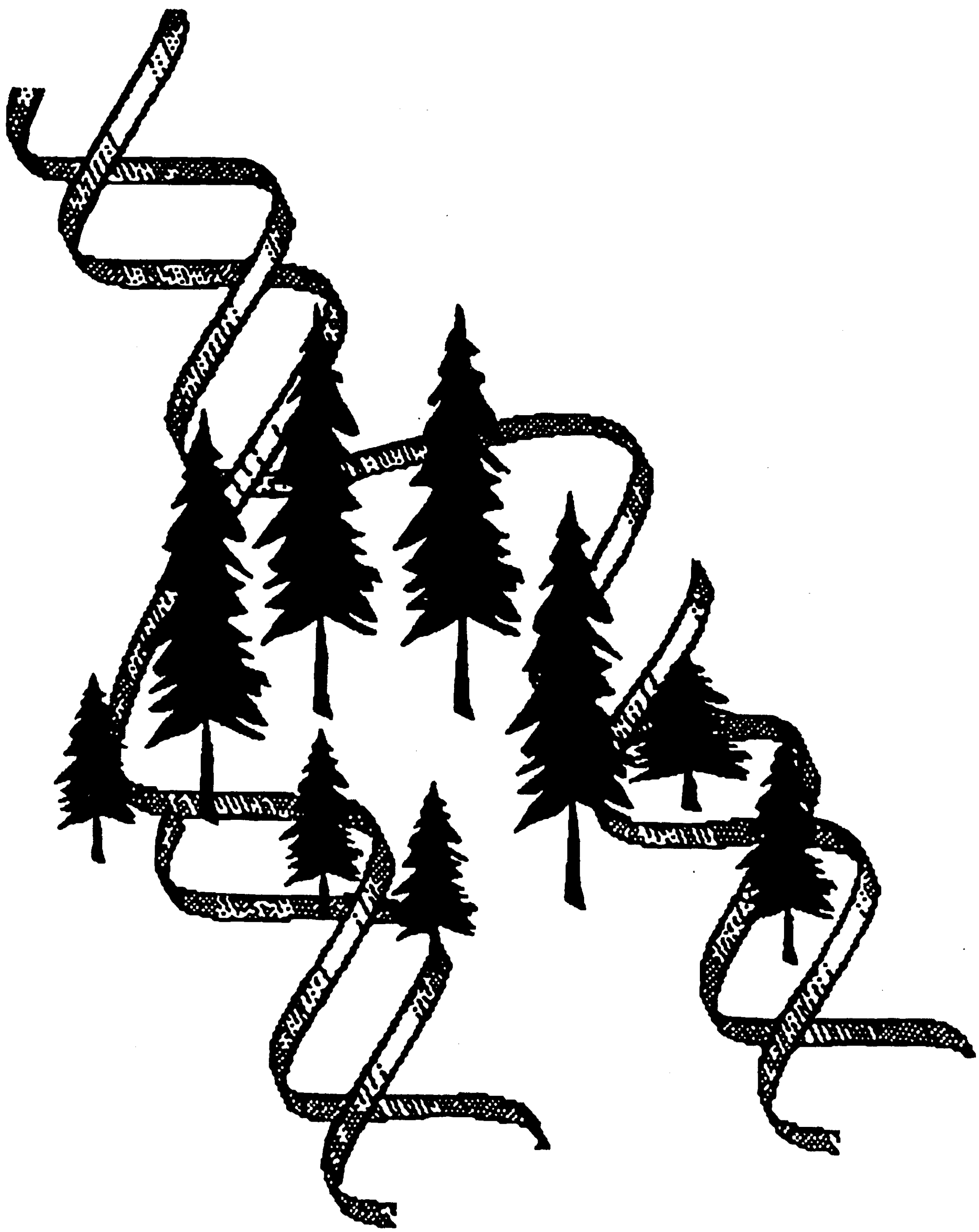
United States
Department of
Agriculture

Forest Service

Genetics/Silviculture Workshop Proceedings

August 27-31, 1990
Wenatchee, Washington



FORWARD

Over the last few years the debate on forest management practices and issues has intensified. The issues are extremely complex—from commodity production (wood, wildlife, mushrooms) to preservation. The biology of the forest ecosystem has not been fully considered in the majority of these debates, yielding to personal feelings, wants, desires and biases. It is now time to objectively determine how the forest ecosystem should be managed to meet the commodity and other needs of our society and to ensure that the land remains capable of meeting all needs for future generations.

The primary objective of the 1990 Genetics/Silviculture Workshop was to review and discuss the virtues, concerns, and opportunities for applying the five regeneration harvest methods and their variations in forest management. The first two papers discuss population dynamics and the importance of understanding genetic variation. These are followed by the moderator's opening remarks, and papers by the silviculturists, geneticists, and research silviculturists for each of the five regeneration methods.

Two silvicultural systems are acknowledged—the uneven-aged system and the even-aged system. Five regeneration harvest methods are recognized under the two systems—single tree selection and group selection under the uneven-aged system, and clearcutting, shelterwood, and seed tree under the even-aged system.

Five panels, each consisting of a moderator, silviculturist, geneticist, and research silviculturist were formed to discuss the regeneration methods. The moderators presented brief opening statements, including definitions, and introduced the other panel members. The silviculturists described the specific harvesting method and appropriate variations including possible effects on soil, water, wildlife, forest health, timber supply, biology of selected species, species and structural diversity, impact on the environment, costs to implement, and labor and technical expertise requirements from sale layout through successful regeneration of the new forest ecosystem. The geneticists discussed the genetic implications of the specific harvesting method including the effects on genetic diversity and adaptability of the regenerated stand over the short and long term. Both natural and artificial regeneration methods were considered. The research silviculturists described specific long term studies that demonstrated success/failure of the particular method, suggested why the studies were successes or failures, and what steps should be taken to ensure success in the future.

We hope that these papers will provide a better understanding of the pros and cons among the regeneration methods and that this information will lead to biologically sound decisions that will create and maintain healthy forest ecosystems capable of meeting our needs for generations to come.

Richard G. Miller, Geneticist
Dennis D. Murphy, Silviculturist
Silviculture Group, Timber Management Staff
USDA Forest Service, Washington, DC
March 1991

ACKNOWLEDGMENTS

The Genetics/Silviculture Workshop was hosted by Region 6, USDA Forest Service, August 27-31, 1990, in Wenatchee, Washington. We want to acknowledge the Wenatchee National Forest staff for their hard work in making the local arrangements, assembling the handouts, coordinating the field trip, and organizing the banquet. Our special thanks go to Gary Man, Geneticist, and Monte Bickford, Silviculturist, for their dedicated service and help in coordinating the workshop activities. Finally, we appreciate and hereby recognize the speakers for their outstanding contributions to this workshop and timely submission of their papers for this proceedings.

Dick Miller
Dennis Murphy

TABLE OF CONTENTS

EVEN-AGED MANAGEMENT SYSTEM

Clearcutting Regeneration Method

Seed-Tree Regeneration Method

Shelterwood Regeneration Method

SUMMARY

POPULATION DYNAMICS WITH SPECIFIC REFERENCE TO CONIFEROUS FORESTS AND WASHINGTON STATE

Sheila R. Martinson
Pacific Northwest Region
Portland, OR

INTRODUCTION

As we view the forest landscape with all its diverse geologic and vegetative components we may wonder about the forces which shaped what we see today. The patterns evident in the forest landscape are the result of the interaction of the genetic component of each species with its environment over a very long time. This is called an evolutionary history.

Environmental changes can occur gradually over a very long period of time, such as mountain uplifting, or environmental change can be sudden, even explosive, such as volcanic eruption. Other examples of environmental change include changes in climate, shifting of continents, filling-in of lakes to become meadows, waterways cutting deep channels, erosion, sedimentation, and forest succession. The environments on earth are continually changing. The environmental changes which have occurred over time are preserved for us to observe in the paleoecological record as fossils. Fossil plants are the "thermometers of the past" because of the evidence they present as to former climates. I will come back to this topic later in this paper with a presentation of the paleoecology of Washington State.

How plants and animals respond to environmental change is based on the genetic "pre-programming" of each individual organism. Does the individual have a sufficiently variable genetic make-up to adapt to the environmental change through successive generations? Or does this organism have just a set genetic program that cannot tolerate the environmental change such that the organism dies?

THE BASICS OF POPULATION GENETICS

The units of genetic change can be the gene, the individual, or the population. The *gene* is the unit of inheritance which remains the same from generation to generation. Each gene constitutes a sequence of DNA that carries the information representing a particular protein (Figure 1). Each gene lies on a specific chromosome. The genes contain coded information that determines the nature and proportions of substances in cells, as well as the ultimate form and structure of an entire organism. An *individual* (also called a genotype) is a unique combination of genes. An individual passes his or her genes onto the next generation which are then recombined into the next generation of unique individuals or genotypes. Individuals tend to aggregate into sub-species groupings called *populations*. A population is a group of interbreeding individuals that exist together in time and space.

Genetic change comes about through four forces: 1) mutation, 2) genetic drift, 3) gene migration, and 4) selection.

Mutation is the source of original genetic variation. A mutation is a change in the DNA's sequence of nucleotides. How this occurs is that there is a change from the parental DNA during DNA replication (Figure 2). This happens when one base is substituted for another, e. g., Thymine is substituted for Adenine in the DNA. This changed strand of DNA is transcripted into a mutant strand of RNA which is then translated into a different amino acid than the original DNA code. This results in a mutant protein. (A protein is a chain of amino acids.) An example of a mutant protein is that of sickle cell anemia in humans where Adenine in the parental DNA sequence is substituted by Thymine. This base point substitution causes the amino acid Valine to be produced instead of Glutamic Acid in the protein chain. People with the mutant protein develop sickle cell anemia disease.

The relative amount of mutation that occurs in nature is very small. Mutation rates occur in the range of 10^{-5} to 10^{-6}. Point mutations for conifers of the family *Pinaceae* fall in this range. However, rates of chromosomal rearrangements at the organismal level in forest trees is extremely small. For instance, Prager et al. (1976) reports for *Pinaceae* a 0.04 change in chromosome number per lineage per 10^{-8} years. This karyotypic evolution rate in *Pinaceae* is 100 times lower than in mammals and 10 times lower than other vertebrates. So, whereas gene mutation is the source of original genetic variation, *Pinaceae* exhibits slow chromosomal evolution.

The second force which shapes genetic variation is called *genetic drift*. Genetic drift is defined as changes in gene frequency caused by random sampling of gametes in finite populations. Neutralist theory, advanced by Kimura (1968) suggests that selectively neutral genetic variants are generated by mutation and changed in frequency by genetic drift. The effects of genetic drift are found at the population level.

The concept of genetic drift is particularly important if population size is small. In small populations, gene frequency can undergo large fluctuations in different generations in a seemingly unpredictable pattern. In a small population, ultimately a gene will either become fixed throughout the population or it will be lost.

How do populations become small? Imagine an isolated population of whitebark pine at timberline on a mountaintop. Perhaps during an era of glaciation, whitebark pine was wide-spread at lower elevations. Today, however, this species may only occur in scattered groups at the highest elevation in the only remaining microsites it can tolerate. Populations may be small due to:

1. Low movement of individuals between suitable habitats.
2. Periodic epidemics which cause population bottlenecks.
3. A population can grow from a few "founder" individuals.
4. Endangered and vanishing species.

The *effective population size* (Ne) is equivalent to that of an ideal population of a given size in which all parents have an equal expectation of being the parent of any progeny individual. What this means is that the census number of a forest population is usually greater than the effective number of individuals contributing to the next generation of forest seedlings. Why is this? One reason is that not all individuals in a forest stand will reproduce. It is common to observe that certain trees in a forest stand will be heavily laden with either cones or pollen while other trees have no reproductive structures at all! Perhaps this tree will eventually reproduce towards the end of its lifespan; perhaps not. Meanwhile other trees produce seed and/or pollen every year. It is the number of individuals which contribute to regeneration which are counted as the *effective number* of a population.

Mating in a small, finite population over time will always lead to *inbreeding*. Inbreeding is non-random mating in which the mating individuals are more closely related than individuals drawn by chance from the population. Inbreeding does not change gene frequency. However, inbreeding does cause a change in the re-organization of genes into genotypes. In an inbred population the frequency of homozygotes goes up and the frequency of heterozygotes goes down relative to random-mating proportions. An individual receives a gamete from its mother and another gamete from its father. For each gene inherited from the parents there may be two or more alternative forms of the gene. These alternative forms are called alleles. If alleles from both parents are the same, the individual is *homozygous* (has only one type of allele) for that gene. If each parent contributes a different allele, the individual is then *heterozygous* (has both types of alleles) for that gene (Figures 3 and 4).

The consequences of inbreeding are:

1. Reduçed vigor and fertility (for outcrossing species)
2. Uniformity and "true-breeding" within lines.

Coniferous forest species tend to be outcrossing species. Therefore the effects of inbreeding for coniferous species is reduced vigor and fertility. Attention to population size is thus of critical importance for coniferous forest species.

Franklin (1980) has proposed what is commonly called the "50/500" rule for effective population size. He suggests that to guarantee the short-term future of a population, the effective population size should not be less than 50 breeding individuals under ideal conditions. He further proposed to secure the long-term future of a population that the minimum effective size should be 500 breeding individuals.

The "50" rule was based on the inbreeding level that breeders of large animals could tolerate; that level where the inbreeding coefficient is equal to a 1% increase in inbreeding per generation.

Franklin's "500" rule was based on an equilibrium model for maintenance of additive genetic variance in quantitative characters in the absence of selection. Franklin calculated an equilibrium between loss of additive genetic variance by genetic drift and gain of additive genetic variance by mutation at effective population size (Ne) equal to 500. This literal interpretation is misleading since an equilibrium between mutation and genetic drift will eventually be achieved for any value of Ne (any effective population size).

A blanket application of either the "50" or the "500" rule is foolish; there is no "magic number", no single minimum viable population size that is universally applicable to all species. The term "viable population" means the population can survive in a state that maintains its vigor and potential for evolutionary adaptation. The term minimum implies minimum conditions for long-term persistence and adaptation of a species or a population in a given place. Minimum viable population analyses are predictions based on a synthesis of all biotic and abiotic factors in the spatial-temporal continuum. What is of concern is the long-term persistence of a population or the capability of the population to maintain itself without significant demographic or genetic manipulation with a probability of 95% given sufficient habitat and "benign neglect" In this vein, the term adaptation implies that a population can maintain a normal level of fitness (individual vigor, fertility, and fecundity) and has sufficient genetic variation to adapt to changes in environmental conditions within a predicted range of environmental frequencies and amplitudes of disturbance and change. Minimum viable population analyses use a quantitative tool, called a Leslie Matrix, to pool genetic, demographic, and ecological data in order to model population dynamics (Figure 5).

The third force affecting the genetic make-up of coniferous forest populations is *gene migration*. Gene migration (or gene flow) is the movement of individuals from one population to another. This results in the introduction of migrant *genes* through mating and subsequent reproduction. For forest trees, which are sessile organisms, gene migration takes place through pollen and seed dispersal. Not all pollen and seed dispersal results in gene flow, but a certain proportion does.

Initial gene frequencies of a population will change at a rate relative to the rate of gene migration. Over several generations, gene frequency change will approach an asympototic equilibrium at a rate dependent on initial gene frequency of a population relative to the gene frequency of the migrant population.

At this point it is necessary to summarize some generalizations about coniferous tree species relative to gene migration.

1. Coniferous tree species are long-lived.
2. Coniferous tree species have distributions which cover large geographic areas.
3. Coniferous tree species are highly fecund (they have LOTS of seeds and pollen!)
4. Pollen and seed are dispersed by wind; their *potential* dispersal distances are very high. Coniferous tree pollen can move several miles; tree seed can move up to one mile.
5. Most pollen and seed is dispersed within 300 feet of the source, BUT immigrant pollen can contribute up to 60% of effective pollinations of a forest stand.
6. Effective pollination is controlled largely by floral synchrony. A female conelet must be receptive at *time* of pollen release.
7. Near neighbors are favored if the male and female flowering is synchronous.
8. Pollen and seed dispersal is affected by:
    *Wind direction and velocity
    *Elevation
    *Temperature
    *Interactions of wind direction, velocity, temperature, and elevation.
    *Interactions of these four factors with floral synchrony and distance between mates.
9. Coniferous tree species have high levels of outcrossing.
10. Self-fertilization is not prevented, although a high level of lethal alleles mostly eliminates selfing. This occurs through embryonic collapse of selfed individuals at the pre-zygotic stage.
11. Coniferous tree species have a high level of heterozygosity.
12. Most genetic variation is *within* populations.
13. There is also a high differentiation *between* populations in growth and phenology characteristics.
14. There is high zygotic (juvenile) mortality. There is a series of reductions of tree density throughout the life of a forest stand.

