of the active layer varied from 22 to 51 cm.

Tree development and productivity is low for all of the upland black spruce sites. Tree density is variable – from 1,400 to 4,000 stems per ha. Tree heights in mature stands range from 7 to 15 m and diameters from 6 to 15 cm. Basal areas range from 7 to 27 $m^2 \cdot ha^{-1}$ with an average for the six stands of 14 $m^2 \cdot ha^{-1}$. Standing crop and productivity are low in these stands. The standing tree biomass ranged from 2,323 to 10,756 $g \cdot m^{-2}$ and annual above-ground tree biomass production from 102 to 148 $g \cdot m^{-2} \cdot yr^{-1}$. The highest values were from a ridgetop permafrost-free site at Bonanza Creek.

The common low shrubs in these open and closed black spruce stands are *Vaccinium vitis-idea, V. uliginosum* L., and *Ledum groenlandicum* Oeder. The dominant moss in these sites is *Pleurozium schreberi*, but there is also a large component of *Hylocomium splendens* in the drier sites and *Sphagnum* spp. in the wetter sites. Lichens, primarily *Cladonia* spp. *Peltigera* spp., and *Nephroma arcticum* (L.) Torss., are common in the stands and can have up to 50 per cent cover in the open stands.

Revegetation Following Fire.--Revegetation following fire in the upland black spruce type is usually rapid. Within weeks of the fire, sprouts from roots and rhizomes of shrubs and herbs are abundant. Even when burning is severe and all underground parts are killed, invasion by mosses and liverworts and the establishment of seedlings is usually accomplished by the spring of the year following the fire. Areas of bare mineral soil are covered with liverworts and mosses, especially *Marchantia polymorpha* L. and *Ceratadon purpureus* (Hedw.) Brid., and herbaceous species with light, airborne seeds such as *Epilobium angustifolium*. Spruce seedlings may become established at this time. Plant cover during this stage increases quickly to as much as 40 to 50 per cent. In the shrub stage, which lasts from 6 to 25 years following the fire, willows and alders dominate the vegetation but herbaceous species remain abundant.

The tree canopy of black spruce begins to dominate at 25 to 30 years following the fire. The young stands of 40 to 60 years are dense, with as many as 4,000 to 6,000 trees and saplings per ha. The most significant event that occurs during this stage is the invasion and rapid development of the feathermosses, *Hylocomium splendens* and *Pleurozium schreberi,* which along with *Sphagnum* species may develop as much as 50 per cent cover. With the establishment of the mosses, the development of a thick organic layer begins, and the depth to permafrost decreases. Once the tree canopy is well established, changes in the vegetation sequence are slower and more subtle. During the older stages, the tree canopy is mostly closed although the density is less than in previous stages, averaging 2,200 stems per ha. The moss layer remains about the same as in the younger stages except for a decline in foliose lichens and an increase in feathermosses, sphagnum, and fruticose lichens. The development of the black spruce type into a mature stand of over 100 years follows without any major changes in vegetation composition.

## Lowland Black Spruce Type

Description of the Site Type.–This type occupies the old terraces of the major rivers and small valley bottoms along drainages in the uplands. Only three of the semiintensive sites were in this type, and all were on older terraces of the Tanana and Chena Rivers at elevations of from 120 to 170 m. The forest communities on these sites are similar to those of the uplands but were separated into three community types based on differences in the shrub and moss layers. The communities are:

a. Open *Picea mariana/Ledum groenlandicum/Hylocomium splendens* community type,

b. Open *Picea mariana/Ledum groenlandicum/Pleurozium screberi* community type, and

c. Open *Picea mariana/Salix planifolia/Ledum groenlandicum/Sphagnum* community type.

The lowland black spruce type is found on the Goldstream and Bradway soil series which are classified either as Histic Pergelic Cryaquepts or as Pergelic Cryaquepts. Soils supporting the lowland black spruce are wet and poorly drained. These soils are generally formed in alluvium with permafrost at a shallow depth. A generalized description of a profile typical of Goldstream silt loam (Histic Pergelic Cryaquept follows).

| | | |
|---|---|---|
| 01 | 30 to 18 cm | Live moss, moss remains, and recently deposited litter. |
| 02 | 18 to 0 cm | Black (10YR 2/1) humus; roots abundant. |
| B21g | 0 to 10 cm | Dark gray (5YR 4/1) silt loam; coarse, distinct dark brown (10YR 4/3) mottles; massive; friable; roots common. |
| B21g | 0 to 10 cm | Dark gray (5YR 4/1) silt loam; coarse, distinct dark brown (lOYR 4/3) mottles; massive; friable; roots common. |
| B22g | 10 to 15 cm | Dark greenish-gray (5GY 4/1) saturated silt loam; common, medium distinct dark grayish-brown (2.5Y 4/2) mottles; massive; friable; few roots. |
| | 15+ cm | Permafrost. |

All three stands studied were underlain by permafrost and had active layer thicknesses varying from 16 to 55 cm. The forest-floor organic layer ranged from 14 to 25 cm in thickness and had a pH of 4.2. Lowland black spruce stands are usually open with trees ranging in height from 8 to 15 m and diameters from 5 to 15 cm. Tamarack *(Larix laricina)* occurs occasionally in the lowland stands along with scattered birch. Basal areas tend to be slightly higher in the lowland black spruce stands than in the upland stands with a range of 8 to 40 $m^2 \cdot ha^{-1}$ and an average in the three stands studied of 20 $m^2 \cdot ha^{-1}$.

Whole tree biomass for the one stand that we studied in the lowland was 1,492 $g \cdot m^{-2}$ and annual, above-ground, tree biomass productivity was only 72 $g \cdot m^{-2} \cdot yr^{-1}$. The shrub and forest-floor vegetation of the lowland stands is very similar to that of the upland stands. *Ledum groenlandicum* is more abundant in the lowland stands, but *Vaccinium uliginosum* and *V. vitis-idaea* have about the same cover in both types. Species of *Salix,* especially *Salix planifolia* Pursh. spp. *pulchra* (Cham.) Argus, are more common in lowland than upland sites. As with upland sites, the lowland sites show a variation in moss species from *Hylocomium splendens* on the driest sites to *Sphagnum* spp. on the wet sites but with *Pleurozium schreberi* the dominant moss in most stands.

Successional Sequence.–The successional sequence on the lowland black spruce sites seems to be similar to that of the upland sites; therefore the sequence is not repeated here.

## Other Site Types

The four site types that we describe above occupy most of the forested terrain in the Fairbanks area. It should be emphasized, however, that there are a number of other site types and transitions within the region. For some of the site types, we have begun to gather soils and environmental information. For example, one of our sites was an aspen stand on a steep, south-facing bluff that we considered to be at the extreme limit of tree growth in the area. This site was occupied by a *Populus tremuloides/Shepherdia canadensis/Calamagrostis purpurescens* community. Soil degrees were over 2,200, and soil

Table 3—Selected site factors for four forest types in interior Alaska

| Forest types | Soil series | Soil classification | Parent material | Drainage class | Forest floor thickness | Depth to permafrost | Soil degree days | Ave. growing-season soil temperature at 10-cm depth |
|---|---|---|---|---|---|---|---|---|
| | | | | | (cm) | (cm) | | (°C) |
| Upland white spruce and successional series (aspen and birch) | Gilmore | Alfic Cryochrept | Loess | Well drained | 2-9 | none | 876-1117 | 8-10 |
| | Steese | Alfic Cryochrept | | | | | | |
| | Fairbanks | Alfic Cryochrept | | | | | | |
| Floodplain white spruce and successional series | Salchaket | Typic Cryofluvent | Alluvium | Well drained | 4-9 | none | 799-1310 | 7-12 |
| Upland black spruce | Ester | Histic Pergelic Cryaquept | Loess | Poorly drained | 12-38 | 22 to 50 or none | 563-761 | 5-7 |
| | Saulich | Histic Pergelic Cryaquept | | | | | | |
| | Fairplay | Aquic Cryorthent | | | | | | |
| | Gilmore | Alfic Cryochrept | | | | | | |
| Lowland black spruce | Goldstream | Histic Pergelic Cryaquept | Alluvium | Poorly drained | 14-25 | 16-55 | 483-729 | 4-6.5 |
| | Bradway | Pergelic Cryaquept | | | | | | |

Table 4—Above-ground tree biomass and annual, above-ground, tree-biomass production for four forest types in interior Alaska

| Forest Types | No. of stands | Tree biomass ($g \cdot m^{-2}$) | | Annual tree production ($g \cdot m^{-2}$) | |
|---|---|---|---|---|---|
| | | Range | x + SE | Range | x + SE |
| Upland white spruce site: | | | | | |
| White spruce | 1 | 24,940 | -- | 353 | -- |
| Aspen | 1 | 18,310 | -- | 760 | |
| Birch | 3 | 9,192-14,713 | 11,156±1,782 | 343-572 | 470267 |
| Floodplain white spruce site: | | | | | |
| White spruce | 3 | 6,216-24,443 | 15,387±5,262 | 238-540 | 370±89 |
| Balsam poplar | 3 | 4,067-18,027 | 12,097±4,165 | 264-952 | 552±206 |
| Upland black spruce site: | | | | | |
| Black spruce | 3 | 2,323-10,756 | 6,14327,467 | 102-148 | 127±14 |
| Lowland black spruce site: | | | | | |
| Black spruce | 1 | 1,492 | -- | 72 | -- |

moisture averaged only 20 per cent for the season. *Shepherdia canadensis* **(L.)** Nutt. and *Arctostaphylos uva-uris* **(L.)** Spreng. are indicator species of this dry site type. At the colder, dry end of the environmental scale, we selected a white spruce-black spruce woodland at treeline at 750 m which we classified as *Picea glauca-Picea mariana/Alnus crispa-Betula glandulosa/ Pleurozium schreberi* community. Although air temperature at this site was lower than at **all** the other sites, soil degree-day accumulations were not as low as at some of the lowland black spruce sites. The dominance of *Betula glandulosa* Michx. in the shrub layer is typical of the open and woodland spruce stands at treeline.

## SUMMARY AND CONCLUSION

Forest sites in the taiga of interior alaska extend over a wide environmental gradient but basically can be divided into cold, black spruce sites, usually underlain by permafrost, and mesic white spruce sites and successional stages leading to white spruce on warm, well-drained, permafrost-free soils. Each of these basic types can be further subdivided on the basis of topographical position, developing vegetation sequence, and mature vegetation. The four basic site types described in this paper are: (1) upland white spruce sites, (2) floodplain white spruce sites, (3) upland black spruce sites, and (4) lowland black spruce sites. For each of these site types, there are a number of successional and climax-forest communities, soil types, typical and indicator species, and environmental factors that can be used to distinguish and describe the types. Some of these site factors are summarized in table **3.** Forest productivity is high on the two white spruce site types and low on the black spruce types (table **4).**

Forest management should be concentrated on the more-productive sites. Each of these sites **has** its own unique management and regeneration problems, and forest management plans will have to be developed for each site type.

The Alaska Vegetation Classification System provides a framework for the recognition and classification of forest site types in interior Alaska, but, because the Alaska taiga flora is made up of a few species with wide ecological amplitude, vegetation alone is not enough for separating differences in site factors. This seems to be especially true with the black spruce types, which are found over a wide variety of soil types. Data such as those presented in this paper should be accumulated on site factors related to each of the vegetation communities so that the information can serve as a basis for classification of ecosystem types (similar to the habitat types of Daubenmire) which can then be used as basic management units. When these units are established and identified, they will be useful for the formulation of management practices, especially as the types relate to forest productivity and regeneration following logging or other disturbance for the principal forest sites in interior Alaska.

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# SITE CLASSIFICATION AND REGENERATION PRACTICES ON FLOODPLAIN SITES IN INTERIOR ALASKA

John C. Zasada

## INTRODUCTION

The floodplains of Alaska's rivers are some of the most productive forest sites in the state. Historically these forests, in particular white spruce *(Picea glauca),* were heavily utilized during the gold rush and settlement period of the early 1900s. As transportation of building and heating materials from outside of Alaska became more efficient, local forest utilization decreased. Present utilization is insignificant except near villages where forests are the only readily accessible source of wood. There is high potential to increase utilization of these stands. The impetus for this increase appears to stem from political and economic interest.