15. The patterns we see in coniferous forests are the result of a balance between high levels of gene flow and strong selection pressures.

GENETIC NEIGHBORHOODS OF FOREST TREES

A genetic neighborhood is a theoretical concept defined by effective population size and migration rate. In mathematical symbols this equates to: Ne x m = Ne(m). It is interesting to consider a few theoretical models of gene migration within the context of genetic neighborhoods. The linear stepping-stone model of gene migration (Figure 6) is one in which individuals move between populations only in a linear manner. Visualize populations, such as red alder, that exist in continuous narrow bands along waterways. Populations that disperse in this type of linear way tend to be highly genetically differentiated from each other.

Another theoretical model of gene migration is the continent-island model (Figure 7). Visualize small islands of populations at the edge of a species distribution (Figure 8). These island populations will be subjected to the most extreme environmental conditions the species can tolerate.

The island model of gene migration (Figure 9) can be visualized by trees which grow in distinctly bounded groups, which could be the result of a complementary environmental mosaic. I can visualize a colonizer species with population clumps on soil of recent volcanic origin, e. g., islands of lodgepole pine in a lava bed. Genetic neighborhood size on the islands would depend on the size of the breeding population size on the islands and the distance between the islands. For instance, if gene exchange between the islands could only occur due to rare, extremely long-distance gene flow, the genetic neighborhood size would be very large (cover an extensive area) relative to groups of islands with more frequent long-distance gene flow events.

Continuous populations are the most typical population pattern of coniferous forest tree species. An example would be a colonizer species such as Douglas-fir which regenerates vast areas following natural catastrophes such as wildfire. What gene migration model best fits this pattern of gene flow? My guess is that it is a combination of the stepping-stone model (gene flow among neighboring populations) combined with a proportion of long-distance gene flow events (Figure 10). Genetic neighborhoods could alternate between being small due to gene flow between adjacent populations and having large genetic neighborhoods due to long-distance gene flow events. So, the result is a mosaic of genetic neighborhood sizes over time within a single species. What happens to genetic neighborhood size when you consider a continuous mixed-species forest landscape? Continuous populations of coniferous forest trees are the most common and the least understood.

The fourth force affecting patterns of genetic variation of coniferous forest trees is *selection*. Natural selection (as opposed to artificial selection imposed by humans) is the differential reproductive success of genetically different individuals. *Fitness* is a measure of the reproductive success of an individual or a genotype. Differential reproduction can result from differences in the survival rates of different individuals (genotypes) or from differences in the success of these individuals in producing surviving offspring.

Natural selection can occur during various live stages of an organism, (Figure 11) such as:

1. In the gametic stage. In *gametic selection*, zygotic proportions may occur that do not reflect the allelic frequencies in the parental genotypes given Mendelian segregation and

random union of gametes. For example, gametes from heterozygotes are not produced in equal proportions due to meiotic drive, or there is non-random union of gametes with respect to the various alleles, such as that due to incompatibilty systems in plants.

2. In the adult x gamete interaction. This is called *fecundity selection* which is selection as a result of differences in the gametic potential of females usually because sperm and pollen production is not limiting in most cases. There is potential for selection via egg, seed, sperm, or pollen production. Also schedule of egg or seed production may be a significant factor determining contribution to the next generation. A case in point is the periodicity of conifer seed crops.

3. In the juvenile stage. This is called *zygotic selection* which is survival of different pre-adult stages. For plants this equates to differential germination of seeds, seedling survival, pre-reproductive survival, and rate of plant development.

4. In the adult stage. This is *sexual selection* and it occurs when the pre-mating, genotypic proportions of males and females are not the same as the genotypic proportions among the mating individuals. For example, some female and male genotypic combinations are favored by assortative mating between like/unlike types. Males may have differential vigor in mating or females may have differential receptivity to males.

The concept of natural selection is incomplete without reference to *inheritance*. As stated previously, natural selection acts on the individual or genotype. This individual or genotype then passes his/her *genes* onto the next generation. Each genotypes is a unique combination of genes. Genes are the unit of inheritance which remain the same from generation to generation.

The patterns of inheritance can be calculated from Mendelian genetics. Mendel's Law I is the "Independent Segregation of Alleles". This law states that alleles do not affect each other when present in the same plant, but segregate unchanged by passing into different gametes at the formation of the next generation. ("Genes do not blend.") With dominance this leads to the 3:1 ratio of inheritance at the 1 locus, 2 allele model (Figures 12 and 13). Mendel's Law II , the "Independent Assortment of Different Genes" states that the assortment of one gene does not influence the assortment of another. This leads to the 9:3:3:1 ratio of inheritance with 2 genes with dominance (Figures 14 and 15). Mendel was unaware of linkage disequilibrium and epistasis; these are the exceptions to Mendel's Laws.

Age structure, or forest stands with trees of varying ages, adds much complexity to simple genetic models. The Leslie Matrix is used to model age-structured populations. This matrix displays age-specific fecundity and viability of individuals within age classes for each genotype in the population.

PATTERNS OF GENETIC VARIATION OF CONIFEROUS FOREST TREES

We have learned from research on coniferous forest trees that as a group they have high overall levels of genetic variation relative to other plant species (Table 1). For isozyme data, most of the genetic variation found in coniferous forest trees is *within* populations. For growth and phenology data, there exists genetic variation *between* populations which can be categorized by geographic descriptors such as, latitude, elevation, and longitude (distance from the ocean/distance from the Cascade Crest). These patterns of genetic variation tend to be clinal.

These patterns of genetic variation for coniferous species match well with Hamrick's (1990) survey of all plant literature. He found that high *within* population levels of variation based on isozyme data were found in species which were (Table 2): gymnosperms, had a regional distribution, were a long-lived perennial, were primarily outcrossed, were wind-pollinated, had a high lifetime fecundity, and have a high chromosome number.

(NOTE: Dr. Greenwood of the University of Maine made the comment at the 1990 IUFRO/WFGA meeting in Olympia, WA regarding haploid genome size that, "*Homo sapiens* has less DNA than corn; conifers have 5 times as much DNA as *Homo sapiens.* No one knows how to interpret this disparity in DNA content.")

From his survey of plant literature, Hamrick (1990) found that plant species which had low differentiation *between* populations (again based on isozyme data) shared these characteristics (Table 3): predominately outcrossed, winged/plumose seed, monoecious or dioecious (as opposed to self-fertilization), polycarpic (bearing fruit more than once), and long-lived.

These trends match well with information we have learned from research regarding patterns of genetic variation in Pacific Northwest coniferous tree species.

Conkle (1990) presented some interesting trends on patterns of genetic variation within conifer tree species. He found that conifer species that had a wide environmental distribution (Table 4) tended to have high average heterozygosity. This group also had the fewest number of fixed alleles. Conifer species with a more restricted environmental distribution (Table 5) had a lower average heterozygosity and as a group had a larger number of fixed alleles than the widely distributed conifer species. Conifer species with very small populations (Table 6) had a higher proportion of fixed alleles, but also high variation.

Coniferous forest trees have a large reservoir of genetic variation. It is unlikely that our management of these species will lower "natural" levels of genetic variation. Even so, our management must respect and maintain the patterns of *within* and *between* population genetic variation found in these coniferous tree species.

PALEOECOLOGY OF WASHINGTON STATE

The rate of change is relative to the time-scale in which it is viewed. Long-term geologic and climatic change has occurred in Washington State. A record of this change is preserved in the paleoecologic record in the form of plant and animal fossils. Fossil plants are considered to be thermometers of the past because of the evidence they present as to former climates. In order to understand the present, we must comprehend the past.

The present landscape of Washington State is characterized by moist and forested conditions on the western side of the Cascade mountain range and an arid shrub-steppe community in the eastern rainshadow of the Cascade mountain range. The westside climate is mild, but we do have periods of severe summer drought.

Washington State was once a tropical rain forest with a uniform, warm and humid climate. Please refer to the Chart of Geologic Time (Table 7) which displays the various geologic eras commencing 1.5 billion years ago. I will describe the geologic, climatic, and vegetative changes which have occurred in Washington state during the Cenozoic Era, which began 63 million years ago.

In the Paleocene epoch the major geologic event was the deposition of sediments (coal) in a low-lying trough which ran from the present-day vicinity of Bellingham, WA southeast to the vicinity of Wenatchee, WA. The climate was tropical to subtropical. Fossils of palm trees have been found in Kittitas County. Major vegetation consisted of tropical ferns and palms.

In the Eocene epoch which began 58 million years ago the coastline of the Pacific Ocean ran south from Puget Sound so that part of present-day western Washington state was submerged. There were low-lying swamplands along the coastline which were periodically inundated by the sea. There were volcanic centers west of the coastline and along the shore. There was a large freshwater lake in the center of the state, located from about the Snoqualamie Pass area south to the present location of the Columbia River. The climate was warm, similar to present-day middle-Atlantic states, with abundant rainfall. In the Eocene angiosperms were dominant with greater than 50% being birch and alder. Metasequoia (dawn redwood) composed 15% of the vegetation. The remaining 35% of the vegetation was composed of oaks, elm, sycamore, basswood, beech, chestnut, sweetgum, and maple.

The Oligocene epoch began 36 million years ago. During this epoch the coastline of Washington state was pushed further west. There was a slowly-rising continental landmass in the state. Volcanoes were active in the present-day location of the Cascade mountain range. The mountain range along the spine of the present-day Cascades was lower in elevation than the present Cascade Range. River drainage patterns in the state shifted from an east-to-west orientation to a northwest-to-southeast orientation. The climate of the Oligocene was similar to that of the present-day middle-Atlantic states. The vegetation of the Oligocene was similar to that listed above for the Eocene.

The Miocene epoch began 25 million years ago. The Miocene landscape was a featureless plain covering Washington state with some older volcanic peaks along the Cascades axis like islands in an ocean of basalt. This was the time of the massive basaltic lava flows in eastern Washington; 250,000 cubic miles of highly fluid lava flowed over the entire state. The Columbia Basin began sagging due to the weight of this basalt. This was the beginning of the ancestral Columbia River drainage. The coastline of the state pushed westward to nearly its present location. The climate during the Miocene was warm-temperate. Vegetation of the Miocene was composed of: swamp cypress, ginkgo, dawn redwood, bald cypress, chestnut, beech, fig, sycamore, tuliptree, magnolia, poplar, birch, elm, and maple. There was also some evidence of *Abies* spp. and *Thuja* spp. Note: this is the first evidence of modern coniferous forest tree vegetation in Washington State!

The Pliocene epoch began 13 million years ago. This was a time of mountain-building. The uplift of the Cascades occurred over 6 million years during this epoch. The Yakima, Snake, and Columbia Rivers cut channels at a rate equal to uplift. The western coastline was within a few miles of its present location. The climate of the Pliocene was temperate, cooler, less humid and had less rainfall than previous epochs of the Cenozoic era. This is related to the uplift of the Cascade mountain range. The vegetation in Washington state during the Pliocene was composed 65% of maple and oak. The remaining 35% composition was composed of: elm, willow, sycamore, alder, redwood (*Sequoia*), ash, sweetgum, and persimmon. *Abies* spp. composed 0.1% of the total vegetation.

The Pleistocene began 1 million years ago. This was the ICE AGE. Ice sheets invaded Washington state 3 or 4 times from the north. The Cascade mountain range continued uplifting. Five volcanic strata cones developed: Mt. Rainier, Mt. Adams, Mt. St. Helens, Mt. Baker, and Glacier Peak. The channeled scablands of eastern Washington were cut by periodic breaking of ice dams and subsequent flooding. The climate was COLD. The vegetation was composed of boreal general such as *Betula*, *Salix*, and *Picea*.

We are currently in the Recent epoch. Current geologic events include the 1980 eruption of Mt. St. Helens. The significant presence of conifers in Washington state began at the end of the Pleistocene and into the recent epoch.

Throughout geologic time, as stated by Stettler (1987):

> . . ."each tree species appears to have migrated in its own fashion, a process in which the production of seeds, their dispersal, germination, and competitive ability were probably the most determining factors. As a consequence, the constellation of species was different in each millenium; old associations dissolved and made room for new ones. The mutual biotic adaptation, therefore, must have been extremely dynamic. Thus, present-day plant associations should be viewed as relatively recent communities".

ADAPTATION AND LIMITS TO ADAPTATION

Adaptation is a biological characteristic that enables an organism to live and reproduce in a given range of environments. It is a physiological attunement by an organism to its environment.

Dr. Reinhard F. Stettler, University of Washington, has graciously given me his permission to present to you his thoughts on the "Limits to Adaptation" which he lists in his paper, "The Forest as an Experiment". The limits to adaptation are as follows:

1. Natural selection is retrospective, not prospective.
   Success in evolution terms is measured by the number of offspring which contribute to the next generation. It is the adaptation of the preceding generation to *its* environment that sets the stage for the current generation and gives the individual its genetic predisposition. Each generation is a reflection of its parent's generation–and–anchored in the parental environment. So, adaptation has a lag period.

2. Natural selection is relative, not absolute.
   The process of adaptation not only lags at least one generation behind, it is also "stuck" with the raw material at its disposal; how much genetic variability is present in the population.

3. Natural selection is imperfect.
   Selection can recognize only those genes which are expressed in an organism. For example recessive genes are exposed to selection only in the homozygotic form. Maladaptive

recessive genes masked in heterozygotic form can be carried undetected through many generations–to possibly exert negative influence later on. A second example would be the linkage of a maladaptive gene with a positive gene of another locus. This complex may be favored by selection even though the phenotype represents a certain compromise. (Dr. Stettler calls this "oversight".) Another linkage example would be "over-reaction", such as an aborting embryo due to a lethal gene will lead to automatic loss of all other genes contained in it irrespective of their selective value.

4. Organisms have developmental constraints.

   Needles, leaves, seeds, physiological reactions, biochemical means of defense–all are canalized in certain developmental grooves. To jump out of them would initially result in lower fitness, even if such a step ultimately opened up new evolutionary opportunities.

5. Evolution is probalistic.

   Consider an example: If under given environmental conditions, specific recombinant types of two parent trees were adaptively advantageous, they could not be "delivered" in a larger frequency than probability permits (Mendelian Laws). Only afterwards can natural selection favor these specific recombinants among all the offspring, assuming they appear at all.

Stettler summarizes by saying, "no tree is perfectly adapted to its current, let alone its future environment. The individual organism represents a compromise. This organism finds itself in an environment for which its genetic program has only limited relevance. As a tree it cannot move to a habitat more suitable to its genetic program. The inadequacies multiply as we move from individual to population to ecosystem level. Each tree in the forest and each forest stand can be seen as an open-ended experiment whose success or failure can be decided only retrospectively."

SUMMARY

In this paper I have decomposed the forest landscape into two components: genetic forces and environmental change. Finally I have discussed adaptation, which can be viewed as the interaction of genetics and environment. We all know intuitively as we view a forest landscape that we witness a complex and dynamic system. I hope I have offered you concrete evidence to validate the complexity of population dynamics.

LITERATURE CITED

Conkle, T. 1990. Presentation at IUFRO Meeting on Population Genetics, Corvallis, Oregon.

Franklin, I. R. 1980. Evolutionary change in small populations. IN ed. Soule, M. and B. Wilcox, Conservation Biology, an Evolutionary-Ecological Perspective. Sinauer Associates, Inc. Sunderland, MA. pp. 135-149.

Greenwood, M. 1990. Presentation at IUFRO/WFGA meeting on Quantitative Genetics, Olympia, WA.

Hamrick, J. 1990. Presentation at IUFRO Meeting on Population Genetics, Corvallis, Oregon.

Kimura, M. 1968. Genetic variability maintained in a finite population due to mutational production of neutral and nearly neutral isoalleles. Genet. Res. 11: 247-269.

Prager, E. M., D. P. Fowler, and A. C. Wilson. 1976. Rates of evolution in conifers (*Pinaceae*). Evolution 30 (4): 637-649.

Stettler, R. F. 1986. The forest as an experiment. Schweiz. A. Forstwes. 137 (3): 205-220.

Stettler, R. F. 1987. On the conservation and renewal of forest gene resources in Switzerland. Schweiz. Z. Forstwes. 138 (8): 673-683.