Management experience and research information that can be applied to management of floodplain sites is limited. The most detailed research on any aspect of management on northern river floodplains (north of 60° N latitude) was reported by Gardner (1983) for the Liard and Meister rivers in southern Yukon. Ganns (1977) reported on regeneration studies on Tanana River (Alaska) sites. Experience gained from management on uplands in Alaska .provides some insight into management alternatives for flood plains. However, ecological conditions on these two physiographically distinct areas are different in several important ways, and practices may not be directly transferable from one type of area to the other (Zasada et al. 1977).

In contrast to the lack of management experience is the availability of a relatively large body of basic ecological information for flood plain sites (Viereck 1970a, 1970b; Van Cleve et al. 1971, 1980; Van Cleve and Viereck 1972, 1980; Juday and Zasada 1984). These studies provide valuable information on site development and forest succession. However, they do not deal with secondary forest succession following such disturbances as fire and harvesting.

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The purpose of this paper is to consider factors that affect white spruce regeneration on flood plains. To do this, we first need to consider, briefly, the development of forests on these sites – how white spruce stands originate and their fate in the absence of disturbance. In the second part of this paper, regeneration alternatives will be discussed using the Willow Island research project as an example. This project is primarily concerned with regeneration options following harvesting, but white spruce stand and site development have also been examined in some detail (Juday and Zasada 1984).

## PRIMARY FOREST DEVELOPMENT

Floodplain sites are dynamic in terms of vegetation change and soil development. These changes are described briefly below. Unless otherwise noted, the following summary is distilled from Viereck (1970a and 1970b), Van Cleve et al. (1971, 1980), Van Cleve and Viereck (1972, 1980), and Juday and Zasada (1984).

Forest developnient on floodplain sites begins with the deposition of a gravel/silt bar that remains stable long enough for vegetation to become established. Various willows ***(Salix*** spp.) and alder (*Alnus incana*) are the first woody plants to dominate the site. Balsam poplar *(Populus balsamifera),* which becomes established at about the same time as the willows and alder, assumes a dominant or codominant position about 15 to **20** years after site formation; it remains the dominant species for 50 to 60 years. Seedlings of other trees, e.g., aspen *(Populus tremuloides),* birch *(Betula papyrifera)*, tamarack (*Larix* ***laricina),*** and white spruce may be present to varying degrees in these early stages of development but either die or do not become important until much later in forest development' (Krasny 1982).

[1] Marianne Krasny, College of Forest Resources, University of Washington, Seattle, WA, personal communication.

Generally, white spruce becomes the dominant species at 80 to 100 years. There are, however, cases where balsam poplar is dominant for at least 200 years. White spruce invades sites early in forest development, but many early seedlings probably die as a result of flooding or other disturbance, and the time at which spruce becomes a permanent component of the developing forest varies with site conditions. Nanson and Beach (1977) reported that conditions on floodplain sites in north-central British Columbia may not be favorable for white spruce establishment until well into the balsam poplar stage.

The first generation of white spruce on these sites may dominate for 200 to 300 years. During this time there is continual attrition, with some replacement of dominants as suppressed and intermediate trees are released. Trees are relatively even-aged for the first 100 to 150 years. However, as the oldest trees in the stand attain ages of 250 to 300 years, the difference in age of dominants and codominants may be as much as 100 years. The number of cycles or generations of white spruce that can occur on a given floodplain site in interior Alaska is not known. Nanson and Beach (1977) reported that three to four distinct generations of white spruce may have occupied a given site in British Columbia.

Regeneration is primarily from seed that germinates on a variety of surfaces: silt deposited by flooding, rotted wood, or mineral soil exposed by windthrows. Layering was reported by Densmore (1980) on the floodplain of the upper Dietrich River, Alaska; both vegetative and seed reproduction were present. This site is near treeline in the Brooks Range.

White spruce stands are subjected to several types of disturbance which have different impacts on tree and stand development. The most serious threat to stand integrity is erosion by the river and ultimate destruction of the stand. White spruce sites do not appear to erode as rapidly as younger sites but may be subjected to continuous bank erosion. For example, it is not uncommon to find erosion of 50 to 100 feet of river bank in one year on sites where willow, alder, and/or balsam poplar predominate. On sites where spruce dominates, erosion probably does not exceed 5 to 10 feet per year.

Stands are flooded periodically. Frequency of flooding is determined by terrace height and river levels. Because white spruce stands are on higher terraces, they are flooded less frequently than stands in earlier stages of development. Some of the most severe flooding occurs in stands situated where ice jams that form downriver cause high river levels upstream. In one instance on the Yukon River (several miles downstream from the Charley River), water level was 15 to 20 feet above normal summer levels as a result of ice jamming downstream. Trees along the edge of the river had substantial stem damage 5 to 10 feet above ground because of ice abrasion.

Flooding occurs at different times of year. For example, on the Tanana River, flooding may occur in late spring or early summer as a result of annual snowmelt and spring runoff, and again in late summer or early fall as the result of heavy rains.

Fire may also affect these stands, even though they tend to be protected by river channels and old sloughs. On the 1977 500,000-acre Bear Creek fire, I observed wildfire in floodplain stands along the Kuskokwim River. Older evidence of burning comes from Willow Island on the Tanana River floodplain. Here fuel sampling revealed significant amounts of charcoal from past fires in the organic layers and on the surface of the mineral soil on one of the oldest sites on the island.

Black spruce *(Picea mariana)* ultimately invades these sites, but the time required for this species to replace white spruce and the influence of the various disturbances is not known, nor is the invasion and establishment process fully understood. It is commonly believed that black spruce invades late in succession, when white spruce is deteriorating. However, I have found scattered black spruce in relatively vigorous 100- to 150-year-old white spruce stands, indicating that establishment can occur before the first generation of white spruce has begun to deteriorate. Paper birch can also become an important component in older white spruce stands. Paper birch, like black spruce, has been found in younger stands, suggesting that in some cases establishment may occur at about the same time as white spruce.

As mentioned earlier, soil changes occur in concert with the vegetation changes. Early in primary succession, the river is the predominant force in soil development. Later in succession, vegetation becomes a relatively more important factor. As vegetation develops, terraces are stabilized, soil is retained, and soil fertility is altered. The soil surface (seedbed) changes from almost pure mineral soil to a well-developed organic forest floor; intermediate conditions include various combinations of silt and organic matter. The developing organic layer regulates moisture, temperature, and nutrient regimes. These variables obviously affect forest productivity. Soil temperature is one of the more easily observed changes. The trend is for a gradual reduction in soil temperature as succession progresses. During the white spruce stage when the forest floor is well developed, permafrost may begin to develop. The black spruce stands on old river terraces have well-developed permafrost layers.

## CONSIDERATIONS FOR REGENERATION OF WHITE SPRUCE

Two broad categories of management practice must be considered for regenerating white spruce on floodplain sites.

1. Practices needed to regenerate white spruce following harvest on sites currently supporting white spruce – the only forests that have commercial value at the present time. Examples of forest types that might require these practices are *Picea glauca/Alnus* spp./*Hylocomium*, *Picea glauca*/feathermoss, *Picea glauca/Alnus* spp./*Vaccinium/Hylocomium*, *Picea glauca/Alnus/Ledum*/feathermoss, and, possibly, *Populus balsamifera-Picea glauca/Alnus/Equisetum* (classification follows Viereck and Dyrness 1980). Practices would be those normally associated with white spruce regeneration (e.g., clearcutting, followed by site preparation and natural or artificial regeneration, or a shelterwood system, followed by site preparation and natural regeneration).
2. Practices that promote or encourage optimum regeneration and early development of white spruce during the initial stages of forest development. Vegetation types requiring these practices (e.g. underplanting or artificial seeding) might include *Populus balsamifera/Alnus tenuifolia*, *Populus balsamifera/Salix-Alnus*/herb, and, perhaps, *Salix-Alnus incana/Equisetum*. The rationale behind these practices is that natural regeneration of white spruce is not always adequate in these vegetation types. The objective would be to bring white spruce stocking to a level that would ensure well-stocked stands as white spruce became dominant during the normal course of succession.

Some cultural practices may be generally appropriate to both these situations, although site conditions may differ considerably. For example, site preparation may be necessary in both situations, but the nature of the forest floor may require different methods to obtain the necessary microsite conditions. There may also be differences in overstory conditions, litter fall, moisture regime, and other variables.

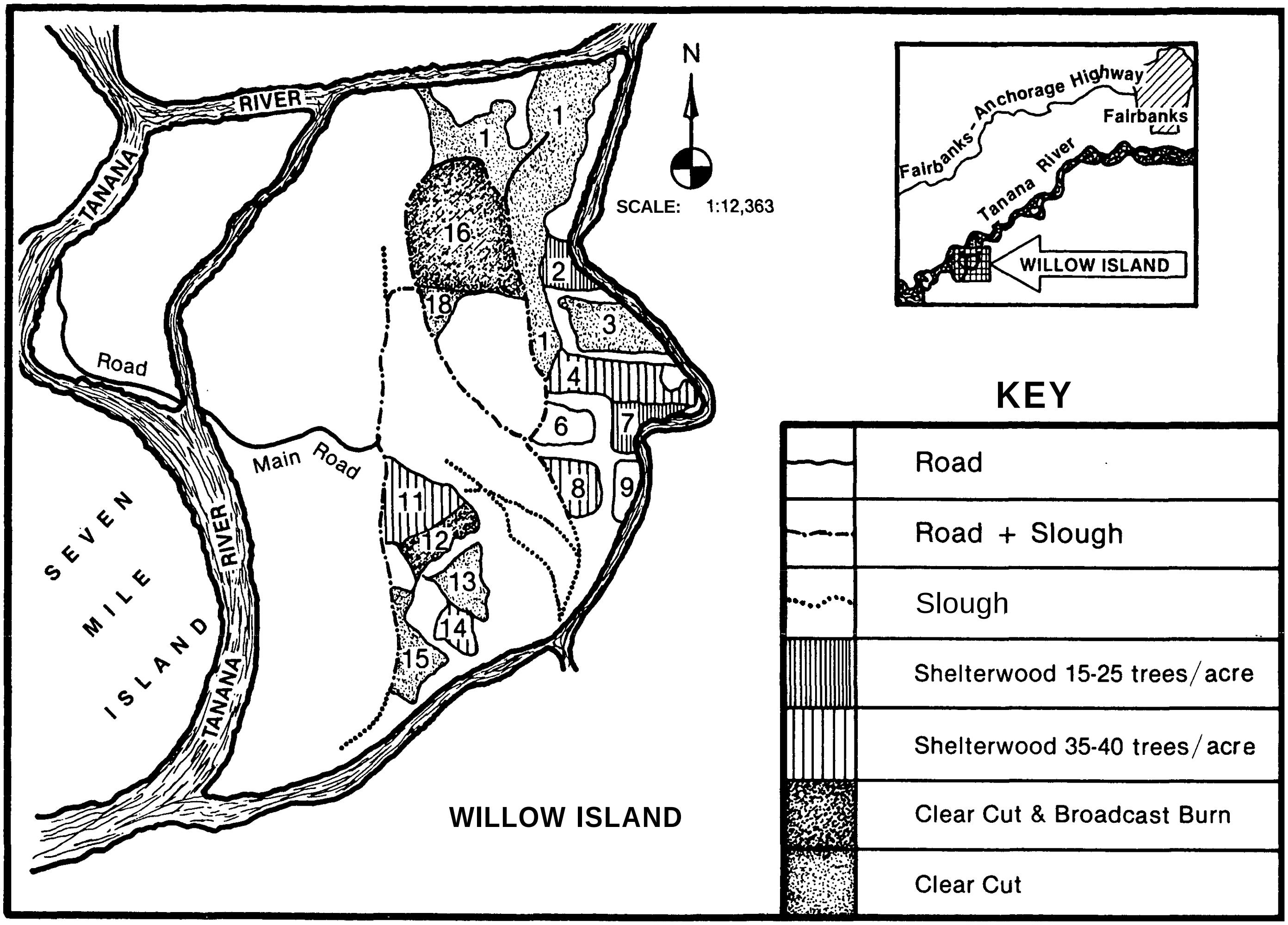


Figure 1.–Location of Willow Island and cutting units. Units 11 to 15 are in the open white spruce/alder/*Hylocomium* type; soil is the deep phase of the Salchaket series. Unit 16 and the part of Unit 1 just north of 16 are in the open white spruce/ alder/*Vaccinium/* Hylocomium type and the woodland white spruce/*Ledum/Vaccinium/*feathermoss type; soils for both are in the Tanana series. The remainder of Unit 1 and Units 2-9 are in the open white spruce/alder/*Vaccinium/Hylocomium* type; soil series for this area is Salchaket intermittent frost phase.