Author

Sheila R. Martinson
Regional Geneticist
Pacific Northwest Region
319 S.W. Pine Street
P.O. Box 3623
Portland, Oregon 97208

Table 1. Within-population allozyme variation (Hamrick 1990).

Group	Number of Taxa	Percent Polymorphic Loci	Number of Alleles	Mean Heterozygosity
Tropical Tree Species	16	60.9		0.211
Coniferous Trees	20	67.7	2.29	0.207
Dicots	74	31.2	1.46	0.113
All Plant Species	113	36.8	1.69	0.141

Table 2. Within population genetic variation based on isozyme data (Hamrick 1990).

High Levels of Variation	Low Levels of Variation
Gymnosperms	Dicots
Regional distribution	Endemic
Long-lived perennial	Biennial
Primarily outcrossed	Primarily selfed
Wind pollinated	Selfed
High lifetime fecundity	Low to moderate lifetime fecundity
High chromosome number	Low chromosome number

Table 3. Between-population genetic variation based on isozyme data (Hamrick 1990).

High Differentiation	Low Differentiation
Autogamous (self-pollinated)	Predominantly outcrossed
Hermaphroditic (having both male and female sexual organs on the same plant)	Monoecious or dioecious
Gravity-dispersed seed	Winged/plumose seed
Annual	Long-lived
Monocarpic (bearing fruit once and then dying)	Polycarpic (bearing fruit more than once)

Table 4. Conifers with wide environmental distribution (Conkle 1990).

Species	Average Heterozygosity
Incense Cedar	0.21
Douglas-fir	0.21
Sugar Pine	0.25
White Fir	0.24
Jeffrey Pine	0.25

As a group, fewest number of fixed alleles.

Table 5. Conifers with more restricted environmental distribution (Conkle 1990).

Species	Average Heterozygosity
Coulter Pine	0.13
Digger Pine	0.14
Monterey Pine	0.16
Bishop Pine	0.15
Knobcone Pine	0.14

As a group, larger number of fixed alleles.

Table 6. Conifers with very small populations (Conkle 1990).

Species	Average Heterozygosity
Torrey Pine	0.00
Monterey Cypress	0.18
Washoe Pine	0.15

As a group, higher proportion of fixed alleles, but also high variation.

Table 7. Geologic time.

ERA	Period	Epoch	Duration MM Yrs	Began MM Yrs Ago	Animals	Plants
CENOZOIC	Quaternary	Recent	Late Archeologic and Historic Time		Mammals	Modern Seed Plants
		Pleistocene	1	1		
	Tertiary	Pliocene	12	13		
		Miocene	12	25		
		Oligocene	11	36		
		Eocene	22	58		
		Paleocene	5	63		
MESOZOIC	Cretaceous	Late	72	135	Reptiles and Ammonites	Ancient Seed Plants
	Jurassic	Middle	46	181		
	Triassic	Early	49	230		
PALEOZOIC	Permian	Late	50	280	Amphibians	Spore-Bearing Plants
	Carboniferous		65	655		
	Devonian	Middle	60	405	Ages of Fish	
	Silurian		20	425		
	Ordovician		75	500	Invertebrate	Seaweeds
	Cambrian	Early	100	600		
PRE-CAMBRIAN			900	1,500	Indirect Evidence of Life	Indirect Evidence of Life

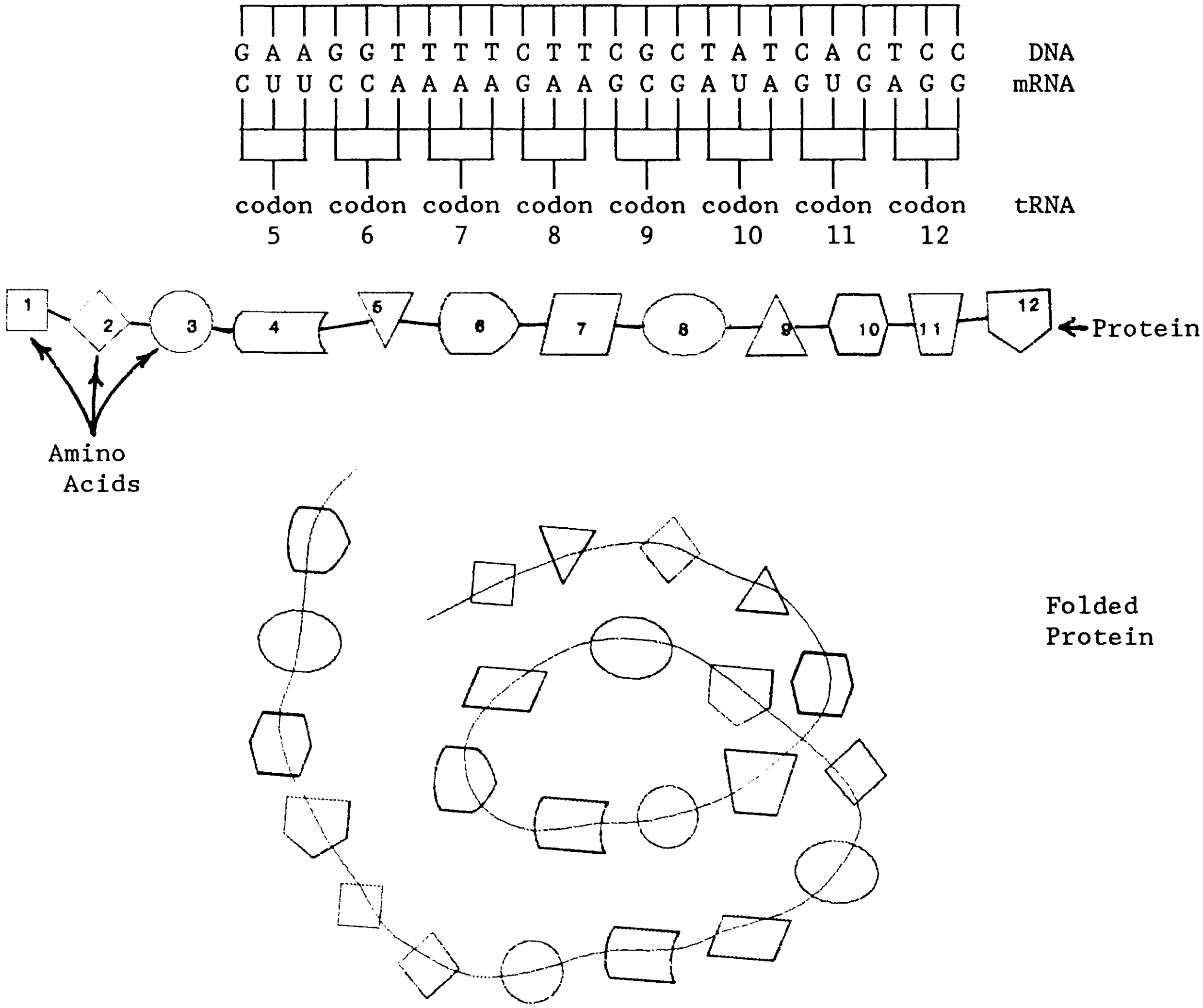


Figure 1. In all life the genetic code is the same.

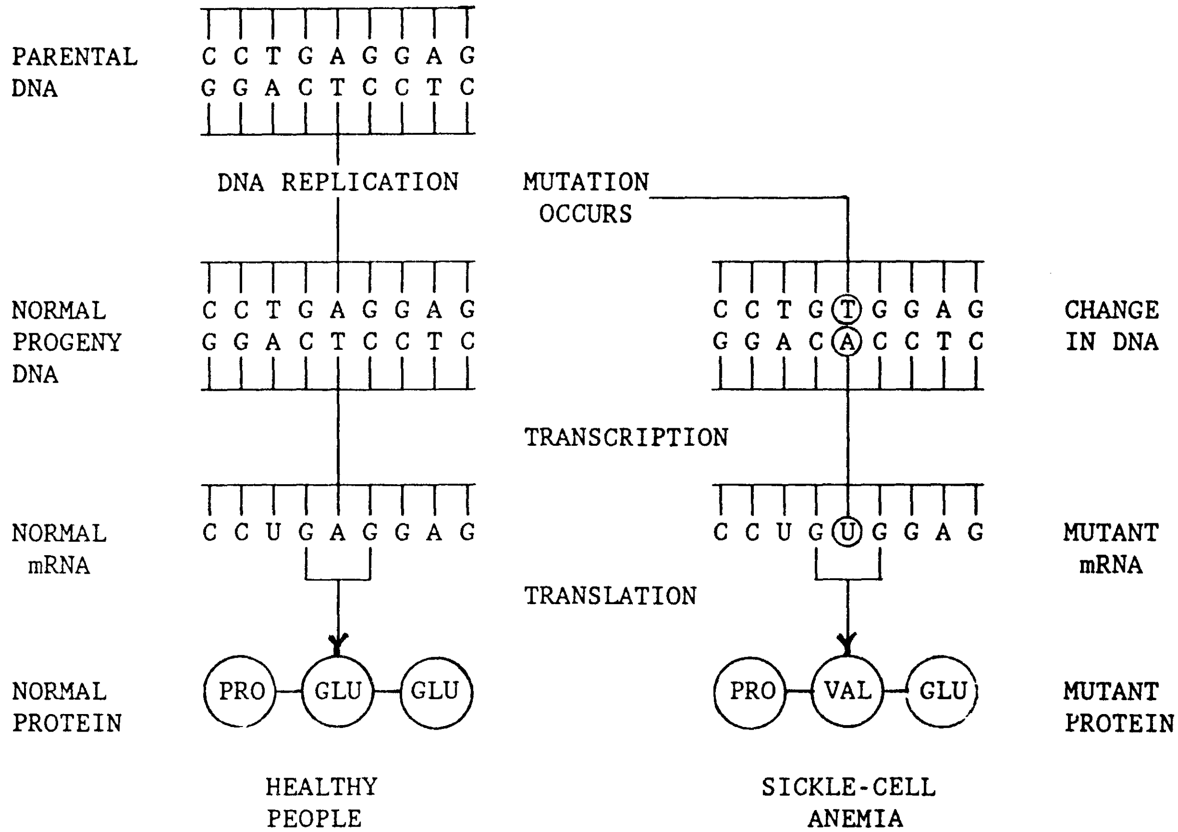


Figure 2. How mutations occur.

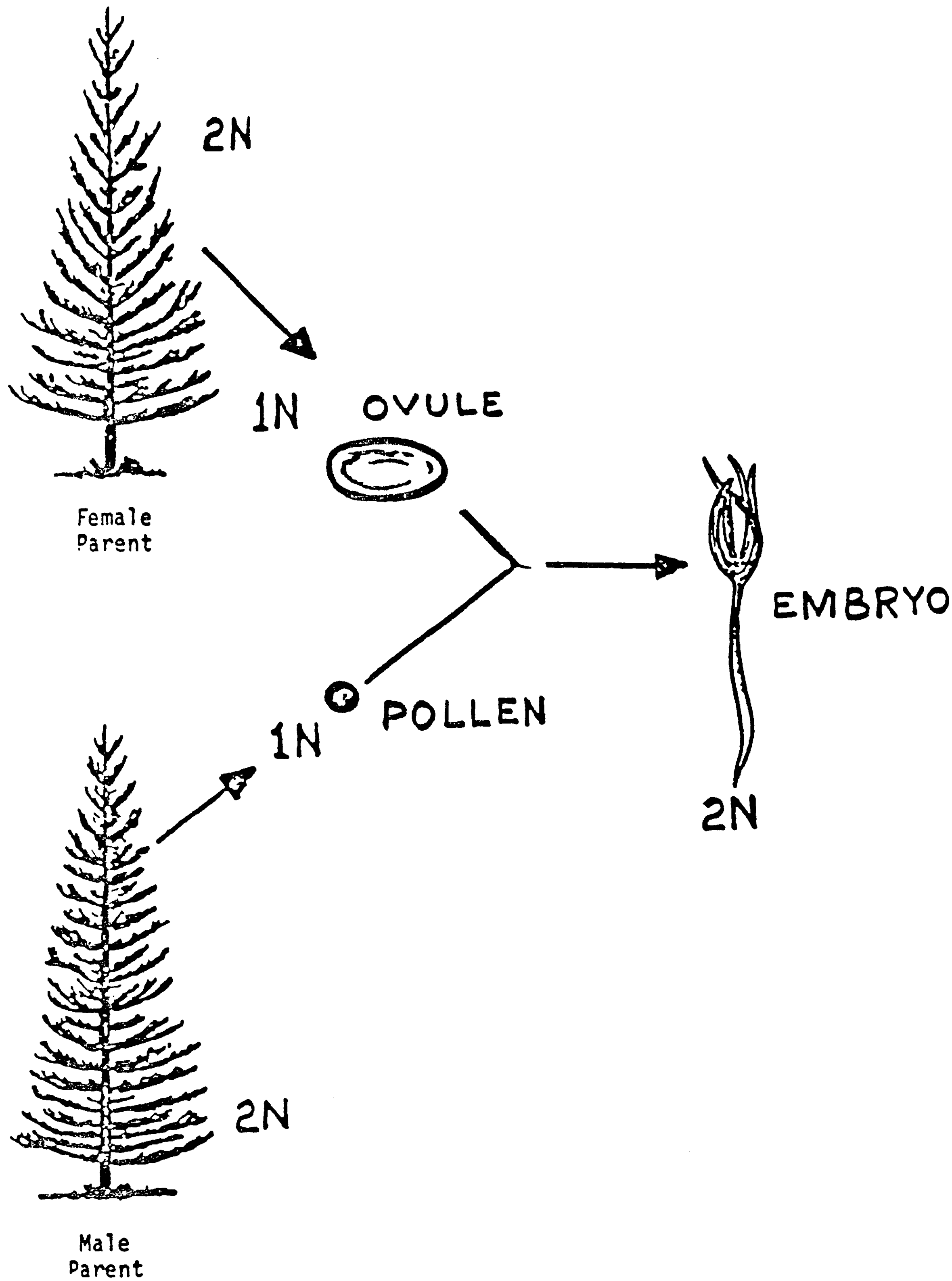


Figure 3 Schematic; diagram of Douglas-fir reproduction.

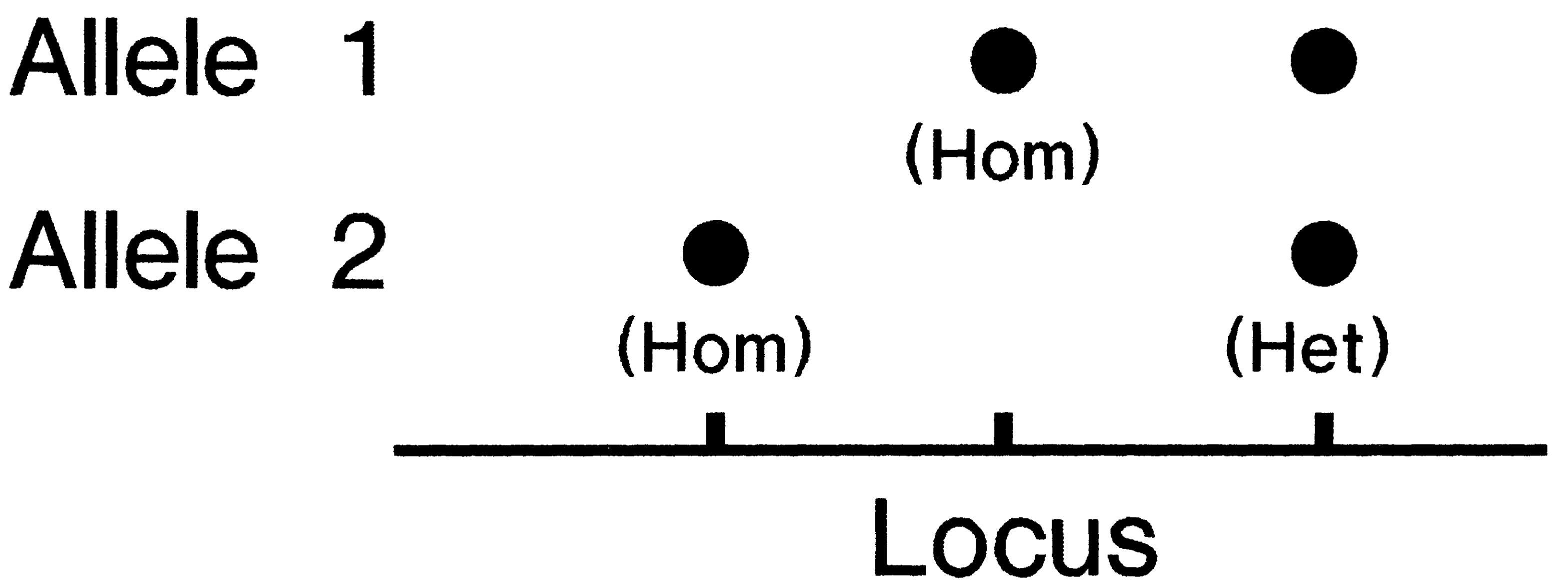


Figure 4. Illustration of homozygosity and heterozygosity at a gene locus .

$$
\begin{bmatrix}
f_{0.ij} & f_{1.ij} & f_{2.ij} & f_{3.ij} & f_{4.ij} \\
v_{0.ij} & 0 & 0 & 0 & 0 \\
0 & v_{1.ij} & 0 & 0 & 0 \\
0 & 0 & v_{2.ij} & 0 & 0 \\
0 & 0 & 0 & v_{3.ij} & 0 \\
0 & 0 & 0 & 0 & v_{4.ij}
\end{bmatrix}
\begin{bmatrix}
N_{0.ij} \\ N_{1.ij} \\ N_{2.ij} \\ N_{3.ij} \\ N_{4.ij}
\end{bmatrix}_{t}
=
\begin{bmatrix}
N_{0.ij} \\ N_{1.ij} \\ N_{2.ij} \\ N_{3.ij} \\ N_{4.ij}
\end{bmatrix}_{t+1}
$$

f_x = fecundity of individuals in age class x

v_x = survivorship in age class x

N_x = genotypes in age class x

t = generation

Figure 5. Leslie Matrix.

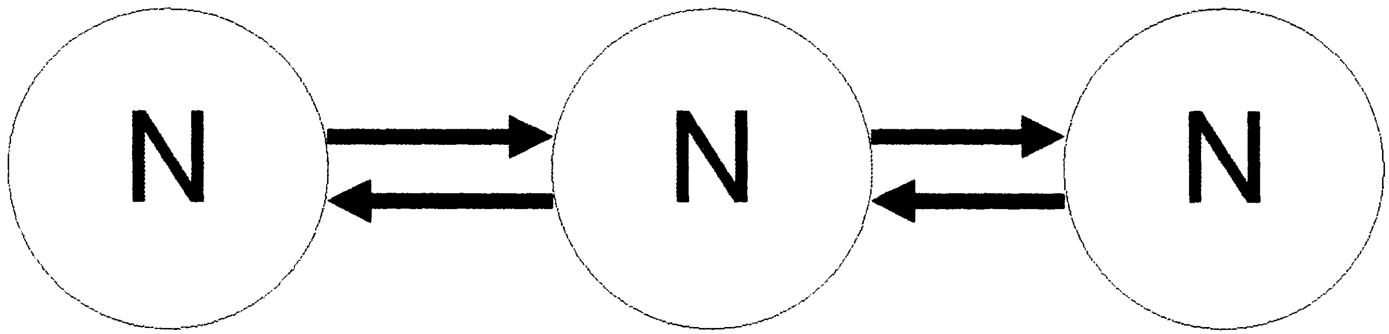


Figure 6. Linear stepping-stone model of gene migration.

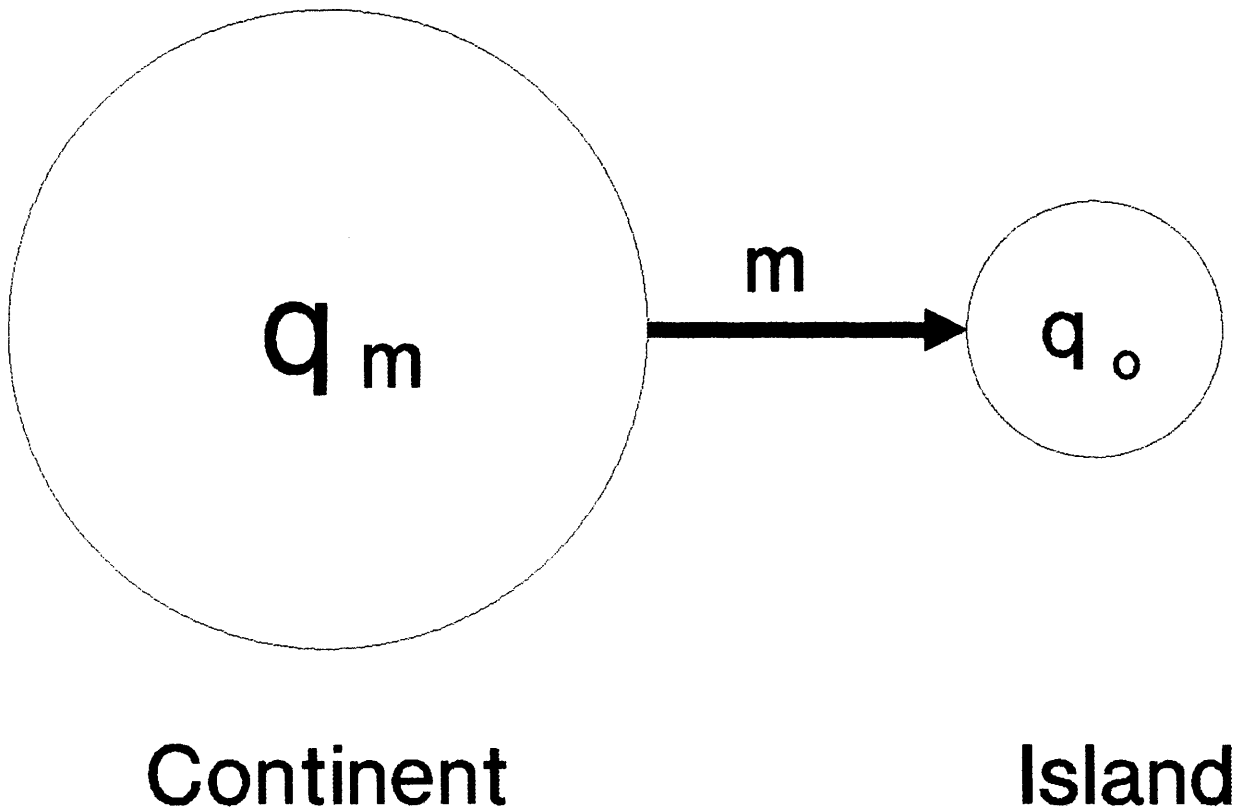


Figure 7. Continent-Island model of gene migration.

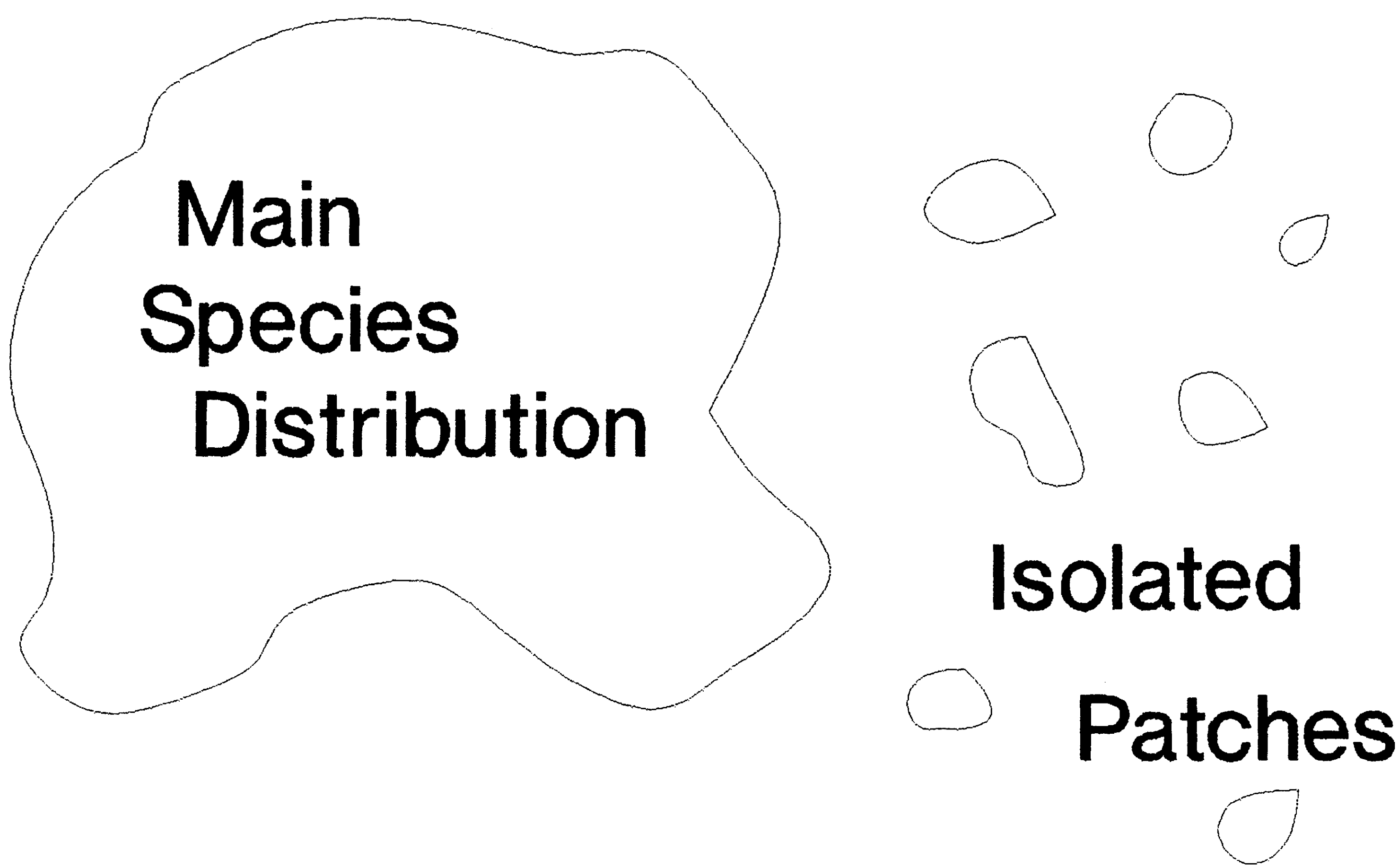


Figure 8. An example of the continent-island model of gene migration.

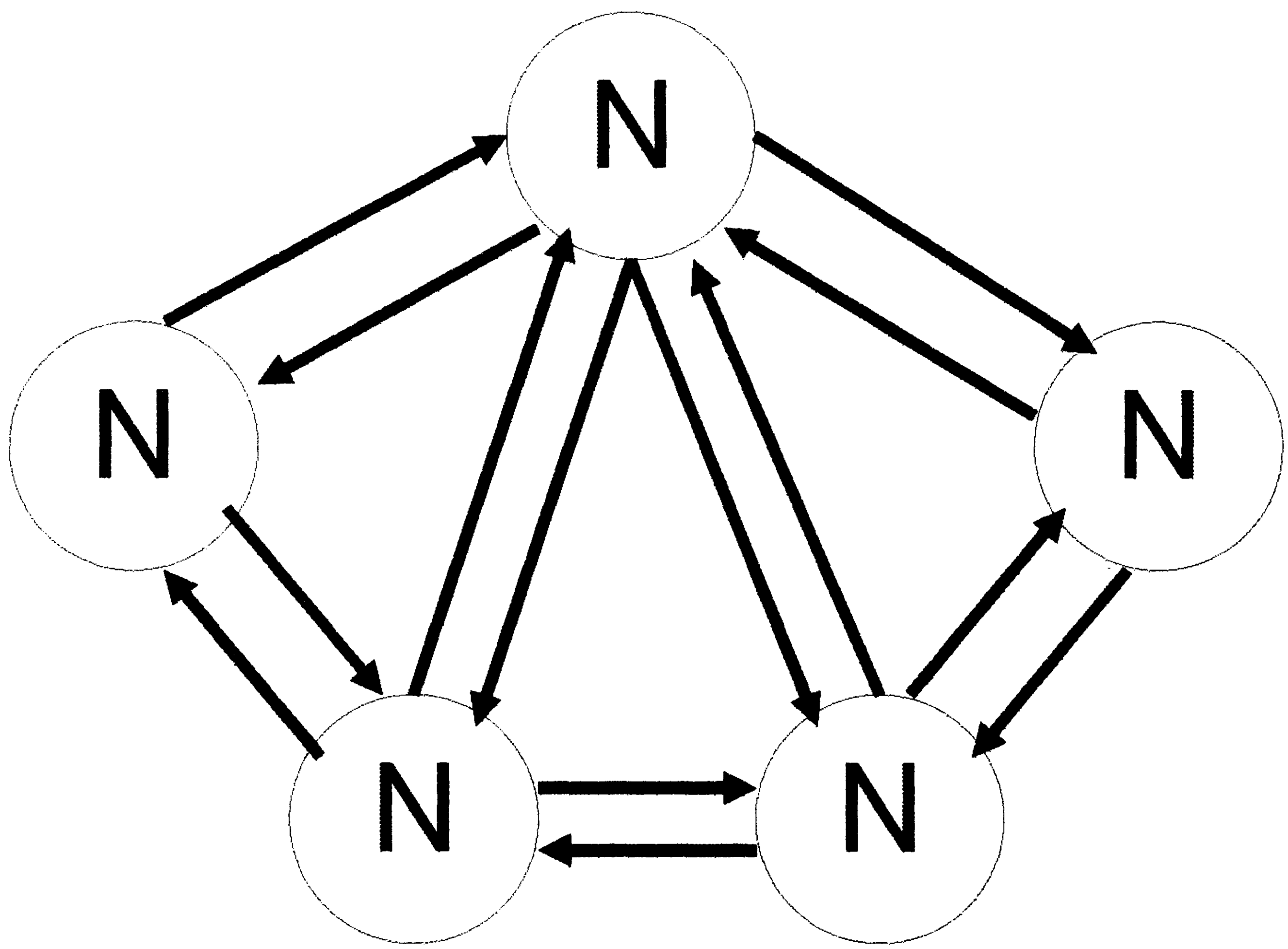


Figure 9. Island model of gene migration.

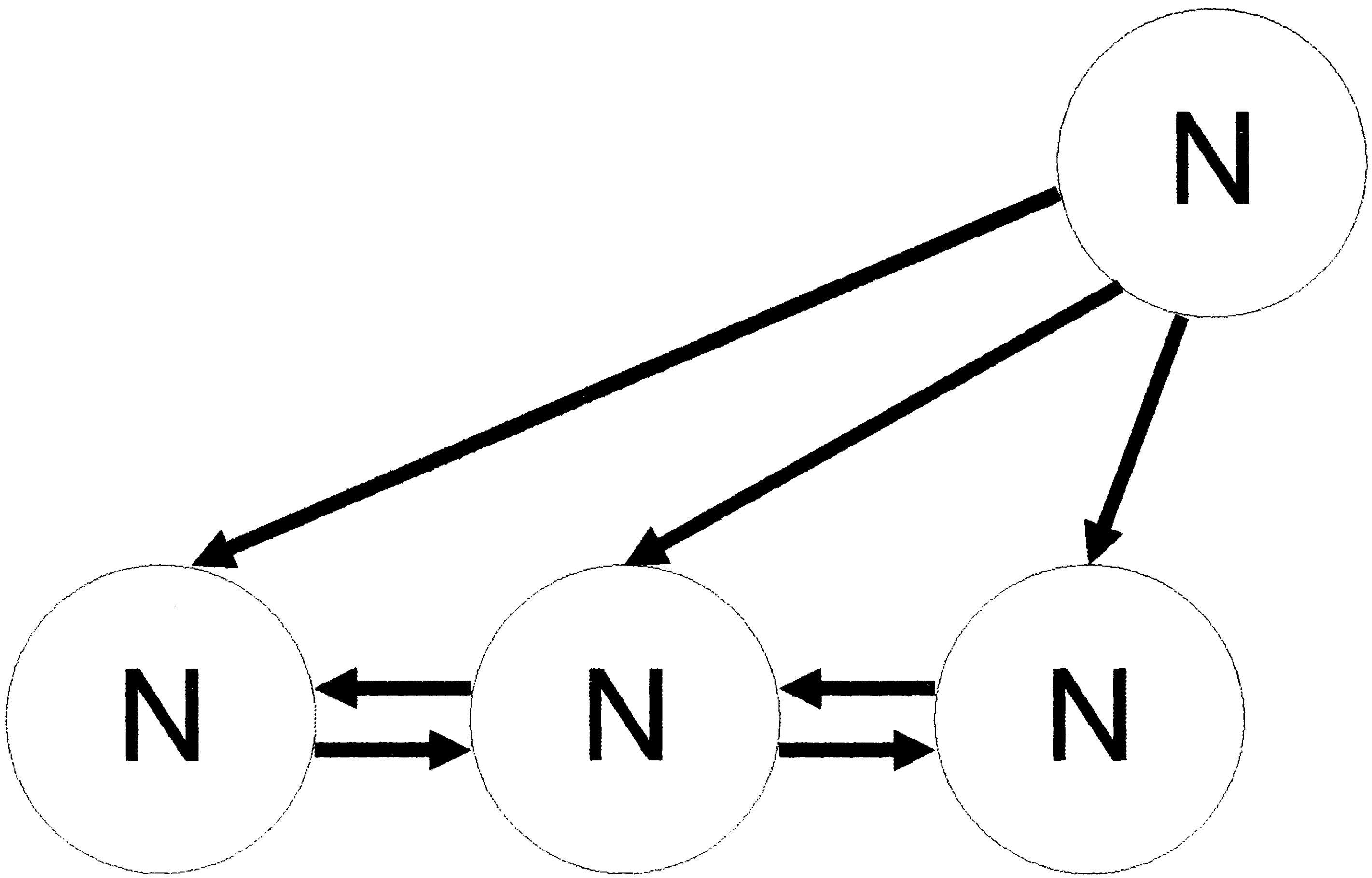


Figure 10. A combination of linear stepping-stone and periodic long-distance gene migration events.