Table 1– Stand type and soil characteristics for seven white spruce stands on Willow Island

| Stand Type[1] | Stand[2] | Soil[1] | Organic layer depth[1] | Permafrost[2] | Age Range[1] | Height of dominants[2] |
|---|---|---|---|---|---|---|
| | | | (cm) | | (years) | (m) |
| Woodland white spruce/ *Ledum*/feathermoss | 1 | Tanana | 15-25 | Present | 131-250 | 17 |
| Open white spruce/alder/ *Vaccinium/Hylocomium* | 3 | Salchaket[3] | 10-23 | Present[3] | 208-326 | 32 |
| | 4 | Salchaket[3] | | Present[3] | 77-370 | 28 |
| | 6 | Salchaket[3] | | Present[3] | 99-380 | 38 |
| Open white spruce/ alder/*Hylocomium* | 2 | Salchaket[4] | 10-15 | Absent | 151-243 | 33 |
| | 5 | Salchaket[4] | | Absent | 91-116 | 29 |
| Closed white spruce/ alder/*Hylocomium* | 7 | Salchaket[4] | | Absent | 95-130 | 29 |

[1] C.T. Dyrness, Institute of Northern Forestry, U.S. Department of Agriculture, Forest Service, Fairbanks, AK. Unpublished data.
[2] As assigned in Juday and Zasada (1984).
[3] Frost described as frost phase of Salchaket soil, much more variable than in Tanana soil.
[4] Deep phase of Salchaket soil.

Regardless of the management practices considered, the question of site stability and longevity must be addressed. Will a given site still be present when the forest crop is ready for harvest? Even though higher terrace elevations make white spruce sites seem relatively more stable than younger sites, they do erode. At present, there is no method of predicting site stability over the length of a white spruce rotation. Examination of old aerial photographs, observation of current rates of bank erosion, distance from main channel, and other variables can help predict stability, but nothing can provide an absolute answer.

The remainder of this paper will consider only regeneration following harvesting of white spruce, although practices that promote optimum regeneraton during early forest development are no less important. Walker[2] is studying the establishment of white spruce and other species in a number of successional stages on the Tanana River floodplain. His study should provide information on which to base management alternatives and to design additional studies to provide practical answers.

Regeneraton of white spruce following harvesting is currently being studied on Willow Island. This island, located near Fairbanks, Alaska, is on the Tanana River floodplain. The Willow Island study was developed to examine regeneraton of white spruce under several combinations of silvicultural systems (shelterwood, clearcut) and methods of site preparation (burning, mechanical) (fig. 1), as well as to provide some insight into the effects of harvesting on white spruce ecosystems.

Willow Island covers approximately 250 hectares, and at least **90** percent of the island was covered by white spruce stands. Topographic relief is about 2 meters. The lowest areas are the bottoms of old river channels (Juday and Zasada **1984).** Dyrness[3] identified four major white spruce stand types and two soil types (table **1).** Juday and Zasada **(1984)** further characterized stands in each of the types identified by Dyrness (table **1).**

We treat Willow Island as one unit of land at present. However, formation of the island was a complex process that has taken several hundred years, and the island continues to change (Juday and Zasada **1984).** The channels on the east and south sides carry water only at high river stages. The channel to the north carries water at all stages but becomes very shallow at low stages. The channel on the west is the most significant and, although not the main channel of the river, appears to be an important secondary channel. There are many old channels on the island (fig. **1)** that carry water only at flood stage.

Site classification, as discussed elsewhere in this workshop, can be used to identify appropriate management alternatives. Some initial observations on Willow Island that have implications for land managers follow:

1. Height-growth patterns of dominant trees in the seven stands identified by forest and soil type in table **1** appear to be quite different (fig. 2). One can only speculate whether these differences will continue following logging or whether the regeneraton growth will be similar to early stand development of first-generation white spruce (see curve for stand **5**, fig. **1).** The stands with the slowest height growth are those growing on the deepest organic layers and coldest soils. Removal of the overstory and disturbance of the organic layers will certainly affect soil temperatures and decomposition rates, and these will affect forest growth and development.

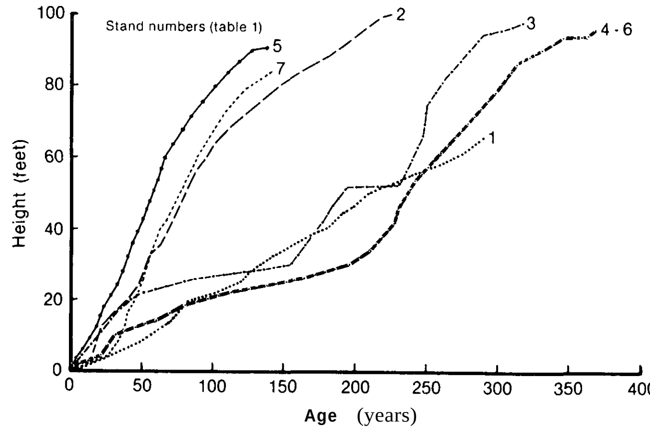


Figure 2.--Height-growth patterns of dominant white spruce growing in seven stand types. See Table **1** for soil characteristics in these stands.

2. Different treatments and/or equipment may be needed for some stand types. For example, site preparation with a patch scarifier and rubber-tired skidder was easier and appeared to be more effective on the better drained, open *Picea glauca/Alnus/ Hylocomium* types than on the open *Picea glauca/Alnus/ Vaccinium/Hylocomium* types. Poorly drained surface soil conditions, due in part to a shallow active layer (i.e., permafrost close to surface), caused the skidder to bog down, and patches made by the scarifier filled with water. This was not a problem on the well-drained sites. This observation suggests that nonmechanical site preparation (e.g. prescribed burning) may be more effective on the wet sites, or that mechanical scarification should be delayed until frost levels are deeper and the surface soil is better drained.
3. Some portions of the *Picea glauca/Alnus/Hylocomium* type have been flooded, and silt deposition has temporarily covered the moss/organic layers, essentially converting this type to a *Picea glauca/Alnus* type. This can be an important distinction because undisturbed *Picea glauca/Alnus* stands can have abundant regeneration, while in *Picea glauca/Alnus/ Hylocomzum* stands regeneration is scattered and not abundant. The portion of the *Picea glauca/Alnus/Hylocomium* type affected by this flooding/siltation process is usually confined to a narrow band adjacent to the river. However, I have observed abundant regeneration in natural stands resulting from this process up to 300 feet from the active river channel. Zufelt[4] has observed abundant regeneration of white spruce following logging on silt layers deposited by flooding. These observations substantiate the belief that recognizing distinctions such as these could be important to regeneration planning.

Other differences between site types will certainly become evident as vegetation develops and the study progresses. There is little doubt that some level of vegetation or site classification must have both soil and vegetation components to be useful in silviculture planning.

[2] Lawrence R. Walker, Institute of Arctic Biology, University of Alaska, Fairbanks, AK, personal communication.

[3] C.T. Dyrness, Project Leader, Institute of Northern Forestry, USDA Forest Service, Fairbanks, AK, personal communication.

[4] W.J. Zufelt, Tanana Chiefs Conference, Fairbanks, AK, personal communication.

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ECOLOGICAL CLASSIFICATION OF ALBERTA FORESTS
AND ITS APPLICATION FOR FOREST MANAGEMENT

Ian G.W. Corns and Richard M. Annas

ABSTRACT: A forest-ecosystem classification for a 4.6 $\times 10^6$-ha west-central Alberta study area was designed using several available sources of vegetation, soil, and forest-productivity information. Management interpretations using available ecological classification and reconnaissance soil-survey information were made for the following management concerns: harvest season and method; site-preparation intensity; soil-compaction, puddling, and erosion hazards; reforestation species, method, limitation, frost-heave hazard, and seedling-transplant mortality; site productivity; fire hazard; vegetation-competition hazard (type and severity); windthrow hazard; rodent-damage hazard; and common soil map units for each of twenty-five ecosystem associations.

## INTRODUCTION

In recent years a greater appreciation of the value of forested land by a variety of potential users has intensified interest in ecosystem classification, evaluation of variation in forest site productivity, and in inventories of rapidly changing landscapes. Early forest-site research in the boreal forest of Alberta, Saskatchewan, and Manitoba has fallen behind other parts of Canada and the United States mainly because only recently (the last 25 years in Alberta) has any real utilization demand been put upon that forest region. The growing concern that forest resources are being depleted too rapidly or are being managed in a suboptimal manner is prompting the search for means to utilize most effectively the forest resource while maintaining its productivity.

Some of the earliest work in the western boreal forest was done in Alberta by Brinkman (1931, 1936) using lichens and mosses as site indicators. Smithers (1956) assessed site productivity in dense lodgepole pine stands in the Kananaskis Forest Experiment station, Alberta. Duffy (1964) used multiple-regression techniques to find relationships between site factors and growth of lodgepole pine in the Alberta foothills. Duffy (1965) developed a forest-land classification for the Mixedwood Section of central Alberta on the basis of differences in soil parent material and soil-moisture status as they influence white spruce site index. Dumanski et al. (1973) evaluated the productivity of lodgepole pine forests using soil-survey maps for the Hinton-Edson area. Lesko and Lindsay (1973) related lodgepole pine and white spruce site index within fifteen forest types to soils in the Chip Lake map area in westcentral Alberta. In addition, several descriptions of vegetation distribution in northern and northwestern Alberta have been made by Lewis et al. (1928), Dowding (1929), Raup (1933, 1934, 1946), Moss (1953, 1955), Moss and Pegg (1963), LaRoi (1967), Achuff and LaRoi (1977), Corns (1978), and, most recently, by Krumlik et al. (1978) during a biogeoclimatic classification of Alberta's forests and also during a biogeoclimatic classification of the British Columbia Forest Products Forest Management Agreement Area (Krumlik et al. 1982). Comprehensive reconnaissance soil surveys and interpretations for the study area have been made by Dumanski et al. (1972), Twardy and Corns (1980), and Knapik (1983).

The objectives of the present study were to classify and describe ecological zones (ecozones) and their component forest ecosystems within the study area with respect to their floristic composition, environmental characteristics, successional relationships, and potential for fiber production, and to make interpretations for forest management. All available, relevant sources of vegetation, soils, and climate information were consulted and, if possible, incorporated into the present classification and interpretations.

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The classification is a hierarchical system that corresponds to the biogeoclimatic system developed in British Columbia by Krajina (1965) and students; it also parallels the scheme used by the Canadian Committee on Ecological Land Classification (CCELC). The system used in western Alberta uses four fundamental classification levels: ecozone, subzone, ecosystem association, and ecosystem-association phase. The ecozone corresponds to the biogeoclimatic subzone as used in British Columbia (Krajina 1965, Pojar 1983), the ecoregion of Strong and Leggatt (1980), and the forest section of Rowe (1972). The ecozone defines a geographic area that is controlled by the same regional climate (macroclimate) and by characteristic zonal soils and vegetation that have developed in response to climate. The subzone, a subdivision of the ecozone, is similarly controlled by macroclimate, but it exhibits less variability in soils and vegetation. Ecosystems at the level of the biogeocoenose of Sukachev and Dylis (1964) are grouped into ecosystem associations which resemble the plant association of Braun-Blanquet (1928) and the habitat type of Daubenmire (1952). Ecosystem-association phases are not a taxonomic category in the ecosystem-classification system but are recognized in order to facilitate more precise resource-management interpretations. Phases of an ecosystem association are distinguished on the basis of differences in physiographic features (slope per cent, slope position, aspect, etc.) soil properties (i.e. texture), parent materials, and bedrock geology (Mitchell and Green 1981). Ecosystem associations and phases are considered to be the most-practical operational units and all management considerations are evaluated at this level.