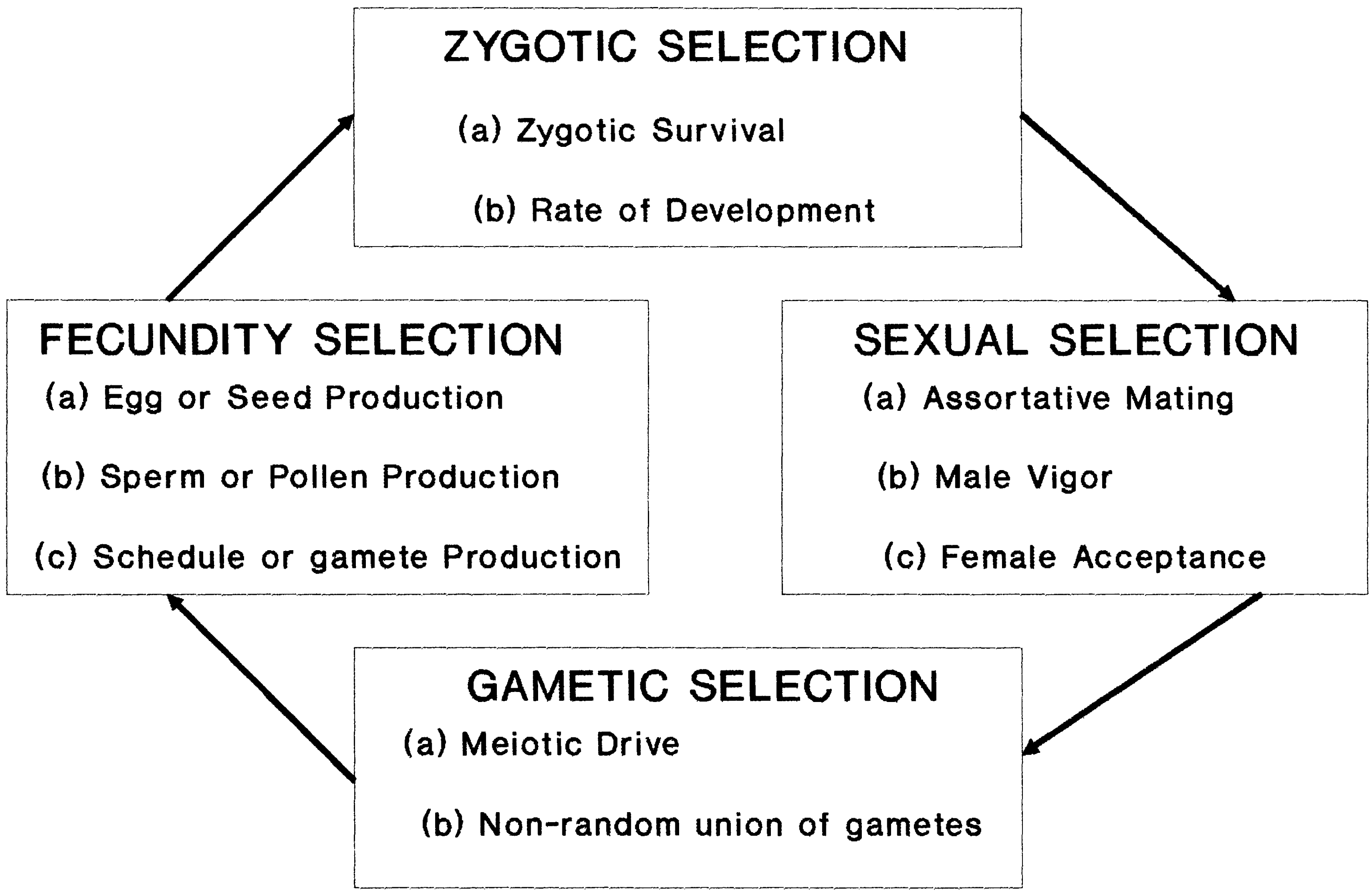


Figure 11. Natural selection can occur during various life stages of an organism.

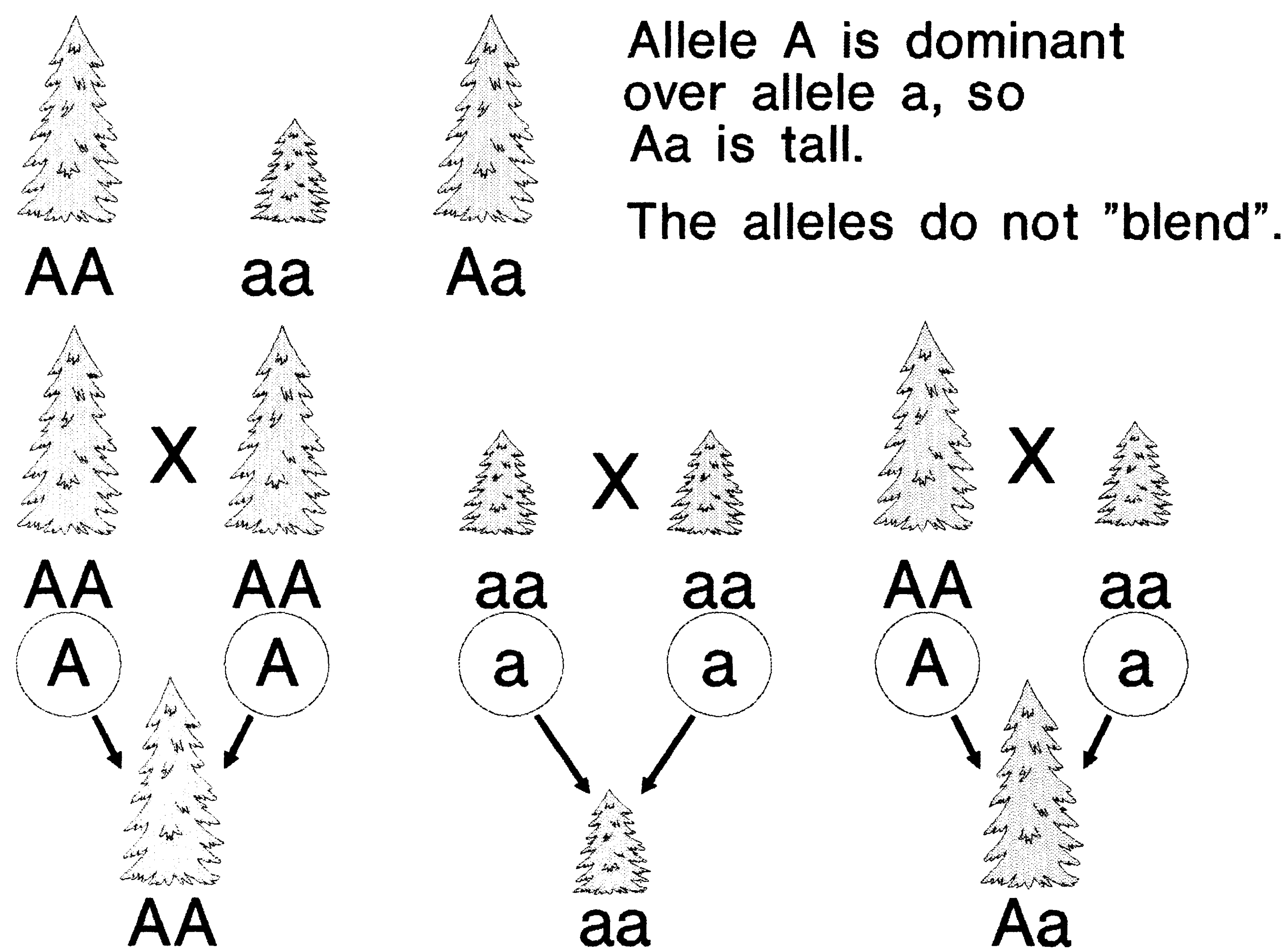


Figure 12. Mendel's Law I, Homozygous Parents.

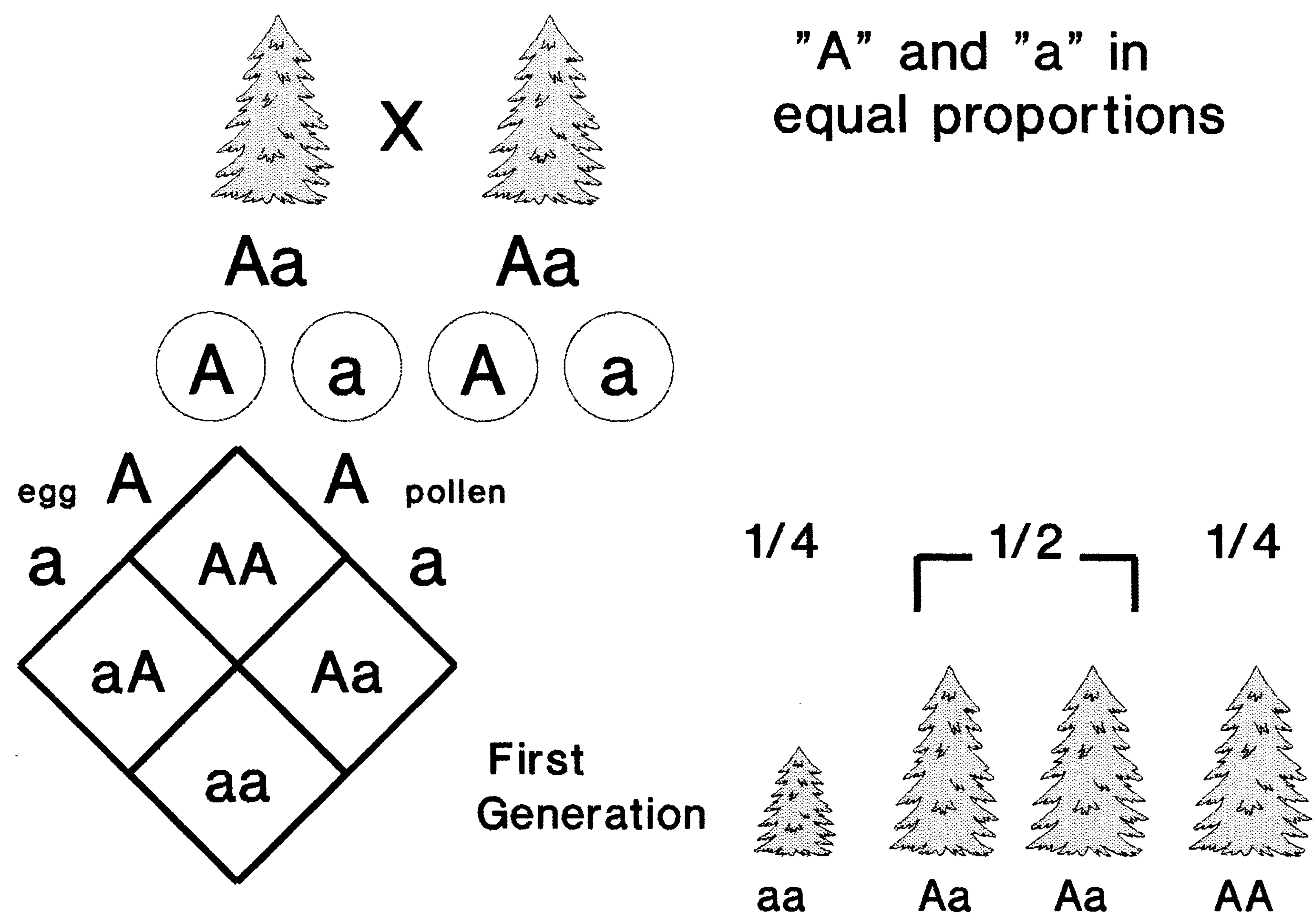


Figure 13. Mendel's Law I, Heterozygous Parents.

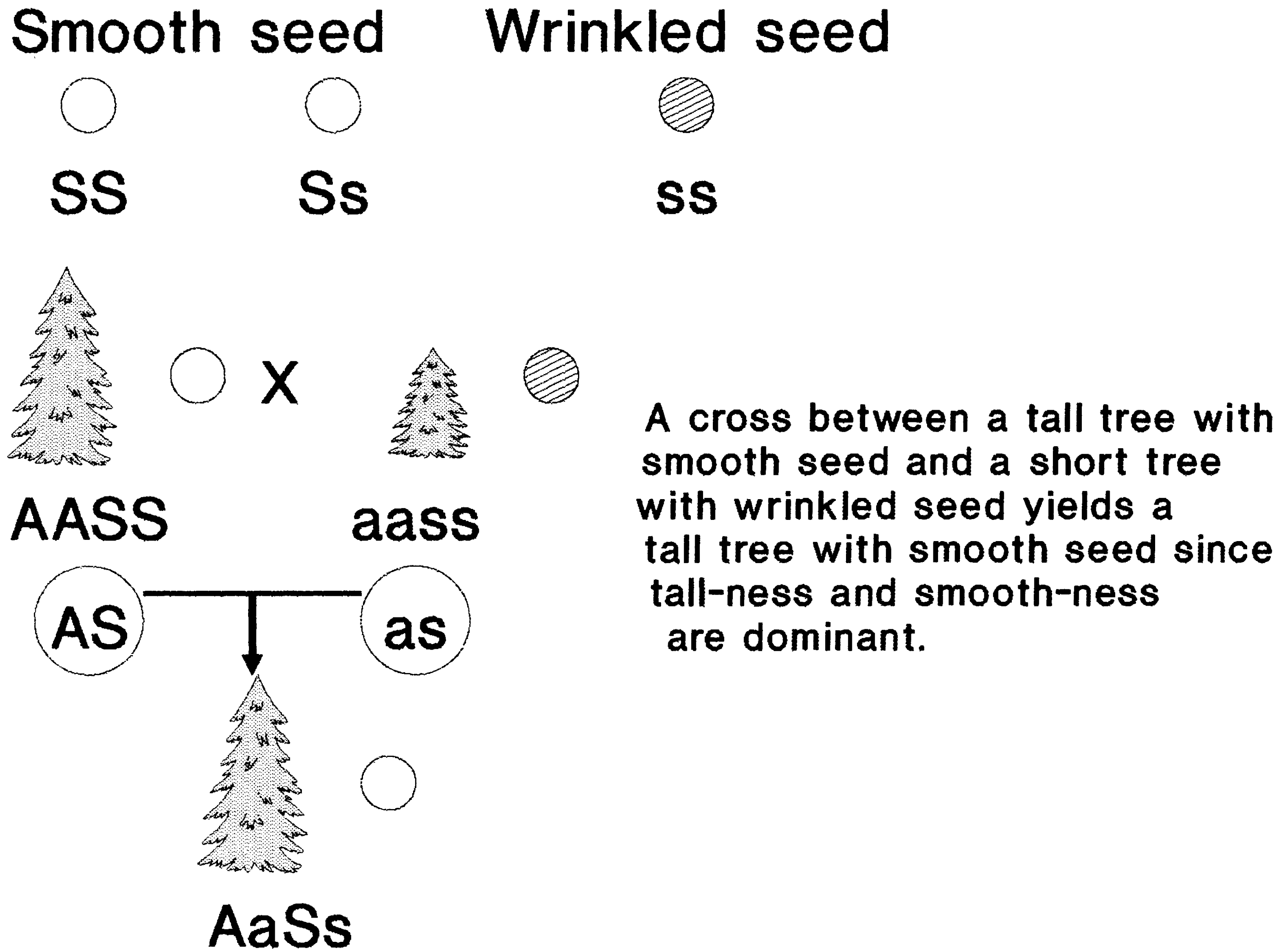


Figure 14. Mendel's Law II. Independent assortment of two different genes.

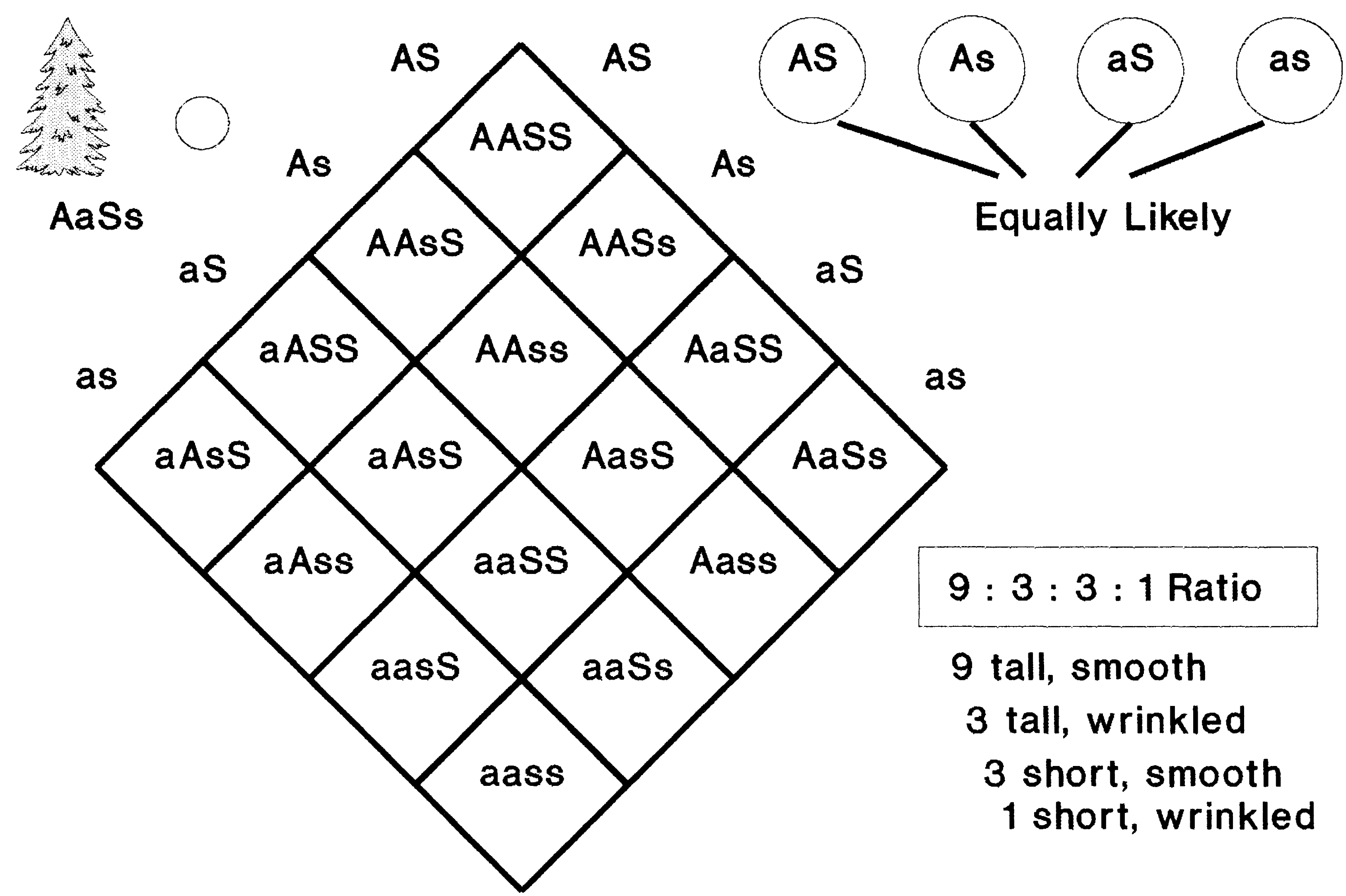


Figure 15. The alleles of one gene sort out INDEPENDENTLY of the alleles of another.

GENE RESOURCE MANAGEMENT: USING MODELS OF GENETIC VARIATION IN SILVICULTURE

Gerald E. Rehfeldt
Intermountain Research Station
Moscow, ID

INTRODUCTION

Sound programs of gene resource management require an understanding of the system of genetic variability. This system, composed of the genetic variability within and between populations, has been molded by natural selection to produce populations that are physiologically attuned to a specific range of environmental conditions. As a result, long-term growth, development, reproduction and survival depend on individuals being genetically suited to the environment in which they grow. Because the environment and the genotype have been matched, genetic resources cannot be effectively managed until one is aware of the environmental conditions to which individual populations are adapted. The following discussion uses the definitions of Levitt (1980): adaptedness reflects physiologically attunement to the environment; adapted plants endure environmental stress without suffering the irreversible strains associated with cell death.

Complicating the accumulation of information appropriate to managing the gene resource is the fact that species differ in the manner by which adaptation to heterogenous environments has been achieved. In the Rocky Mountains, for instance, adaptive clines tend to be steep in Douglas-fir; relatively gentle in ponderosa pine and western larch; and flat in western white pine (Rehfeldt 1984). Yet, in northern Idaho, Douglas-fir, western larch, lodgepole pine and western white pine can occur as components of the same stands across an elevational interval of 3000 feet. Along such an environmental gradient, genetic differences are detectable among populations separated by about 650 feet of elevation for Douglas-fir, 700 feet for lodgepole pine, and 1500 feet for western larch. But systematic differences cannot be detected for western white pine. There is little doubt that populations of these species have responded much differently to selection along the same environmental gradient. Effective management must recognize these differences.

The discussion that follows illustrates the versatility of models of genetic variation for programs of gene resource management. Unless otherwise referenced, the discussion relies on four papers (Rehfeldt 1989, 1990a,b,c), each of which evolved from the conceptual framework of Campbell (1974a,b).

SYSTEMS OF GENETIC VARIABILITY

Genetic variability is molded by an environment that is variable in both space and time. Spatial heterogeneity is reflected in the environmental gradients associated with differing ecology, geography, or physiography. In Idaho and Montana, a climatic gradient from west to east occurs across a series of rugged mountain ranges. To the northwest, the climate is generally the mildest, the elevational distribution of species is the lowest, frost-free periods can be relatively long (110 days), and the climate can be mild and moist. To the east and southeast, the midpoint of elevational distributions gradually increase, the frost-free period tends to decrease, and the climate becomes cold and arid (U.S. Department of Commerce 1968). Superimposed on these general patterns are the environmental variations associated with the mountainous terrain including, for example, a frost-free season that decreases by 75 days across an elevational interval of 3000 feet (Baker 1944). Thus, mountainous terrain superimposed on a climatic transition results in extreme spatial environmental heterogeneity. Even though environmental variation in time (between days, seasons and years) is also extreme, one should recognize that variation in time at a specific locality is repeated in space at a given time. This relationship places an upper limit on adaptive differentiation: natural selection cannot so finely attune physiological processes to specific environments that the genetic variability needed to accommodate temporal environmental variation is lost.

When species, seed sources or families are grown in the same environments (common gardens), genetic differences can be observed directly. This type of research has demonstrated several fundamental principles, all of which are documented for Rocky Mountain species (Rehfeldt 1984):

1. The manner by which adaptedness has been achieved differs among species. Populations of some species are adapted to a relatively small segment of the environmental gradient while those of other species have a broad adaptability.

2. Patterns of genetic variation correspond to environmental gradients, with most of the genetic variation among populations within species reflecting adaptation to frost-free periods of variable length.

3. Because much of the genetic variation results from selection by a variable frost-free period, adaptive traits tend to be correlated with each other. Intercorrelation typically involves traits controlling growth potential, patterns of shoot elongation, and responses to environmental stress (notably tolerance to freezing, drought and snow loads). Frequently included are resistances to insects and diseases.

4. Because patterns of genetic variation among populations are systematic, the patterns can be described mathematically.

5. With the possible exception of western redcedar (unpublished data), all species display substantial genetic variability within populations.

Because patterns of variation can be described mathematically, another principle became apparent: recurrence. Similar genotypes tend to recur across the landscape presumably in association with the recurrence of those environmental variables that are operating in natural selection. The principle of recurrence is illustrated by the elevational clines for Douglas-fir in Figure 1. Populations with a standardized height (growth potential) of about 2.0 are expected to occur in several drainages at elevations that span about 2500 feet. But, in a given drainage, such genotypes are expected to occur across an elevational distribution of only 650 feet. (In Figure 1, heights are standardized by subtracting the mean and dividing by the standard deviation so that data from disparate studies could be compared directly). Also apparent in Figure 1 is the corollary to the principle of recurrence: populations occurring at the same elevation in different drainages tend to be different genetically. Genetic variation, however, occurs for several traits simultaneously, and portraying the complex patterns by which genotypes are distributed across the landscape can be simplified greatly by querying the models themselves.

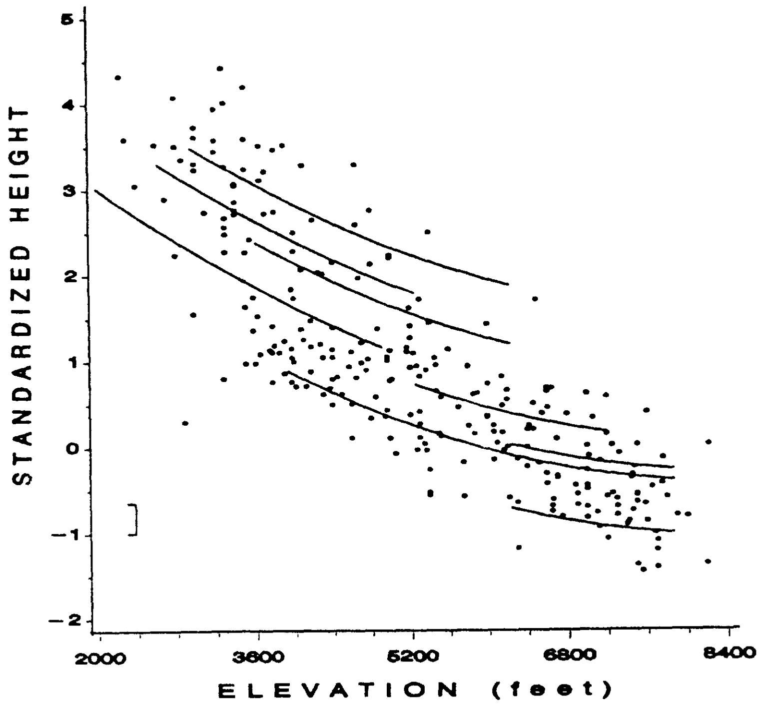


Figure 1. Standardized 3-year height of Douglas-fir populations plotted according to the elevation of the seed source. Each regression line represents predicted values for single drainages; the bracket near the origin quantifies lsd 0.2. Height is presented in standard normal deviates (from Rehfeldt 1990c).

MODELS OF GENETIC VARIATION

Regression models that describe patterns of variation can be used for prediction as well as for description. Models of genetic variation that are being developed for Rocky Mountain species include:

SPECIES	EFFECTS PREDICTED	VALIDATION
Douglas-fir	growth potential and cold hardiness	strong
ponderosa pine		
var. *ponderosa*	3 principal components of 9 variables	supportive
var. *scopulorum*	2 principal components of 19 variables	non-existent
lodgepole pine	model not yet completed	

All of the models describe genetic variation among populations as complex functions of elevation, latitude, and longitude. The models, therefore, can be used to build data sets that contain predicted effects for the geographic and elevational distributions of the species in the area of study. And once available, these data bases can be queried. Thus, one can request the Douglas-fir model to locate those stands with highest growth potential and lowest tolerance to freezing. Figure 2a shows that such genotypes are expected to occur at the lowest elevations (2000 to 3500 feet) in the mildest portion (northern Idaho and northeast Washington) of the Inland Northwest. Quite similarly, one can request a listing of those genotypes that are slightly above average in growth potential and slightly below average in freezing tolerance. Figure 2b suggests that such genotypes are widespread within the region. These genotypes are expected to occur across an elevational interval of nearly 2500 feet, despite the fact that in any single drainage such genotypes are expected to be distributed across only 650 feet of elevation.

All models, however, need validation. While several statistical tests exist for assuring that a model is unbiased, the confidence one ultimately places in predictions depends on the degree by which the models have been validated with data that are independent of those from which the models were developed. Validation of the Douglas-fir model (which I consider to be the weakest of the models) has been particularly strong. First, observed frost damage to 159 seedlots at the Forest Service nursery in Coeur d'Alene, Idaho was significantly correlated with the relative amount of injury expected according to the model (Rehfeldt 1986). Secondly, observed site index in 135 natural stands in northern Idaho and northwestern Montana was closely related to genetic variation in 3-year height predicted by the model (see Monserud and Rehfeldt 1990). Validation of the model for ponderosa pine (var. scopulorum) from the Colorado Plateau cannot be attempted because independent data do not exist, but validation for the model of ponderosa pine from the Inland Northwest has been supportive. In the latter case, variation predicted by the model was significantly correlated with various data from 12-year old field tests. Although statistically significant, the correlations were not excessively strong, the power of the statistical tests was weak, and the amount of independent data was limited. Users of unverified models must be aware of potential biases and should support validation efforts.

APPLICATION

Models of genetic variation have a variety of potential uses in gene resource management. These uses range from guiding seed transfer in artificial reforestation of the economically important species to assessing the threat of extinction to minor species. Applying the models, however, requires two assumptions:

1. The adaptedness of naturally occurring local populations approaches the optimum. In the Inland Northwest, the costs of testing have prohibited implementation of testing programs that intensively sample the breadth of environmental variation faced by a species. As a result, the ecological amplitude of individual populations cannot be defined mathematically. Therefore, despite evidence to the contrary (e.g., Raymond and Lindgren 1989, Roberds and Namkoong 1989), despite the effects of a changing climate (Stettler 1990), and despite the probability that the adaptedness of all populations has not achieved optimality, the assumption must be made that the natural population is well adapted to its site, and, therefore, its productivity in the long term will approach the optimum.

2. Adaptability equals the least significant difference among populations at the 20% level of probability (lsd 0.2). Surrounding a population mean with a confidence interval of $\pm 1/2$ lsd 0.2 means that two populations lying at opposite sides of the confidence interval of a third mean will differ genetically with a probability of about 0.2. The 20% level is used to guard against Type II errors—accepting no differences among populations when differences actually exist.

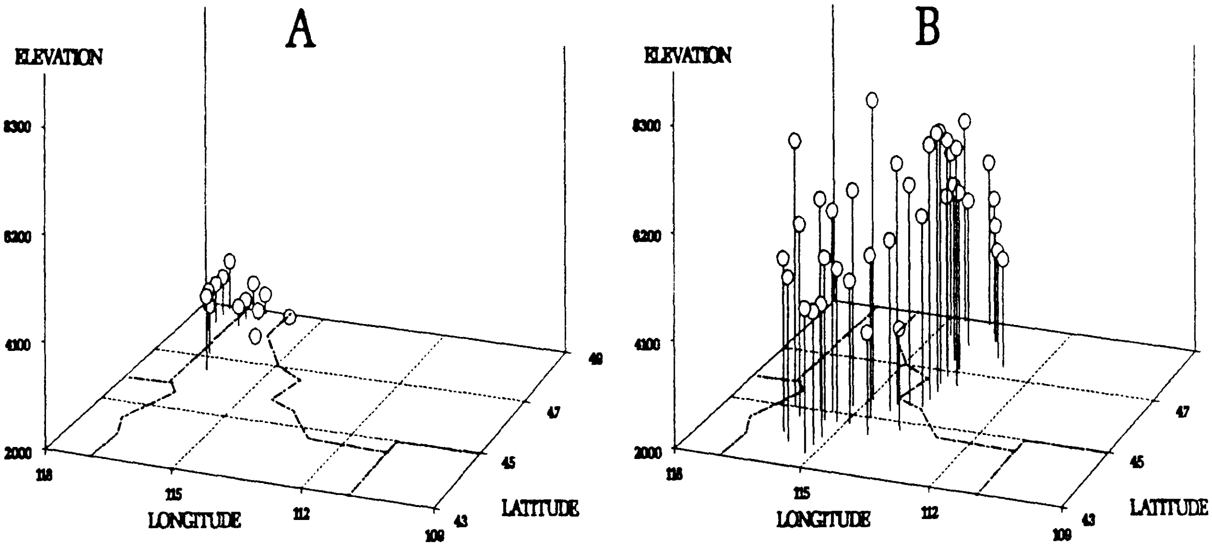


Figure 2. Geographic and elevational distribution of recurring Douglas-fir genotypes. Heavy lines on the floor of the diagram outline state boundries. A. Populations with highest growth potential and lowest tolerance to freezing. B. Populations with a growth potential slightly below average and freezing tolerance slightly above average (from Rehfeldt 1990c).