## STUDY AREA

### Location and Extent

The study area is located in west-central Alberta between latitudes 53" - 55" N and longitudes 116° - 120° W. The area includes four National Topographic Series map sheets: Wapiti (83L), Iosegun (83K), Hinton-Edson (83F), and part of Mount Robson (83E, fig. 1) comprising an area of approximately 4.6 x $10^6$ ha.

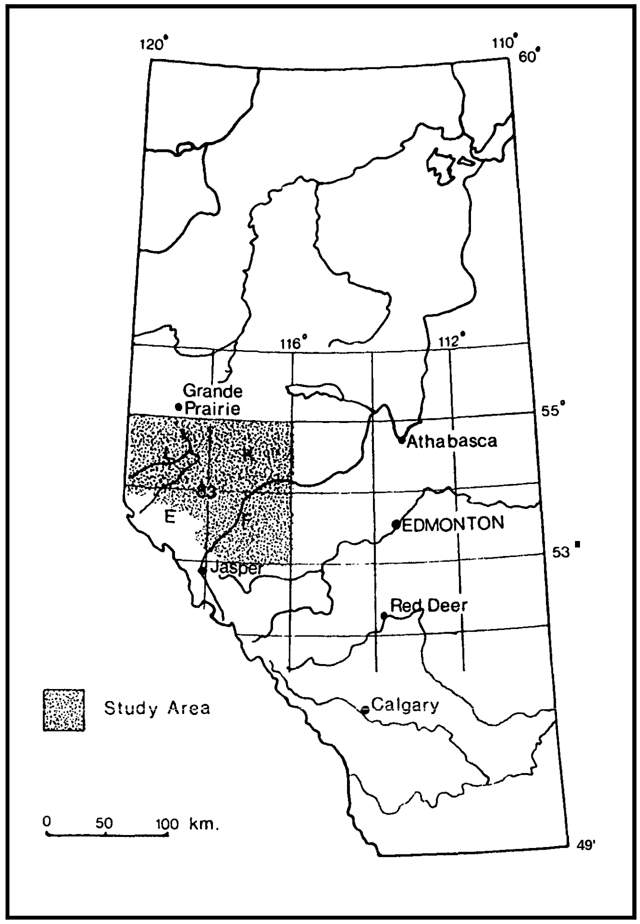


Figure 1.--Location of the Alberta study area.

### Physiography, Geology, and Soils

The predominant physiographic regions in the study area are in the Alberta Plateau (Bostock 1970) and the Rocky Mountain Foothills. The area is underlain primarily by the Paskapoo Formation of Paleocene to Late Cretaceous age and consists of weakly consolidated beds of shale, sandstone, coal, and chert conglomerate.

Both Cordilleran and Keewatin (Continental) glacial ice-covered parts of the study area. The influence of the Cordilleran ice was restricted to the south and west and affected over one-third of the study area. The remainder of the area was covered by the Keewatin ice sheet in at least two ice advances. Surficial deposits include glacial till of Keewatin and Cordilleran origin occurring as ground moraine, glaciolacustrine silts and clays with bedding, glaciofluvial coarse gravels occurring as river terraces, aeolian sands, recent alluvial deposits, and organic peat. A few small areas of shale, sandstone, coal, and conglomerate outcrops are present in the more mountainous areas in the southwestern portion of the map area. Elevations range from 600 to 2450 m ASL.

Soils of the Luvisolic, Brunisolic, Gleysolic, Regosolic, Podzolic, and Organic orders of the Canadian soil classification system (Canada Soil Survey Committee 1978) are represented in the study area. The dominant soil subgroups are Orthic Gray Luvisols, Brunisolic Gray Luvisols, Gleyed Gray Luvisols, Podzolic Gray Luvisols, and Orthic Eutric Brunisols (Boralfs, Aqualfs, Atalfs, Cryochrepts, and Eutrochrepts. (Soil Survey Staff 1975).

More detailed descriptions of the nature and extent of the soils in this area are discussed by Knapik (1983), Twardy and Corns (1980), and Dumanski et al. (1972). These reports are accompanied by 1:126,720 scale maps.

### Climate

Köppen's classification of climate describes the study area as a cold snow forest (Stringer 1972). This climate is characterized by cool summers and cold winters. The May 1 to September 30 period has a mean air temperature of 10-11°C, an average precipitation of 38-46 cm, 25-50 per cent of which falls as snow between November and March, a potential evapotranspiration of 38-43 cm, and a frost-free period (greater than 0°C) of 60 to 160 days (MacIver et al. 1972). Mean January air temperature (mean of daily max. and min.) at Edson is -14.0°C. Grande Prairie to the north of the study area is colder (-17.3°C), and mean monthly air temperatures are below freezing for all stations between November and March inclusive (Environment Canada 1975).

### Vegetation

Most of the forest vegetation of the study area lies within the Mixedwood (B 18a), Lower Foothills (B 19a), and Upper

Table 1--Examples of management interpretations from ecosystem classification

| Ecosystem association | Season[1] | Method[2] | Site preparation intensity[3] | Soil compaction hazard | Soil puddling hazard | Soil erosion hazard | Reforestation interpretations: Species[4] | Method | Limitations | Frost heave hazard | Seedling transplant mortality |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Boreal Subzone: | | | | | | | | | | | |
| *Picea glauca/Equisetum arvense/Hylocomium splendens* | W | CC PC | H | H | M-H | M-H | wS | Bare-root | Excess moisture | H | H |
| *Populus tremuloides/ Vibernum edule/Aralia nudicaulis* | S | CC | M-H | H | M-H | H | A, wS, lP | Bare-root, container | Excess moisture, fine texture | M-H | M |
| *Pinus contorta/Elymus innovatus* | S | CC | L | L | L-M | L-M | lP, A | Natural seed, container | Drought | L | M |
| Upper Boreal Subzone: | | | | | | | | | | | |
| *Pinus contorta/Alnus crispa/Cornus* | S | CC | L-M | M | L-M | L-M | lP wS | Container, natural seed | Competition | M | L-M |
| *Pinus contorta-Picea mariana/Ledum groenlandicum/ Pleurozium schreberi* | S | CC | L-M | M-H | M-H | M-H | lP | Container, natural seed | Excess moisture on some sites | M | L-M |
| *Pinus contorta/ Vaccinium myrtilloides/ Cladonia* spp. | S | CC | L | L | L | L | lP | Container, natural seed | Drought | L | M |
| Subalpine Zone: | | | | | | | | | | | |
| *Pinus contorta/ Rhododendron albiflorum/ Rubus pedatus* | W | CC | L-M | M | M-H | AI-H | lP | Container | Excess moisture in spring | M-H | M |

[1] Season: W - winter; S - summer
[2] Method: CC - clearcut; PC - patch cut; SC - selective cut
[3] Site Preparation intensity and others: H - high; M - medium; L - low
[4] Species: wS - white spruce; lP - lodgepole pine; A - aspen; bS - black spruce

Foothills (B 19c) sections of the Boreal Forest Region plus a small area within the East Slope Rockies Section (SA 1) of the Subalpine Forest Region (Rowe 1972). These units correspond to the Boreal Mixedwood, Boreal Foothills, Boreal Uplands, and Subalpine Ecoregions mapped at 1:1,500,000 for Alberta by Strong and Leggat (1981).

## METHODS

### Plot Sampling and Classification

Data were obtained from approximately 900 sample plots from the following studies: Krumlik et al. (1978, 1979, 1982), Nemeth et al. (1981), Corns (1978), and Lesko and Lindsay (1973). Although the work of Lesko and Lindsay (1973) is from the Chip Lake map area adjacent to the southwest corner of the study area, it is relevant to much of the lower elevations of the study area farther north. The 0.01 to 0.04-ha sample plots were selected using forest-cover maps and aerial photographs within well-developed homogeneous forest stands on a variety of soils and landforms. In all the studies the sample plots were placed subjectively to best represent soil and vegetation conditions. Plot location and general physiography (elevation, slope gradient and aspect, topographic position, relief shape, and landform) were recorded on field sheets. Soils were described according to the Canadian System of Soil Classification (Canada Soil Survey Committee 1973-1978). Vegetation was sampled in a fashion compatible with Braun-Blanquets' (1932) methods or those described by Walmsley et al. (1980). Classification was done by tabular comparison (Mueller-Dombois 1974) using computer-generated vegetation and environment tables. Additionally, all sample plots included forest mensurational data. Site index was determined for all plots based on dominant and codominant trees, and for most plots stand volumes and mean annual increment in total volume (MAI) were also determined.

### Interpretations for Forest Management

Interpretations for forest management (table 1) are made within an ecosystem association framework and are based upon a variety of information sources including reconnaissance soil-survey reports, available forest ecological information, and observations by operational foresters and the authors. Quantitative data were not available for many interpretations nor for some ecosystem associations. In these instances, data from similar environmental/ecological situations were extrapolated. Interpretations were made for a variety of attributes significant for forest management: season and method of harvest, site-preparation intensity, soil-compaction hazard; soil-pud-

Table 1--continued

| Ecosystem association | Productivity Species | X MAI (m³/ha/yr) | Site index (70) (m) | Fire hazard[5] | Vegetational type | Competition severity | Windthrow hazard | Rodent damage hazard | Common soil map units |
|---|---|---|---|---|---|---|---|---|---|
| Lower Boreal Subzone: | | | | | | | | | |
| *Picea glauca/Equisetum arvense/Hylocomium splendens* | wS | 3.7 | 11.8 | M-L M-L / M-L M-L | Reedgrass, sedge | M-H | H | M | SIP, SKY, GUN |
| *Populus tremuloides/ Vibernum edule/Aralia nudicaulis* | A | **4.3** | 19.8 | L-M L-M / H L-M | Reedgrass, forbs, willow | M-H | M | H | LDG, DON |
| *Pinus contorta/Elymus innovatus* | lP | **3.4** | 16.0 | M-H M-H / H M-H | Ryegrass | L | L | L | RBB |
| Upper Boreal Subzone: | | | | | | | | | |
| *Pinus contorta/Alnus crispa/Cornus canadensis* | lP | 4.0 | 17.6 | M-L M-L / H M-L | Alder, reedgrass | M | L | H | EDS, MLB TOR |
| *Pinus contorta-Picea mariana/Ledum groenlandicum/ Pleurozium schreberi* | lP | **3.8** | **15.8** | M-L M-L / H M-L | Reedgrass | L-M | M | M | EDS, SIP, TOR, COP |
| *Pinus contorta/ Vaccinium myrtilloides/ Cladonia* spp. | lP | 1.3 | 11.9 | L-M L-M / H L-M | Ryegrass | L | L | L | BKM |
| Subalpine Zone: | | | | | | | | | |
| *Pinus contorta/ Rhododendron/albiflorum/ Rubus pedatus* | lP | 3.0 | 13.1 | M-H M-H / H M-H | Reedgrass, Rhododendron | L | M | L | RBB, COP |

[5] Fire hazard: $\frac{\text{cured dormant crown (early spring, late fall) active growth crown (late spring to early fall)}}{\text{cured dormant surface (early spring, late fall) active growth surface (late spring to early fall)}}$

Table 2–Optimum season of harvest

| Season | Internal drainage | Texture B Horizon | Soil map unit |
|---|---|---|---|
| Winter only | Imperfectly to very poorly | CL-HC | DON1; SIP1, **2**; EDS2; **2,3,4** |
| Summer or winter | Rapidly to moderately well | S-CL | |

dling hazard; soil-erosion hazard; reforestation method, limitations, preferred species, seedling frost-heave hazard, and anticipated seedling mortality; productivity in site index and MAI for dominant species; fire hazard; vegetational competition (type and severity); windthrow hazard; and snowshoe hare-damage hazard. Summary tables used in making interpretive evaluations are included in the following section.

## RESULTS AND DISCUSSION

### Ecosystem Classification

To date twenty-five ecosystem associations have been described for the west-central Alberta study area. The descriptions of these are the subject of another manuscript in preparation.