Seed Transfer

In artificial reforestation, the models can be used for determining the limits that seeds can be transferred before the effects of poor adaptation begin limiting productivity. In this usage, the models can list either the location of sites that are environmentally compatible for a particular seed source or the location of seed sources that are genetically compatible with a particular site. One can, for example, input the longitude, latitude, and elevation of a site; request the models to calculate the attributes of genotypes adapted to the site; construct confidence intervals about the estimates; and then list from a data base other localities where similar genotypes are expected to occur. If the original locality had represented a planting site, the listing would include the sources of seed appropriate for maintaining the adaptedness and growth potential typical of the wild population. If the original locality had represented a seed source or seed production area, the listing would include the range of sites where the seeds could be used with a low risk of maladaptation. R. A. Monserud (1990), in fact, has prepared an expert system that performs this series of operations for ponderosa pine (var. *scopulorum*) on the Colorado Plateau. A similar system is forthcoming for Douglas-fir and ponderosa pine in the Inland Northwest.

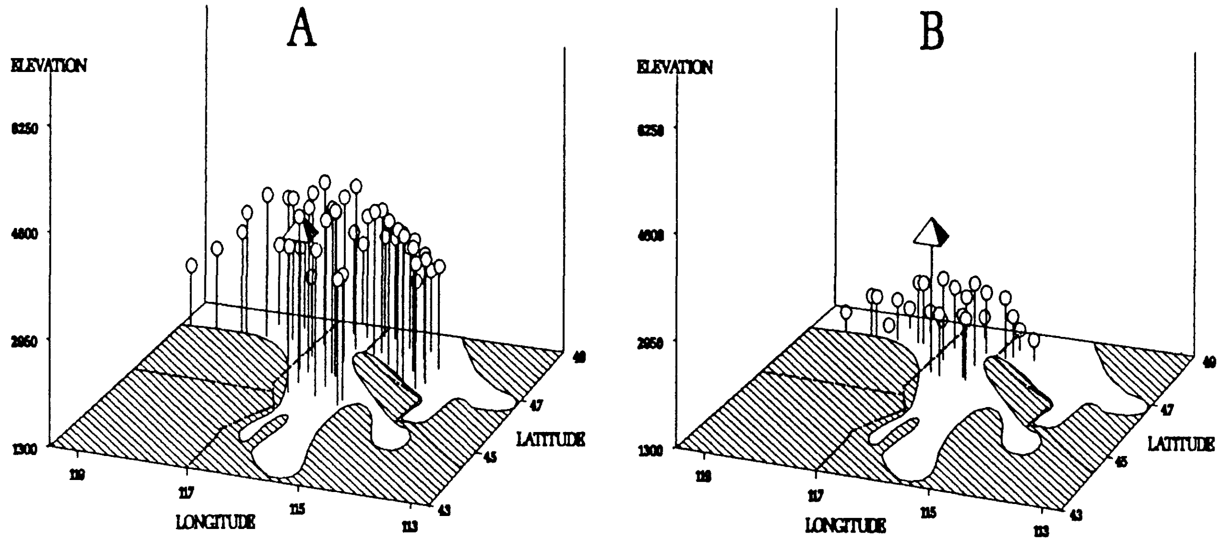


Figure 3. The pyramid locates a ponderosa pine site at an elevation of 3600 feet in northern Idaho. Bold broken lines on the floor of the diagram outline state boundries; cross hatching indicates lands not inhabited by the species. A. balloons locate populations genetically suited to the site. B. Balloons locate populations with a growth potential two times larger than that of populations native to the site (from Rehfeldt 1990b).

For example, Figure 3a locates a site at 3600 feet in northern Idaho. Seed sources of ponderosa pine that are expected to be genetically compatible with this site tend to come from (1) slightly higher elevations toward the northwest where the environment is milder than at the site itself, and (2) elevations lower than the site toward the south and east where the environment is more severe. For this locality, compatible sites are widespread, spanning an elevational distribution of nearly 2500 feet. At the site itself, however, compatible locations are limited to ±550 feet of elevation.

A second example of using the models in artificial reforestation might involve a strategy of maximizing productivity without regard to the risks associated with poor adaptation. Figure 3b locates sources of ponderosa pine seed that should have twice the growth potential of local trees. Appropriate sources tend to come from the lowest elevations in the mildest portion of the region.

Uses similar to these examples might include planning cone survey routes, cone collection strategies, and rehabilitation programs.

Seed Zones and Breeding Zones

In an application similar to guiding seed transfer, the models could be used to help design the seed zones and breeding zones that are intended to control poor adaptation in artificial reforestation. Current practice usually involves delineating discrete seed zones that are consistent with patterns of genetic variation. Discrete zones, therefore, should be areas within which indigenous trees are adaptationally similar. However, by imposing a system of classification on continuous genetic variation, discrete zones are convenient managerially but tend to be inefficient and uneconomical.

An example: genetic variation in ponderosa pine on the Colorado Plateau was detected for 19 variables. Two principal components (linear combinations of the variables) nicely described genetic variation among populations. The patterns of variation followed three clines: a gentle geographic cline and a steep elevational cline both of which related growth potential to the length of the frost-free season, and a second geographic cline of gentle slope that related patterns of shoot growth (growth rhythm) and leaf length to patterns of precipitation. Delineating seed zones so that populations within a zone differ by less than lsd 0.2 for both principal components produced eight geographic zones. Within each zone, moreover, recommended transfers encompass only about 1000 feet of elevation. This meant that 25 zones would be required to represent the ecologic distribution of ponderosa pine on the Colorado Plateau.

A major disadvantage with this approach involves the boundaries between zones. Once zones are delineated, the boundaries tend to be regarded as fixed. One tends to forget that zonal boundaries represent a system of classification that has been superimposed on continuous variation for managerial convenience. Another disadvantage with discrete zones involves regions such as the Colorado Plateau where artificial reforestation concerns rehabilitation after wildfire as much as timber management. For this region, maintaining seed inventories for 25 zones is managerially unrealistic.

Discrete zones, moreover, fail to consider the principle of recurrence: similar genotypes tend to recur across the landscape in association with the recurrence of similar environments. For ponderosa pine of the Colorado Plateau, patterns of recurrence are complex. Conceptual problems, however, can be simplified by using the regression models. Figure 4 shows the distribution of genotypes expected in the various physiographic provinces of the region. For any province, elevational clines are represented diagonally: low elevation is in the lower left while high elevation is in the upper right. Any point in two-dimensional, principal component space is surrounded by a confidence interval of $\pm 1/2$ lsd 0.2, values of which are indicated by the dimensions of the rectangle in the lower right of the figure. A point lying outside the rectangle surrounding a first point thus differs from the first with a probability of at least 0.2.

By using the rectangle like a cookie cutter, one can group the genotypes of Figure 4 according to genetic similarity rather than the physiographic criteria that were used to delineate discrete seed zones. Assorting the distribution of genotypes into the least number of rectangles possible produces 12 groups of genotypes for the same region that needed 25 discrete seed zones. The number of zones could be halved without altering the risks of maladaptation. To be sure, the model of genetic variation would be required for determining to which group belong the trees growing at a specific elevation in a particular physiographic province.

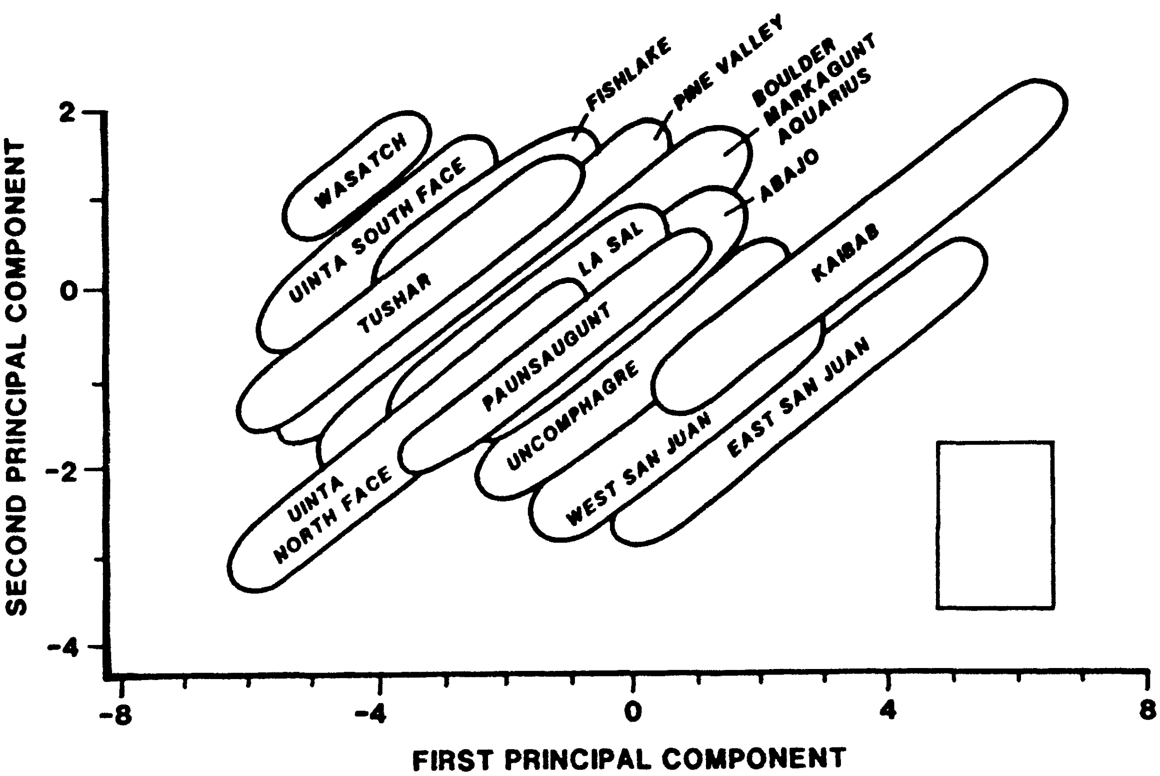


Figure 4. Ellipses outline the distribution of genotypes for two principal components expected in various physiographic provinces that support ponderosa pine on the Colorado Plateau. The rectangle in the lower right quantifies lsd 0.2 (from Rehfeldt 1990a).

A similar approach allows one to assemble individual seed orchards or breeding populations. Seed orchards thus could be delineated according to site productivity rather than by geography. An extension of this concept, moreover, recognizes that the distribution of genotypes in Figure 4 mirrors patterns of genetic variation across the landscape. It is conceptually feasible, therefore, for the entire Colorado Plateau to be served by a single seed orchard within which the distribution of genotypes is precisely that shown in the figure. Enormous managerial problems undoubtedly would focus on the pollen management required to prevent excessive mixing. For this reason alone, a large orchard probably would be necessary. Although the application of breeding theory would not be direct, few orchards would be needed, and flexibility would be large. Cone collections could be customized (by rows and tiers) for specific planting sites. Recurring problems associated with the zone boundries would be eliminated. And since the layout reflects natural patterns, alterations demanded by a changing climate could be absorbed readily. The concept seems worthy of exploration.

Phenotypic Variation

Because the phenotype is the sum of genetic and environmental effects, phenotypic variance among stands results from the genetic effects, the environmental effects, and the interaction between genetics and environment. In Douglas-fir, phenotypic variance among stands is high. In a study of site index, for example, Monserud (1984) showed that the mean 50-year height of three index trees in 135 natural stands from northern Idaho and northwestern Montana varied from 28 to 100 feet. Because of the broad range of slopes, aspects, elevations, soils, and habitat types under which Douglas-fir occurs, the common assumption is that most of the phenotypic variance results from the direct effects of an extremely heterogeneous environment. A recent analysis, however, refutes this assumption.

The analysis performed by Monserud and Rehfeldt (1990) allowed the phenotypic variance in site index to be apportioned into its genetic and environmental components. Doing this required the cause and effect system of Figure 5. According to this system, the phenotype results from the direct effects of both the genotype and the current environment, the latter of which occurs during the life of a tree. Genotype and environment are intercorrelated because both are influenced by the long-term historic environment. The historic environment controls genetic variation through natural selection and is related to the current environment simply because environmental trends are autocorrelated. By itself, genetic variation in 3-year height predicted by the model of genetic variation accounted for 42 percent of the variance in site index; environmental effects, represented by elevation and habitat series (Daubenmire and Daubenmire, 1968), accounted for 39 percent. (It is noteworthy that these environmental effects were better predictors of site index than a variety of soil physical, soil chemical, and physiographic descriptors; Monserud et al. 1990). Together, the genetic and environmental effects accounted for 46 percent of the variance in 50-year site index.

Path analyses allowed the separate effects of genotype and environment to be determined. The results astounded the authors: Of the 46 percent of the variance in site index that was accounted for, the environmental effects accounted for 9 percent, the genetic 17 percent, and the interaction 20 percent. The ratio of path coefficients showed that genetic effects were approximately one-third more important than the environmental effects in controlling phenotypic variation in site index. Both the size of the genetic effects and the size of the interaction were undoubtedly a reflection of the steep adaptive clines that are typical for this species (Figure 1). The large interaction translated into a simple correlation of 0.76 between the genotype and the environment, a value that also develops from the steep adaptive clines. This correlation affirms that genotypes of highest growth potential tend to be found on the best sites.

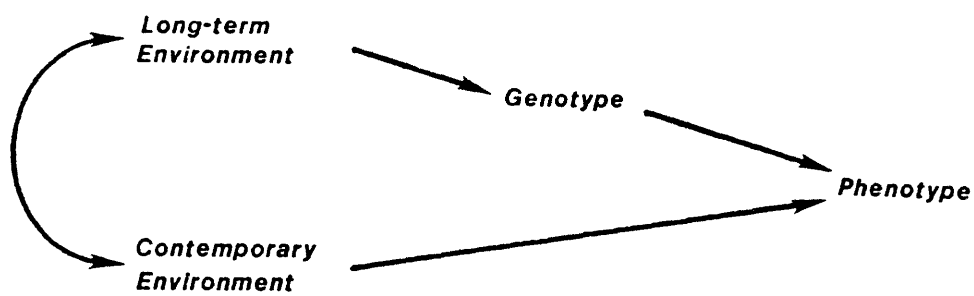


Figure 5. Cause and effect network outlining the control of phenotypic variation by environmental and genetic effects (from Monserud and Rehfeldt 1990).

The analyses of Monserud and Rehfeldt left unexplained slightly more than half of the variance in site index. As the authors note, much of this unexplained variance undoubtedly represents mensurational, genetic, and statistical sampling errors. Another portion reflects random genetic, random environmental, and microenvironmental effects. Because of these potential sources of error, the authors acknowledge that it was perhaps remarkable that nearly half of the variance in site index could be accounted for. These results underscore the importance of the genetic system in understanding forest biology. The results aptly illustrate that the forest resource is synergistic: more than the sum of soils, genotypes, or weather, the forest develops from a strongly intercorrelated network of genetic and environmental factors. Monserud and Rehfeldt are currently engaged in determining whether genetic differences among trees within stands can be determined from the phenotype. The results of this study will have obvious practical application in silviculture.