### Management Interpretations

Management interpretations were made of nineteen forest management concerns using the ecological classification and reconnaissance soil surveys for the study area (table 1). A discussion of these follows.

Timber Harvest.–

A. Season: The recommended season of harvest (table **2)** is designated as winter (W) when ground is frozen or summer *(S)* depending largely upon the wetness of the site and its ability to support heavy equipment without site degradation. Sites suitable for summer harvest are generally also suited for winter operations. All sites should be avoided during spring snow melt, when soil moisture is above field capacity.

B. Method: The harvest method includes both the method of falling the timber and the means of removing the fallen logs from where they were fallen.

Table 3--Logging method

| Method | Tree cover |
|---|---|
| Large clearcut | Lodgepole pine, mixed pine, and spruce |
| Patch or strip cut | Even-aged spruce |
| Selective cut | Uneven-aged spruce |

i. Logging Method (table 3) – Clearcutting (CC) generally proved to be a satisfactory method of harvest on a wide variety of forest sites in Alberta, particularly those cut for lodgepole pine pulpwood. Small (e.g. <20 ha) patch cuts (PC) are desirable in even-age spruce-dominated stands to facilitate spruce natural regeneration. In old growth and uneven aged spruce, selective cutting (SC) may be appropriate so that old trees are removed and younger trees are preserved and released as well as providing seed for natural regeneration. There are other methods and modifications available (e.g., seed tree, shelterwood) but these presently appear not well suited for most Alberta conditions, especially from an economic point of view.

ii. Log removal – The widely used rubber-tired skidders are satisfactory for most sites, although low ground-pressure track skidders (e.g., FMC) will minimize soil disturbance, compaction, and erosion on wet, fine-textured soils logged when the ground is not frozen. Heavy equipment such as feller-bunchers should be restricted to well drained, coarse-textured soils to minimize compaction or should be used during winter when soils are frozen.

Site-preparation intensity.--Site-preparation intensity recommendations (table 4) were made as low, medium, or high depending upon the environment (including soil properties), vegetation-competition hazard, and seed supply. Several options may be available to accomplish similar results. These are discussed below:

Low intensity: These sites are generally moderately well to rapidly drained, have shallow (>10 cm) soil organic layers, minimal plant-competition problems, and low to moderate slash abundance. Satisfactory lodgepole pine regeneration may be achieved on many sites with a good cone supply without site-preparation if the slash and cone are well distributed. Methods of low-intensity site preparation include the following:

a. Screefing (mattock, boot, spade). This may be appropriate when planting bare-root stock on topographically irregular sites, sites inaccessible to large machinery, sites where soil compaction may be a problem, and sites where plant competition, especially reedgrass (*Calamagrostis canadensis*), is well established and where more-severe site preparation may further stimulate competition.

b. Anchor-chain drags. This method gives satisfactory results on a wide variety of sites and scarification intensity and degree of coverage can be regulated by the number and length of the drags. Caution should be taken to minimize soil compaction on sites with fine soil texture or weak structure.

c. Toothed scarifier blade. The main concern should be to redistribute slash (cones) if necessary as the shallow organic layer should not pose a significant impediment to rooting seedlings. Soil compaction may be significant on fine-textured soils or on those with weak structure.

Moderate Intensity: These sites are moderately well to imperfectly drained, have moderately deep (10-15 cm) soil organic layers, moderate to high plant-competition ratings and low to moderate slash abundance. Methods of moderate-intensity site preparation include the following:

a. Shark-fin barrels. This equipment does a satisfactory job on level to gently sloping moist sites with moderate slash abundance and moderately deep organic layers. Degree of scarification can be regulated by the amount of fluid put in the drums as well as number and length of the attached anchor-chain drags.

b. Toothed scarifier blade. This equipment on a large tractor (e.g., Caterpillar D6 and larger) is capable of spreading large amounts of slash and penetrating deep organic layers.

c. Bracke scarifier. This machine can provide good results on wet sites or where plant competition is a problem and can provide planting sites with a wide range of moisture regimes.

High Intensity: These sites are poorly to imperfectly drained, with deep (15-30 cm) organic horizons, generally high plant-competition ratings and low to high slash abundance. Methods of severe-intensity site preparation include the following.

a. Martinni plow. This rear-mounted plow is capable of exposing mineral soil on wet sites with deep organic layers. Its relatively large size and weight make it more difficult to maneuver and increase the chances of getting stuck with resulting soil damage compared with alternative equipment. Chances of subsoil glazing and compaction are greater with the Martinni plow than with some other "severe" methods (e.g., the ripper plow). Flooding of the furrow is a problem on very wet sites. Furrows should run parallel to slope contours to minimize soil erosion particularly during spring runoff and on fine-textured till and lacustrine materials. On very gentle, short slopes on less erodible materials (e.g., some tills), downslope orientation of the furrows could provide some drainage, with minimal erosion.

b. Ripper plow (Craig - Simpson, C & S). This plow and adaptations of it have proved to be versatile machines for site preparation on wet sites, requiring less energy than the larger Martinni and creating less disturbance of the site. The ripper plow is often used in conjunction with a brush rake or toothed scarifier blade to move heavy slash, particularly the presently unutilized hardwoods, into windrows.

Table 4--Site-preparation intensity

| Intensity | Internal drainage | Vegetational competition | Slash abundance | Organic layer thickness | Soil map unit |
|---|---|---|---|---|---|
| | | | | (cm) | |
| Low | Rapid to moderately well | Low | Low to moderate | < 10 | COP1; SHP1,2; EDS1,2,3,4 |
| Moderate | Moderately well to imperfectly | Moderate to high | Low to moderate | 10-15 | COP3; DON1 JUY1,2 |
| High | Imperfectly to very poorly | High | Low to high | 15-30 | GUN1; KN2; SFP1,2 |

Table 5--Soil compaction hazard[1] (use chart from left to right)

| Texture | Coarse fragments | L + F thickness | Structure | Character of coarse fragments | Soil map unit | Rating |
|---|---|---|---|---|---|---|
| | (%) | (cm) | | | | |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | <35 | <5 | Strong | All | DON1; SIP1,2 | Moderate |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | <35 | <5 | Mod. & weak | All | EDS1; RBB7 | Severe |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | <35 | >5 | Mod. & weak | All | EDS1; RBB7 | Severe |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | <35 | >5 | Strong | All | RBB6; SHPl | Moderate |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | <5 | Mod. & weak | Rounded | RBB6; SHPl | Moderate |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | <5 | Mod. & weak | Angular | SMT1; MBN4 | Low |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | <5 | Strong | All | SMT1; MBN4 | Low |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | >5 | Mod. & weak | Angular | SMT1; MBN4 | Low |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | >5 | Mod. & weak | Rounded | ERR3; STT | Moderate |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | 35-60 | >5 | Strong | All | COP1; CAW | Low |
| L, SiL, SiCL, CL, Si, heavy SL, vfSL | >60 | any | All | All | COP1; CAW | Low |
| LS,S | any | any | All | All | COP1; CAW | Low |
| SiC, C, sc, SCL | >35 | any | All | All | COP1; CAW | Low |
| SiC, C, sc, SCL | <35 | <5 | Strong | All | COP1; CAW | Low |
| SiC, C, sc, SCL | <35 | <5 | Mod. & weak | All | COP3; BKM6 | Moderate |
| SiC, C, sc, SCL | <35 | >5 | Mod. & weak | All | COP3; BKM6 | Moderate |
| SiC, C, sc, SCL | <35 | >5 | Strong | All | ESH; LDMl | Low |

[1] In making a rating, consider the characteristics of the litter and upper 30 cm of mineral horizon(s). A wet or moist condition is assumed. The horizon which gives the poorest rating is used. Table adapted from Boyer (1979).

c. Brush rake. This multitoothed bulldozer blade can effectively increase the receptive area for regeneration by putting heavy slash and unutilized hardwoods into windrows and by removing excess organic matter from the soil surface. As with other treatments that involve use of heavy equipment, soil compaction is likely to result.

d. Cazes and Heppner plow (C & H). This wide, front-mounted V-blade can effectively remove virtually all vegetational competition (including well-established trees) plus soil-organic and surface-mineral horizons. The resulting denuded surface can be very susceptible to erosion on slopes, especially where soils are fine textured. Soil compaction and glazing of the subsoil could also be anticipated on fine-textured soils. The edges of the bladed strips are usually the best sites for planting. In these situations, organic matter and nutrients are likely to be more abundant, and susceptibility to drought and frost heave is likely to be less. It is believed that less-severe scarification methods are probably adequate as preparation for planting on most sites and that the C & H plow should be restricted to areas of stable soils where stand conversion (e.g., aspen to lodgepole pine) is being attempted.

Soil interpretations.– Soils interpretations for the various ecosystem associations are based upon the predominant soils found with each type. Reconnaissance soil surveys, completed over most of the study area, have rated soil-mapping units for a variety of relevant interpretations, including soil-erosion hazard, windthrow hazard, and transplant mortality. Work done by others (Boyer 1979, Townsend 1982) has enabled ratings for soil compaction and puddling to be made for the predominant soils of each ecosystem type.

It must be recognized by the users of this manual that the ratings are general and relative and that variation outside the ratings in table 1 can be expected as the soils occurring with a given soil subgroup or map unit will have a range of properties. It is thus important to evaluate sites individually where site-specific information is desired. The ratings given in table 1 can be approximated by the operational forester by using the information and criteria provided below. The background information used to make the ratings comes from detailed sample-plot data plus relevant soil-survey reports (Twardy and Corns 1980, Dumanski et al. 1972, Twardy and Lindsay 1971, and Knapik 1983). Only relative ratings can be provided as quantitative data are scarce.

A. Soil compaction

The degree of soil compaction is influencd by a number of soil physical properties including texture, per cent coarse fragments, per cent organic matter, organic-layer thickness, structure, and the type of coarse fragments. Table 5 is adapted from Boyer (1979). Compaction reduces porosity and rate of water infiltration as well as increasing physical impedence to growing roots. The horizon which gives the poorest rating in the upper 30 cm of mineral soil will determine the rating for the soil. Most of the soils of the study area, particularly those of the Lower Boreal and Aspen-White Spruce zones are susceptible to compaction, moreso than those in the foothills within the Upper Boreal zone due to predominantly finer textures and fewer coarse fragments in the predominantly continental tills in the east.

Increased soil compaction has been shown to reduce forest. productivity in many parts of the world. Quantitative data are not available for our area. Soil compaction can be minimized by keeping heavy machinery off the more susceptible soils when they are wet, by minimizing the area of logging roads or clearcuts, and by minimizing the number of passes over an area (Rothwell 1978). On susceptible soils, most compaction occurs during the first pass over the area by heavy equipment.

Table 6--Soil puddling hazard[1] (Use chart from left to right)

| Texture | Coarse fragments | L + F thickness | Structure | Soil map unit | Rating |
|---|---|---|---|---|---|
| C, SiC, Si SiL, SiCL, sc, CL, vfSL | <35 | ≤5 | Strong | DON1; SIP1,2 | Moderate |
| | | | Mod. & weak | EDS1; RBB7 | High |
| | | >5 | Mod. & weak | | |
| | | | Strong | RBB6; SHPl | Moderate |
| | 35-60 | ≤5 | Mod. & weak | | |
| | | | Strong | SMT1; MBN4 | Low |
| | | >5 | Strong | | |
| | | | Mod. & weak | ERR3; STT | Moderate |
| | >60 | any | All | COP1; CAW | Low |
| LS, S | any | any | All | | |
| L, SCL, SL | >35 | any | All | | |
| | <35 | ≤5 | Strong | | |
| | | | Mod. & weak | COP3; BKM6 | Moderate |
| | | >5 | Mod. & weak | | |
| | | | Strong | ESH; LDMl | Low |

[1] In making a rating, consider the characteristics of the litter, and upper 30cm of mineral horizon(s). A wet soil condition is assumed. The horizon which gives the poorest rating is used. Table adapted from Boyer (1979).

Table 7--Soil erosion hazard[1]

| Hazard | Parent material | Texture B horizon | Slope % | Soil map unit |
|---|---|---|---|---|
| Low | Till | Medium to coarse[2] | <10 | RBBl |
| | Colluvium, glaciofluval gravels, unconsolidated bedrock (sandstone, shale), organic | Variable | <5 | JUY1, 2;STT |
| Moderate | Till | Fine to moderately fine | <10 | EDS1,2,3 |
| | Till | Medium to coarse | 10-15 | LDG 1,2,4,5,6,8 |
| | Till | Very stony variable texture | 16-60 | MBN1,7 |
| | Colluvium | Variable | 5-30 | ERR3 |
| | Eolian | Coarse | 0+ | HRT1,3; HTN1 to 8 |
| | Unconsolidated bedrock | Variable | 5-9 | COP1 |
| | Organic | -- | 5-9 | KNZ |
| High | Glaciolacustrine | Fine | 0+ | DON1 |
| | Glaciofluvial | Medium to coarse | 0+, especially Gleysols | GUN1 |
| | Till | Fine to moderately fine | >10 | EDS4; MBN4 |
| | Till | Medium to coarse | >15 | SHP1,2 |
| | Colluvium | Variable | >30 | |
| | Unconsolidated bedrock | Variable | >10 | COP3 |
| | Organic | -- | >10 | KNZ |

[1] Ratings assume unvegetated surface. Dense vegetation cover will reduce hazard by at least one class.
[2] Textural groups are as follows: fine—sandy clay, silty clay, heavy clay; moderately fine—clay loam, sandy clay loam, silty clay loam; medium—very fine sandy loam, loam, silt loam, silt; moderately coarse—sandy loams; coarse—sands, loamy sand.

Compaction effects can be long lasting in the Pacific Northwest. Under some conditions, the surface few centimeters of compacted soil will recover within a few years to a few decades. The deeper soil compaction appears to require substantially more time, and the rate of this recovery is still largely unknown (Froelich 1982). Less is known of soil-compaction effects for the Canadian boreal forest, where repeated freeze-thaw cycles may be expected to help ameliorate compaction damage. Winter logging and site preparation minimizes compaction and the desirability of restricting summer operations to welldrained, coarse-textured soils is emphasized. Soil compaction effects are discussed further in reviews by Lull (1959) and Froelich (1973, 1982).

B. Soil Puddling

Puddling is the soil physical condition that results from the dispersal of soil particles causing destruction of the soil structure and the formation of a dense crust on the soil surface. This crust has the same effect as a thin compacted layer, and is most common on soil surfaces where litter has been removed by burning or by mechanical means. Reduced germination and increased mortality may be expected on soils compacted or puddled by logging equipment (Pritchett 1979). Wet, fine-textured soils with few coarse fragments, shallow organic layers, and weak structure are most susceptible to puddling, while soils of any texture with thicker organic layers, abundant coarse fragments, and strong structure are least susceptible (Boyer 1979, table 6). The ratings given in table 6 make the assumption that the organic layer is < 5 cm. If the organic layer is >5 cm, a rating one class less severe (e.g., from moderate to low) would be applied.

C. Soil-Erosion Hazard

Soil losses from forested areas are normally very small. Increase in erosion and stream turbidity are due mainly to road construction and other activities that expose large areas of mineral soil (Pritchett 1979). There are many factors which influence the erodibility of soil and parent materials: texture, type of structure, degree of carbonate cementing (parent materials), stone content, amount and type of vegetation cover, slope angle, length of slope, occurrence of recent fire, rainfall intensity and seasonal distribution, and rapidity of snow-melt. Only water erosion is considered here. Wind erosion is generally not a problem in the study area with the possibile exception of some local soils in the Athabasca Valley southwest of Hinton. Infiltration capacity and structural stability are regarded as most important in controlling water erosion (Buckman and Brady 1960). Soil-erosion hazard is the. expected rapidity and amount of soil loss due to wind and/or water that may be expected following removal of the protective vegetation cover in areas where the proper erosion-control measures are not implemented (Dumanski et al. 1972). Because of the many factors determining erodibility, generalized relative erodibility hazard ratings for soils under a plant association must be made assuming average rainfall intensity and rate of spring snowmelt using information published in reports by Dumanski et al. (1972), Twardy and Corns (1981), Knapik (1983) and Rutter (1968). Erosion will increase as slope steepens up to 80 per cent (40°); thereafter decreasing to zero as steepness approaches 200 per cent (90°) (Rutter 1968). Erosion will be greater on long slopes.

The relative erosion-hazard ratings described (table 7) are based primarily on soil texture, estimates of infiltration and permeability rates, soil structure, soil wetness, and slope angle, where surface organic layers have been removed.

a. Low – Parent materials (and soils developed on them) with a usually low erosion hazard include medium- to coarse-textured tills (slopes <10 per cent), colluvial materials (slopes <5 per cent), glaciofluvial gravels, unconsolidated bedrock (sandstones and shales; slopes <5 per cent), and organic soils (slope <5 per cent).
b. Moderate – Parent materials (and soils developed on them) with usually moderate erosion hazard include fine to moderately fine-textured tills (slopes <10 per cent), medium to coarse textured tills (slopes 10-15 per cent or up to 60 per cent if very stony), colluvial materials (slopes 5-30 per cent), aeolian deposits, unconsolidated bedrock (sandstones and shales; slopes 5-9 per cent), and organic materials (slopes 5-9 per cent).
c. High – Parent materials (and soils developed on them) with a usually high erosion hazard include glaciolacustrine deposits (any slope), glaciofluvial sands and silts (any slope – especially Gleysolic soils), fine- to moderately fine-textured tills (slopes >10 per cent), medium- to coarse-textured tills (slopes <15 per cent or steeper depending on stoniness), colluvial materials (slopes >30 per cent), unconsolidated bedrock (slopes >9 per cent), and organic materials (slopes >9 per cent).

Ratings of individual soil units mapped in the study area are available in reconnaissance soil surveys by Dumanski et al. (1972), Twardy and Corns (1980), and Knapik (1983).

Methods for minimizing erosion as a result of logging and road construction in Alberta are discussed by Rothwell (1978) and Lengellé (1976). **A** variety of practical "bioengineering" methods using vegetation as a means of stabilizing slopes and reducing erosion is discussed by Schiechtl (1980).

Reforestation Interpretations.--

A. Species selection

The species selected to reforest a site will depend upon both its biological and economic suitability. The latter is more difficult to judge since it is virtually impossible to know what forest products will be available to and desired by the consumer at the end of the rotation.

Clues to tree species biologically well adapted to a site can be determined from soil physical and chemical properties and the species (tree and understory) that occupy the site. Climate, soil-moisture regime, and to some extent nutrient regime can be inferred from the composition of the vegetation. Soil properties, particularly drainage and pH, will have a strong bearing upon the species selected for planting a site.

The current Alberta Forest Service Planning and Harvesting Ground Rules for Forest Management Area holders specify that tree regeneration on cut-over areas must average 1.8 to 2.5 m in height before adjacent trees can be removed in the second cut. This guideline appears to encourage reforestation using initially faster growing pine on sites that might be better suited to spruce production when the whole rotation period is considered. The rapid initial growth advantages of establishing pine rather than spruce may not result in the best economic yield or wildlife habitat in the long term.

The interpretations made for tree-species suitability consider only those species native to the study area and are based primarily upon the inferred ecological suitability of the site. Current markets for particular forest products have no bearing upon the interpretations The principal factors considered are climate, soil drainage, soil reaction (pH), organic-layer pro-

Table 8--Species selection for reforestation

| Species | Elevation | Drainage | pH | Organic thickness | Texture | Soil map unit |
|---|---|---|---|---|---|---|
| | (m) | | | (cm) | | |
| Aspen | <1100 | Well to moderately well | 5-7 | <10 | Heavy clay-loam | DON1; EDS1, 3 |
| White spruce | 600-1300 | Well to imperfectly | 4.5-7.5 | <20 | Heavy clay-loam | SIP1,2; ESH1; LDMl |
| Black spruce | 600-1650 | Well to poorly | 3-6.5 | 10-30 | Organic, heavy clay-sandy loam | KNZ; DVS1,2 |
| Engelmann spruce | 1300-1650 | Well to imperfectly | 4.5-7.5 | <20 | Clay loam-sandy loam | BKM3; ERR3 ;MSK4 |
| Lodgepole pine | 600-1650 | Rapid to imperfectly | 3-6 | <10 | Clay-loamy sand | EDS3; ERR1; HRT1,2,3,4 |
| Balsam fir | 600-1300 | Well to imperfectly | 4.5-6.5 | 10-20 | Heavy clay-sandy loam | BKM6; DON2; SIP1 |
| Subalpine fir | 1300-1650 | Well to imperfectly | 4.5-6.5 | 10-20 | Heavy clay-sandy loam | BKM3; ERR3; MSK4,5 |

Table 9--Reforestation method on cutblocks'

| Site conditions | Seed availability* | Species/reforestation options: Lodgepole pine | White spruce | Black spruce | Aspen | Soil map unit |
|---|---|---|---|---|---|---|
| Soil moderately well to rapidly drained, organic layer generally <10 cm, vegetation competition not usually a problem | Abundant | Natural | Natural | Natural | Natural root suckers | COP1,3 EDS1,2,3,4 |
| | Sparse | Container, aerial seed[3] | Container, aerial seed | Container, aerial seed | Natural root suckers | |
| Soil imperfectly or more poorly drained, organic layer generally >10 cm, vegetation competition often a problem | Abundant | Container, bare root, natural | Container, bare root, natural | Container, natural | N/A | SIP1,2 ETH1,2,3 |
| | Sparse | Bare root, container | Bare root, container | Container | N/A | |

[1] This table should be used in conjunction with Table 8.
[2] Seed abundance is a function of slash and cone abundance plus proximity to adjacent seed-producing trees (especially important for spruce).
[3] Aerial seeding will have best results when 40-60% mineral soil is exposed and soil moisture is near field capacity.

perties (principally thickness), soil texture, and knowledge of tree growth on various sites. Table 8 presents the basis for species selection. Most of the soil information can be determined for the area in question from the reconnaissance soil survey reports and accompanying maps (Twardy and Corns 1980, Dumanski et al. 1972, and Knapik 1983). All factors should be considered together when rating a site in order to select the best-suited species. On sites that are environmentally suitable for more than one species, anticipated future markets may determine the selection.

B. Reforestation Method

Reforestation method here refers to the means by which satisfactory tree stocking is achieved on logged areas. The alternatives are natural seeding from slash or adjacent trees, root suckers (aspen), manual or aerial seeding, containerized planting stock, and bare root planting stock (table 9). The situations applicable to the various options are discussed below:

Natural: a. Pine – Sites with good cone crops, soils that are moderately well or better drained, and organic layers less than 10 cm thick can generally be adequately restocked without additional planting. A light scarification might be necessary to distribute cones more evenly.
b. Spruce – Satisfactory natural spruce stocking is likely to be attained only on sites with a continuing seed source such as on small patch or strip cuts or where seed trees are left. Spruce stocking on such sites will be favored where mineral soil is exposed and moisture is neither limited nor in excess.
c. Aspen – Satisfactory natural aspen stocking is usually achieved by root suckering from cut trees without additional silvicultural input.
d. Balsam and subalpine fir – These species generally acheive satisfactory natural regeneration only under the canopy of other trees.

Direct Seeding: Satisfactory stocking results from direct seeding can be expected only where there is a large amount of exposed mineral soils (40-60 per cent), minimal vegetational competition, and enough moisture to ensure germination and seedling establishment. Timing of the seeding operation is crucial.

Table 10—Frost heave hazard

| Hazard | Internal drainage | Mineral soil exposure | Texture B horizon | Slope position | Soil map unit |
|---|---|---|---|---|---|
| | | (%) | | | |
| Low | Rapidly to well | 0-25 | s-SL | Upper, crest | HRT1,2,3; BKM 1,4,6 |
| Moderate | Moderately well | 26-50 | SCL-L | Mid | MBN1,4; RBB1 |
| High | Imperfectly to poorly | >50 | Si-Sic CL-HC | Lower, toe | DON1,2,3; SIP1,2 |

Table 11—Seedling transplant mortality[1]

| Hazard | Soil reaction (pH) | Water-holding capacity | Organic-layer thickness | Moisture regime | Soil map unit |
|---|---|---|---|---|---|
| | | | (cm) | | |
| Low | 4.0-6.5 | High | <10 | mesic to permesic | DON1; EOS1,2,3,4 |
| Moderate | 6.6-7.0 | Medium | 11-15 | subhygric | COP1,3; LDG1,2,3,4 |
| High | >7.0 | Low | >15 | hygric to hydric subxeric to xeric | HRT1,2,3,4; HTN 1 to 8 |

[1]See Dumanski et al. 1972. This table should be used with Table 10.

Planting Containerized Stock: In general, seedling survival and early growth is proportional to the volume available for root growth and development. Consequently, a seedling grown in a unit such as a Spencer-Lemaire 55-cc container will generally outperform those in the standard 40-cc container, particularly on sites with potential vegetation competition or snowshoe hare-damage problems.

Bare-Root Stock: Bare-root planting stock can generally gain an advantage over containerized stock. This is especially so on sites with abundant vegetational competition because of the greater size and age of the bare-root stock. This is more true with white spruce than with pine, due to the slow initial growth of the spruce.

C. Limitations to Reforestation Success

The limitations discussed here are those of the site and do not include management considerations such as planting errors which can be just as significant as site limitations (Froning 1972). The limitations are self-explanatory and mainly include considerations such as excess moisture, drought, steep slopes, and vegetational competition. High soil reaction (pH) is a problem on some soils of ecosystem associations in the Athabasca Valley near Hinton. These are not described in this report.

D. Frost-Heave Hazard

Frost-heave hazard is rated for the predominant soils of the ecosystem associations described on the basis of their likelihood of heaving tree seedlings upon freezing (table 10). This rating is based primarily upon the texture of the surface soil horizons and upon the moisture content of the soil, reflected by its drainage class. The most susceptible soils are those with fine-textured surface horizons with high silt content and imperfect drainage and where surface organic layers have been removed. Topographic situation can be an important determinant of frost-heave susceptibility with depressional situations being most susceptible.

Table 12--Factors affecting fire-hazard rating

| Environmental factors | Forest stand and vegetation factors |
|---|---|
| moisture regime | tree species present |
| soil drainage | crown diameter and depth |
| topography | flammability of understory species |
| prevailing wind direction | size distribution of fuels |
| climate | abundance of fuels, bark thickness, rooting depth, organic-layer thickness, stand density, abundance of lichen growth |

E. Seedling-Transplant Mortality

Potential mortality of planted seedlings has been rated on the basis of the most prevalent soil types occurring with each ecosystem association (table 11). The ratings were based largely upon early survival of very young transplants in unprepared, natural soils in the Hinton-Edson area (Dumanski et al. 1972). Ecosystem associations' soils are rated as high in terms of seedling mortality if they exhibit abnormally high soil reaction (pH), if they have low water-holding capacities, or if they have thick organic-surface horizons and are excessively wet during the growing season (Dumanski et al. 1972).

Productivity of the ecosystem associations.--Average values of ***gross,*** mean, annual, total volume increment (MAI), and site index (70 yr) are given for the dominant species of each ecosystem association. The values are from sample plots in natural, unmanaged stands. Site index is primarily estimated using the curves by MacLeod and Blyth (1955), although data for 137 plots in the Wapiti map area are from stem analysis (Corns 1978).

Fire hazard.--Fire hazard is inferred from knowledge of the flammability of the component species of the ecosystem types and from observed fire behavior in various forest types. These ratings were assigned for "cured dormant state" (early spring and late fall) and "active growth state" (late spring to early fall) for both "crownfires" and "surface fires" with the help of the fire-research unit of the Northern Forest Research Centre, Edmonton. The subjective ratings (table 12) will be greatly influenced by weather, topography, and by local fuel loading.

Table 13--Vegetational competition hazard

| Hazard | Internal drainage | Texture B hor. | Elevation | Soil map unit |
|---|---|---|---|---|
| | | | (m) | |
| Low | Well to rapidly | s-SL | >1200 | HRT1,2,3; BKM 1,4,6 |
| Moderate | Moderately well | L-SCL | 1000-1200 | COP1,2,3; MLB4,6 |
| High | Imperfectly to very poorly | CL-HC; Si-Sic | <1000 | LDM1,2; SIP1,2,3 |

Table 14--Windthrow hazard

| Hazard | Internal drainage | Organic layer thickness | Exposure to strong wind | Soil map unit |
|---|---|---|---|---|
| | | (cm) | | |
| Low | Rapid to well | <10 | Slight | BKM1,4,6; COP1,3 |
| Moderate | Moderately well to imperfect | 11-20 | Moderate | DON1; MBM3; NMP1 |
| High | Poorly to very poorly | 21-30 | Severe | SIT: SIP1,2,3; SKY1,2 |

Table 15--Hare and rodent damage hazard on regenerating cutblocks

| Hazard | Abundance of, low dense woody vegetation | Slash abundance | Elevation | Soil map unit |
|---|---|---|---|---|
| | (%) | | (m) | |
| Low | 0-20 | Low | >1200 | |
| Moderate | 21-40 | Moderate | 1100-1200 | |
| High | >40 | High | <1100 | |

Vegetational competition.--Vegetational competition is rated according to type (predominant species or species groups) and severity, with respect to its influence upon young tree seedlings (table 13). Competition occurs for light, nutrients, water, and space.

Types of vegetational competition include that by reedgrass (primarily *Calamagrostis canadensis),* sedge *(Carex* spp.), ryegrass (*Elymus innovatus),*green alder *(Alnus crispa),*willow *(Salix* spp.), bracted honeysuckle (*Lonicera involucrata*), and forbs (especially those with large amounts of biomass and dense roots/rhizomes including *Mertensia paniculata, Aralia nudicaulis, Aster conspicuus,* and *Epilobium angustifolium).* Within the study area, *Calamagrostis canadensis* is the most serious competitor with conifer seedlings. It can form a dense sod that can influence soil-moisture and nutrient regimes and rooting abilities of tree seedlings. Seedlings can also be greatly shaded by the dense grass cover and they can be pushed down by the grass when it is laid down by heavy snow, wind, or rain. *Calamagrostis* is most abundant on moist, fine-textured soils over a wide elevational range and appears to be most prevalent in the eastern portions of the study area. The other species mentioned also seem to be most competitive on moist, fine-textured soils at lower elevations. Thus the occurrence of a particular ecosystem association on such soils would result in a high rating for vegetation competition.

Windthrow hazard.--Windthrow-hazard ratings reflect characteristics of the predominant soils occurring as part of the ecosystem associations described (table 14). These characteristics affect the development of tree roots and, therefore, the risk of trees being blown over by normal winds. These ratings, termed low, moderate, and high, are estimated from knowledge of root development under varying soil conditions and from field observations (Twardy and Corns 1980). It appears that trees are most subject to windthrow on soils having thick organic-surface horizons that are affected by high water tables, or on lithic soils having thin soil over consolidated bedrock. Windthrow is most often a problem on Organic and Gleysolic soils. When rating specific sites, however, exposure and occurrence of winds of high velocity should be considered as additional factors. It was not possible to consider these latter factors in the present general rating.

Rodent-damage hazard.--The potential for seedling browsing by snowshoe hares and rodents (table 15) is dependent upon the presence of suitable habitat. Preferred habitat for snowshoe hares, the species causing most damage, is low, dense, woody vegetation (Buehler and Keith 1982, Keith 1966) and heavy slash that provides cover from predators as well as food. In the study area, such habitat is most plentiful in the Aspen-White Spruce zone and Lower Boreal subzone at elevations below 1100 m, particularly on moist sites. The hare and rodent damage hazard is based upon the presence of dense, shrubby understories in the ecosystem associations described. The ratings are relative and are given for near peaks in the population cycle in years of very high hare abundance. Other species groups responsible for girdling damage to young conifers include squirrel, mouse, vole, and porcupine.

## CONCLUSIONS

A forest-ecosystem classification framework, used in conjunction with reconnaissance soil-survey information, appears to provide complementary bases for making forest-management interpretations. The classification framework has the potential for providing a basis for additional interpretations related to forest management, hydrology, wildlife management, recreation, etc. as well as for research.

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# HOW TO CHOOSE SITE PREPARATION METHODS BASED ON SITE CLASSIFICATION

Per H. Stahl

Stand description or classification data can be most helpful in selecting suitable silvicultural treatments. This paper attempts to examine how they are used for selecting site preparation methods in Sweden.

Site preparation is necessary for good reforestation, except on the very most easily regenerated sites. It should provide the best possible environment for young plants to get established in. What characterizes this good environment varies from site to site and depends on soil characteristics, climate, etc. When specifying what is a good site preparation method this must therefore be qualified to a certain environment.

A good situation for plants to get established in is not necessarily the best for growing a maturing stand, so when choosing a site-preparation method, we must also consider its long-term effects on stand productivity. Site preparation must be site adapted.

I hope to be able to briefly describe a theoretic model, developed to help us select and develop site-preparation principles which combine the biological requirements for a good establishment with what is good for high sustained yield. After that I will describe a system which the Forest Service uses for choosing a site-preparation method. This system also considers some of the technical, environmental, and economic aspects of the choice.

The biological model has been developed by the Royal College of Forestry and the Logging Research Foundation. The purpose of the job was

- to judge, from a biological point of view, how suitable a number of different site-preparation principles are on different sites, and
- to determine how much of the forests, on mineral soils, should be site prepared according to the various principles.

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The philosophy of the work, a joint evaluation of short- and long-term biological considerations, should be applicable on many occasions.

The basis for the analysis is a sitedescription system. In this, Sweden was divided into nine climatic zones, using regions (north or south of the “limes norrlandicus”), temperature sums, and the risk for early summer drought (fig. 1).

Within each of the nine zones, a number of different site types were defined using all possible combinations of
- soil-moisture class (dry, fresh, moist, wet)
- site-vegetation class (e.g. lichen, dwarf shrub, herb)
- humus-layer thickness
- soil texture.

All these data are available in our National Forestry Survey, and we can therefore determine how much land there is of the different types.

A number of different site-preparation principles are evaluated in the model, e.g. mineral-soil patch, mineral-soil strip, mineral-soil mound on humus, substantial ridge of mineral soil on a double layer of humus. These principles are more or less similar to what we can produce with today’s methods. To widen the analysis, a number of other principles, for which we still have no technical solution, were defined, e.g. loosened up mineral soil or mixed humus and mineral soil.

The biological suitability of a certain site-preparation principle obviously depends on a number of factors, but the analysis only considers a few of the key factors. For the establishment, the two most critical factors seem to be the soil temperature and the water/oxygen relationship in the soil (i.e. the local drainage). The two critical factors for long-term productivity are nutrient release and the effect on the site’s water balance (hydrology).

The method of analysis is summarized in figure 2.

1. Start the analysis by defining, for each site type, how the key factors should be influenced to make the site most suitable for establishing a new stand and as productive as possible.

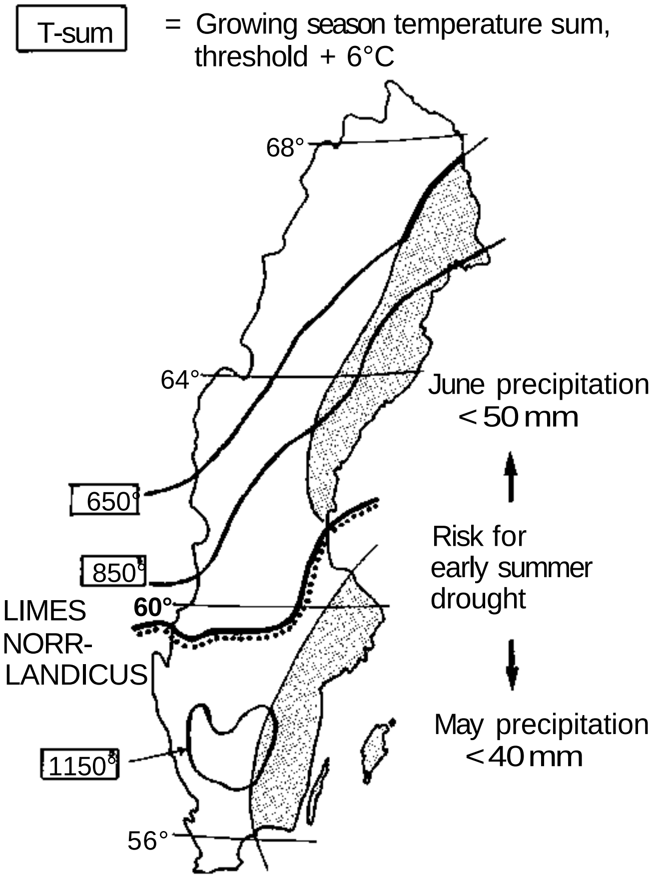


Figure 1.-Definitions for regions used in the model.

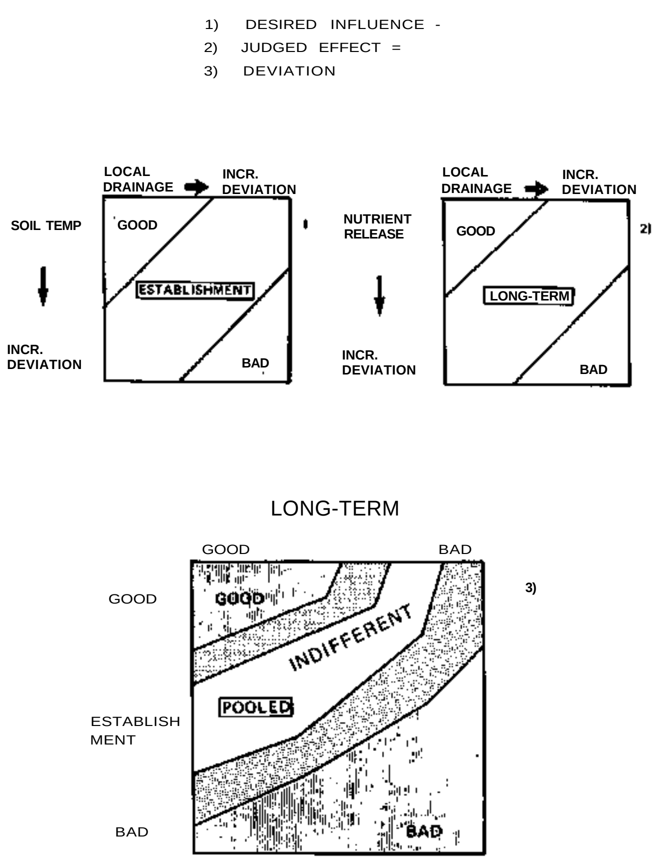


Figure 2.-Method of evaluation of site-preparation principles.

For example, on a cold and wet northern site with silty soils, one would certainly want to increase the soil temperature a lot and also get the planting spot well drained. The site may also need a strong cultivation, both to improve the water balance and to speed up the breakdown of the organic matter, i.e. to provide the stand with more available nutrients over a long period. On a dry southern site, with sandy soil, it would not be as important to increase the soil temperature, but it would be essential not to cause any loss of water. There is probably only a thin layer of humus on a site such as this, which should not be disturbed too much.

2. Then determine how each of the site-preparation principles will affect the four key factors on each site type.

A mineral-soil mound on a single or double layer of humus will, for instance, provide a warmer and better drained planting spot than a mineral-soil patch. In the long run this site-preparation principle should cause an insignificant change in the site's water balance and only a slight increase of the speed of organic material break down.

3. The third step in the analysis is to compare the desired change (1) with the effect of the different site-preparation principles (2). The comparison is made for all site types, and the result will be a list of larger or smaller deviations from the desired results.

The deviations for the factors soil temperature and drainage are combined to express the site-preparation principles' suitability from the point of establishment. In the same way the deviations for nutrient release and hydrology are combined to express the principles' value for long-term productivity.

4. The result of steps 1-3 are then separate gradations of the suitability of the site-preparation principles from the points of establishment and long-term productivity. These gradations are finally pooled for a total evaluation of the different site-preparation principles. In this operation the importance of a good establishment environment is given a slightly higher weight than the long-term productivity.

One result of the analysis is a regional list of the areas in which a certain site-preparation principle is good or bad. Several principles can have the same total value on a given site type. A second result is a list of the areas and site types for which we still do not have suitable site-preparation methods.

The model has a number of limitations. The risk for frost heaving, insect damage, frost damage, or competition from weeds are examples of biological considerations not included in the model. They must also be considered before a certain site-preparation principle's total biological value can be determined.

The method and the results of the analysis will be presented in publications from the Logging Research Foundation. My presentation has followed a brief description of the method published in a Swedish forestry magazine (Lundmark et al. 1983).

Regrettably, even when all the biological factors have been considered, that is not enough. We do not, as mentioned before, have the techniques necessary to bring about all the site preparations from the theoretical examples on all sites and then there are, of course, a number of nonbiological restrictions to consider. This has made it necessary for the Forest Service to develop our own recommendations, where also, for example, some technical, economical, and environmental restrictions are included. The full recommendations can be found in the Swedish Forest Service's Silvicultural Manual (Domanverket 1982).

An absolute demand with us is, that where there is a need for scarification, the result of the site preparation must be at least the same number of well-distributed planting spots in exposed mineral soil as we need to put out plants. This is usually no problem with the continuously working disk harrows, our most common type of scarifier, but it definitely limits the number of sites on which plows and mound makers can be used.

Not all of our scarification methods, for environmental reasons or because of competing forms of land use, can be applied everywhere. For example, in southern Sweden, where the population pressure on the land for recreational use is heavy, the plow cannot be used. The criticism we would get would not be compensated for by the marginal superiority of plowing over alternative methods on these southern sites. Neither can the method be used on all the suitable areas in the north because of such activities as reindeer husbandry. Access to land areas required by the Lapps and their reindeer would become severely limited, and certain ranges rich in lichens would be ruined.

I regret that I must now introduce two more classifications that we use in our stand description data, for slope and ground roughness.

Slope is self explanatory, I hope:

| Slope class | Gradient |
|---|---|
| 1 | 0-10 % |
| 2 | 10-20 % |
| 3 | 20-33 % |
| 4 | 33-50 % |
| 5 | 50 + % |

Ground roughness is determined by the incidence and size of obstacles on the site. Obstacles refer to:

- depressions that have hard edges and are well defined
- stones, boulders and ground obstructions at least 0,1 m high. N.B. stumps are not counted as obstructions.

Without getting into detail here on the frequencies of different obstruction sizes in the five classes, we then get to a five-grade classification as follows:

| Ground roughness: class | |
|---|---|
| 1 | Very even |
| 2 | Slightly uneven |
| 3 | Uneven |
| 4 | Rough |
| 5 | Very rough |

Sites with class 5 slopes and/or ground roughness, and those with both slope and ground roughness 4 cannot be treated with mechanized mthods. The only possible method on these areas is burning, if the method is acceptable by other criteria.

Where slope or ground roughness is 4, and on the more difficult part of the areas with both roughness and slope 3, excavators provide the only possibility for mechanized scarifications. The method is quite expensive and only used on such areas where reforestation would otherwise be impossible or where the total reforestation cost can be lowered by putting in a very expensive but good site-preparation method.

Sites with hardpan are plowed whenever it is technically possible.

For the remaining sites, and they make up a large majority of our land, we have then developed recommendations for the choice of site-preparation method. These sites, which are accessible with regulator-mechanized scarification methods, we divide into two groups: those with easy terrain, i.e. ground roughness class 1 and the better half of 2, and difficult ones.

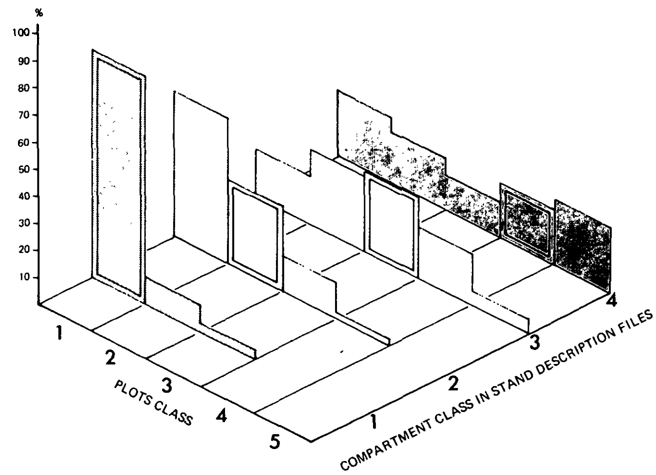


Figure 3.--Variation in ground roughness within the compartment. Average figures from Forest Service files of stand descriptions.

I must here mention two major problems. The data in our stand-description files primarily have reference to logging condition's and are also averages for a very variable reality. To get some information about the variability of our sites, the Forest Service carried out an examination on 65 randomly selected clearcuts, average size 14 ha. On these compartments, we then systematically put out a number of plots, 41 per clearcut in average, on which were measured a number of site factors, e.g. slope, ground roughness, soil-texture class. As expected, there was a tremendous variation around the compartment mean value. See figure 3 for an example.

Because of the two problems mentioned above, it is necessary to make an inspection of the site before applying the recommendations.

In the recommendations the soils have been grouped together, based on their texture and permeability, into three groups:

Soil texture class:

| | |
|---|---|
| Coarse texture | Gravel and coarse sands |
| Medium texture | Sand and sandy loams |
| Fine texture | All finer textures |

The part of the recommendation shown in table 1 is for fresh blueberry sites, the most common type in northern Sweden. There are separate recommendations for the northern and southern parts of the country.

Where more than one method is suggested for a site type, the one numbered 1 is the best alternative, then number 2 etc.

The recommendations, which are based on strict forestry considerations, must, of course, only be seen as a help in choosing the site-preparation method and are not imperative in any way. Not everywhere can one find, for instance, all kinds of scarifiers, and there are normally aspects other than forestry to be considered. We do, however, warn against using methods which are not listed, as they tend to be inadequate or too strong.

Try to be flexible when selecting a site-preparation method. In our recommendations the harrows are, for example, a possible alternative on most reforestation sites. This should not be used as a motive for using only harrows indiscriminately. Other methods may be much better on certain site types.

| Vegetation class | Soil texture class | Humus layer thickness | Terrain class | No soil scarification | Mound making | Patch scarification | Harrowing | Plowing | Burning | Excavating |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Fresh Vaccinium uliginosum | Coarse | < 6 cm | Easy | | 1 | 3 | 2 | | | |
| | | | Difficult | | | 2 | 1 | | | |
| | | > 6 cm | Easy | | 1 | | 2 | 1 | 3 | |
| | | | Difficult | | | | 1 | | 2 | |
| | Medium | <6cm | Easy | | 1 | | 2 | | | |
| | | | Difficult | | | | 1 | | | |
| | | >6cm | Easy | | 1 | | 2 | 1 | 3 | |
| | | | Difficult | | | | 1 | | 2 | |
| | Fine | < 6 cm | Easy | | 1 | | 3 | 1 | 2 | |
| | | | Difficult | | | | 2 | | 1 | |
| | | >6cm | Easy | | 1 | | 3 | 1 | 2 | |
| | | | Difficult | | | | 2 | | 1 | |

Table 1. Hard climate zones in interior northern Sweden.

The recommendations are intentionally complete and may seem complicated. On the average site, however, the choice of site-preparation method is not a difficult one, and the recommendations may therefore be reserved for the occasions when one is faced with an unusual combination of site factors.

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Murray, Mayo, ed. Forest classification at high latitudes as an aid to regeneration. Proceedings of the fifth international workshop: **1983** August **15-17;** Fairbanks, AK Gen. Tech. Rep. **PNW-177.** Portland, OR: **U.S.** Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 56 p.

The proceedings contains seven papers presented at a workshop on regeneration at high latitudes. Reflecting the international nature of the workshops, papers on work in forests of Scandinavia, Canada, and the northern United States were presented.

Keywords: Classification (site), boreal forests, latitude **(-site,** regeneration (stand) **.**

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