Environmental Change

Because models describe genetic variation in relation to environmental gradients, they can be used to address the effects of environmental change on the adaptedness of populations. The Douglas-fir clines of Figure 1 suggest that populations separated by as little as 650 feet of elevation in the same drainage tend to be different genetically. This amount of elevational difference is associated with a change of about 16 frost-free days (Baker 1944). If, for example, the environment should warm to the extent that the frost-free period increases by 20 days, a different assortment of genotypes would be adaptationally suited to a planting site than are currently suited. This amount of change is roughly equivalent to mean temperatures increasing by 2.4° F. and current elevation zones moving upward 700 feet (Baker 1944). In this eventuality, the distribution of populations genetically compatible with a site at 4200 feet in western Montana is shifted toward the milder environments to northwest and toward lower elevations (Figure 6a). Quite similarly, Figure 6b illustrates the distribution of sources of seed that would be compatible to the same site if the mean frost-free period is shortened by 20 days. Here the shift is toward the southeast and toward higher elevations. These predictions, however, assume (1) the original site will still be suitable ecologically for Douglas-fir after the environmental change has occurred, and (2) the correlation among climatic variables remains unchanged even though the mean may be changing.

Other Applications

As custodians of the natural resource, land managers now are being required to demonstrate that their programs are not allowing the gene resource to erode. Programs and treatments that are compatible with the models of genetic variation spontaneously demonstrate that natural genetic diversity is being promoted. As a result, the models are ideally suited to developing forest plans.

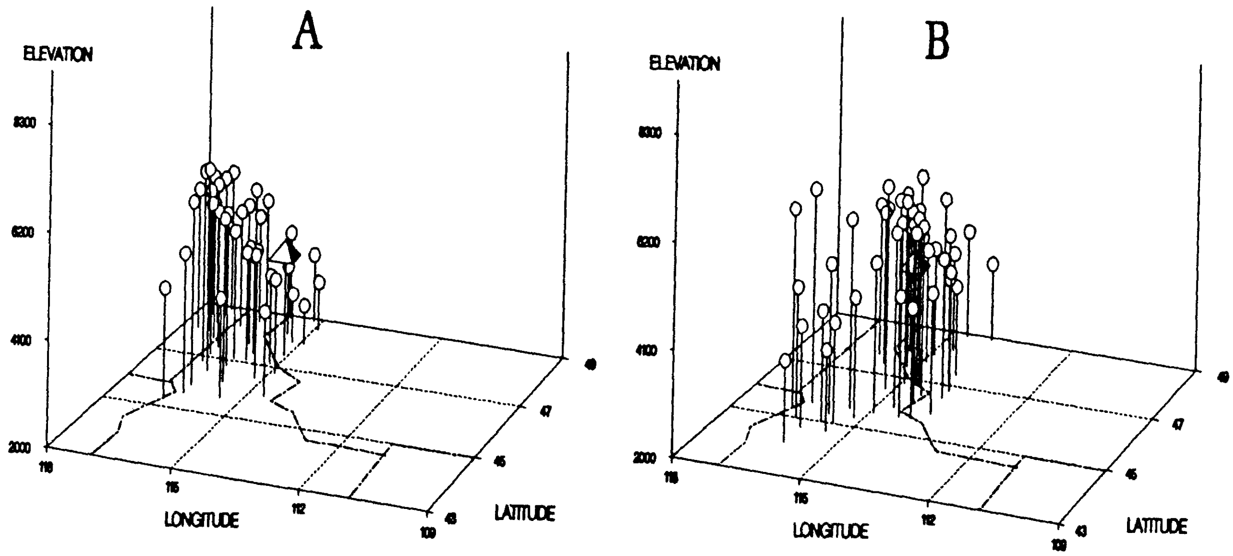


Figure 6. The pyramid locates a Douglas-fir site at an elevation of 4200 feet in western Montana. Bold broken lines on the floor of the diagram outline state boundries. A. balloons locate populations that would be adapted to the site if the frost-free period increased by 20 days. B. Balloons locate populations adapted to the site if the frost-free period decreases by 20 days (from Rehfeldt 1990c).

For economically important species, the models can be used to prepare silvicultural prescriptions. Another application might involve inventorying gene reserves to determine the proportion of the genetic system that is represented by the reserves. And another might be to locate populations that are genetically unique and thereby in need of special treatment. This latter application is illustrated in Figure 7: southcentral Idaho seems to be an area in which the recurrence of genotypes is relatively limited in both ponderosa pine and Douglas-fir. Since one can readily envision catastrophes in which much of a population is lost, programs in gene conservation may be particularly desirable in this area.

For rare, threatened, or endangered species, biologically sound programs of gene conservation will begin after the system of genetic variability is understood. Given the probability of environmental change and the possibility of catastrophe, habitat preservation is insufficient unless adapted genotypes are available. Perpetuation of rare species is determined as much by the system of genetic variability as it is by habitat availability. Minor species of the Interior for which special programs seem desirable include whitebark pine, subalpine larch, yew, Washo pine, Arizona pine and Apache pine.

Regardless of the economic importance of a species, programs that develop in concert with the natural genetic system will reinforce adaptation of populations to natural environments, maintain diversity of the wild gene resource, and support gene conservation.

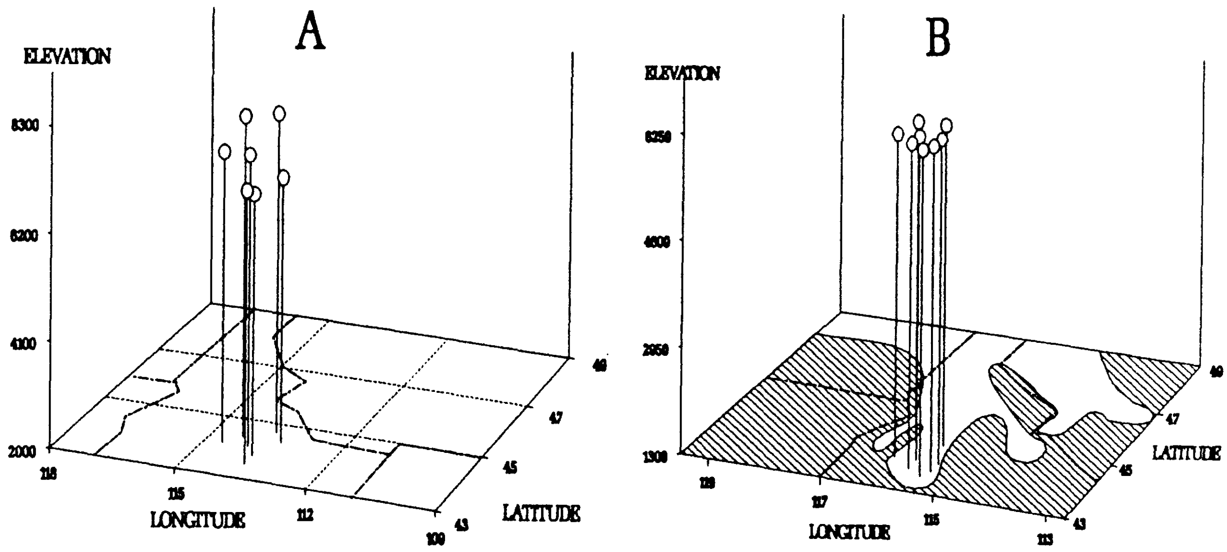


Figure 7. Expected distribution of genotypes for which recurrence is limited. A. Douglas-fir (from Rehfeldt 1990c). B. Ponderosa pine (from Rehfeldt 1990b).

FINIS

Gene resource management thus begins with an understanding of the system of genetic variability. The genetic resource cannot be preserved, conserved, controlled, manipulated, or reconstituted without an understanding of the manner by which species have achieved adaptedness to heterogeneous environments.This is particularly true when dealing with environmental change, regardless of whether the change is stimulated by management, mismanagement or nature.

A rudimentary understanding of the system of genetic variability allows models of genetic variation to be developed. These models are well suited to guiding programs involving the gene resource. The credibility of a model, however, depends on validation. Managers should use unvalidated models with discretion while supporting validation efforts. Credibility of a model also requires that the appropriate species are ecologically suited to those elevations within specific localities for which predictions are made. Thus, data bases must be firmly coordinated with the ecological distribution of the species. For these reasons, predictions made by the present models are best suited to general interpretation, i.e., with regard to the region as a whole.

A plight sorely in need of alleviation is the lack of understanding of genetic variation for all but a few of the economically important species. The lack of knowledge is not insurmountable: much of the work can be accomplished with a five-year testing program that incorporates modern laboratory procedures with common garden tests. Now, in fact, is the time for defining objectives, eliciting support, and implementing the appropriate programs. Until the system of genetic variability is understood, comprehensive programs of gene resource management cannot be implemented.

LITERATURE CITED

Baker, F. S., 1944. Mountain climates of the western United States. Ecol. Monogr. 14:223-245.

Campbell, R. K., 1974a. A provenance transfer model for boreal regions. Norsk Institutt for Skogforskning 31:544-546.

Campbell, R. K., 1974b. Use of phenology for examining provenance transfers in reforestation of Douglas-fir. Journal of Applied Ecology 11:1069-1080.

Daubenmire, R. and J. B. Daubenmire, 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Washington Agric. Exp. Stn., Pullman, WA.

Levitt, J., 1980. Responses of plants to environmental stress. Academic Press, New York.

Monserud, R. A., 1990. An expert system for determining compatible seed transfer locations. AI Applications in Natural Resources 4:44-50.

Monserud, R. A. and G. E. Rehfeldt. 1990. Genetic and environmental components of variation in site index in Inland Douglas-fir. Forest Sci. 36:1-9.

Monserud, R. A., 1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest type. Forest Sci. 30:943-965.

Raymond, C. A. and D. Lindgren, 1989. A model of genetic flexibility. pp. 159-177 In: Lindgren, D. (ed), Provenances and forest tree breeding for high latitudes. Report No. 6. Swedish University of Agricultural Sciences, Umea.

Rehfeldt, G. E., 1984. Microevolution of conifers in the Northern Rocky Mountains: a view from common gardens. pp. 32-46 In: Lanner, R.M. (ed), Proc. 8th North American Forest Biology Workshop, 1984, Utah State University, Logan.

Rehfeldt, G. E. 1986. Development and verification of models of freezing tolerance for Douglas-fir populations in the Inland Northwest. Research Paper INT-369. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 5 p.

Rehfeldt, G. E., 1989. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*): a synthesis. Forest Ecology and Management 28:203-215.

Rehfeldt, G. E., 1990a. Genetic differentiation among populations of *Pinus ponderosa* from the upper Colorado River basin. Botanical Gazette 151:125-137.

Rehfeldt, G. E., 1990b. Models of genetic variation for *Pinus ponderosa* in the Inland Northwest (U.S.A.). Manuscript submitted to Can. J. For. Res.

Rehfeldt, G. E., 1990c. The genetic resource of Douglas-fir in the Interior Northwest. In: Baumgartner, D. M. and Lotan, J. E. (eds), Interior Douglas-fir: the species and its management. In press.

Roberds, J. H. and G. Namkoong, 1989. Population selection to maximize value in an environmental gradient. Theor. Appl. Genet. 77:128-134.

Stettler, R. F., 1990. The global forest experiment. Unpublished lecture presented at the workshop, Ecology of Forest Landscapes of the Northern Rocky Mountains, Missoula, MT, April 8-13, 1990.

U. S. Department of Commerce, 1968. Climatic atlas of the United States. Washington, D. C., U.S. Department of Commerce, Environmental Data Service, 80 pp.

Author

Gerald E. Rehfeldt
Plant Geneticist
USDA Forest Service
Intermountain Research Station
1221 South Main Street
Moscow, Idaho 83843

SINGLE-TREE SELECTION METHOD

Jack Amundson
Intermountain Region
Ogden, UT

In light of new perspectives, new forestry, or other current initiatives, it appears there is a demand for the use of uneven-aged systems. This demand is based upon the assumption all negative connotations associated with even-aged management systems will be completely and forever avoided. From what I observe, many of our publics and internal customers believe that uneven-aged silvicultural systems are the objectives to be strived for. This is absolutely the wrong idea. Uneven-aged systems or even-aged systems are only the silvicultural processes used to achieve more specific forest vegetative management objectives. Too often the process is mistaken for the land management objective. The silvicultural system is the management process whereby forests are tended, harvested, and replaced. Systems are classified according to the method of carrying-out fellings that remove the mature crop and provide for regeneration.

Uneven-aged management is the application of a combination of actions needed to simultaneously maintain a continuous high forest cover by recurring regeneration of desirable tree species and orderly growth and development of trees through a range of diameter or age classes to provide sustained yield of forest products. Cutting is usually regulated by specifying the number or proportion of trees of particular sizes to retain within each area thereby maintaining a planned distribution of size classes. Cutting methods that develop and maintain stands are single-tree selection and group selection.

The single-tree selection method involves the removal of mature and immature trees singly or at intervals. Trees are cut to maintain a desired range of tree sizes, number per size class after harvest, regulate the number of trees per unit area, attain a specific species composition, and with harvest occurring at intervals that are economically feasible. The continuous cycle of removals maintains a sustained yield of products, while the openings created by harvesting provides areas for seedling reestablishment and growth.

Our panel will discuss the silvicultural, genetic, and research implications and applications of the single-tree selection method. **Ron Hamilton**, Silviculturist/Geneticist from the Intermountain Region (Region 4), will present a brief overview concerning the use of single-tree selection. **George Howe**, Geneticist from the Northern Region (Region 1), will discuss the genetic implications of the method. **Jim Baker**, Research Silviculturist from the Southeastern Forest Experiment Station, will provide a research prospective on the single-tree selection method.

Author

Jack Amundson
Regional Silviculturist
Intermountain Region
324 25th Street
Ogden, Utah 84401

SINGLE-TREE SELECTION METHOD
AN UNEVEN-AGED SILVICULTURE SYSTEM

Ronald C. Hamilton
Intermountain Region
Ogden, UT

BASICS AND DEFINITIONS

To understand about the single-tree selection regeneration method, we need to understand from where it is derived. Basically it is a forestry term, and forestry, as F. S. Baker in 1950 pointed out, is "the scientific management of forests for continuous production of goods and services." Baker also pointed out it was essential that forestry be both biologically and economically sound. The basis for handling the forest was the application of silvics, whose methods, modified by economics, is silviculture.

Silviculture defined for all forest resources is "the science and art of managing forests to meet resource needs, no matter the resource or management objective—be it esthetics, water, timber, wildlife, or recreation—silvicultural practices are the driving force, the means used to achieve the desired end" (Schmidt 1990). The silvicultural system is a process, with all its attendant practices and treatments, necessary for replacement and development of the forest stand. Silvicultural systems are defined by the harvest cutting method that characterizes each system (Burns 1989).

The Individual (Single) Tree Selection Method involves the removal of mature and immature trees singly at intervals. Regeneration is established almost continuously. The objective is the maintenance of an uneven-aged stand, with trees of different ages or sizes intermingled (Burns 1983). In this method, mature and immature trees are cut to maintain a desired range of tree sizes or diameters over a prescribed distribution, regulated by the number of trees per unit area, with a specific species composition, with regular harvests to control the structure and provide the openings necessary for establishment and growth of the continuously occurring regeneration. In practice harvest (cutting) cycles are established to accomplish the above actions. Their frequency is dependent on the productive capacity of the sites, the silvics of the species present, and desired economic considerations and management objectives.

With the single-tree selection method, each tree is evaluated based on its silvicultural condition—age, merchantability, health, seed production capability, and potential—to survive and meet the objectives until the next treatment. In addition, it is evaluated relative to the desired level of stocking and its size. Removal of this single-tree creates a small opening in the stand similar to natural mortality. The resultant regeneration normally favors shade tolerant species, rather than species that require partial or full sunlight to grow and regenerate.

The forest created by the single-tree selection method has, in close proximity to each other, trees ranging from the largest sizes to the smallest seedlings. The canopy of such a forest is relatively irregular and rough, but is mostly continuous with only small openings present. Vertically the stand area is generally closed at all times providing what appears to be a high level of site protection from the forest canopy.

In theory, the single-tree selection method has a 3-step process that must be applied following the choice of a suitable stand on which to employ the method. A principal step that must be taken *before* any of this is undertaken—**determine what the management objectives are for the stand and ensure that single-tree selection is the appropriate method of choice.** The resultant stand should conform to the desired future condition for the area. The first decision following the above evaluation is to determine the appropriate residual stocking rate to remain following cutting. It must be appropriate to the site's quality and management objectives. The next step is to determine what the maximum tree size is to be left after each cut. Third is the development of a diameter distribution goal necessary to regulate the harvest and yields from the stand. The kind of diameter distribution must be evaluated to determine the ratio among ages or size classes. Harvesting of growth and regulation of the diameter classes is performed by a series of cutting cycles applied at frequent intervals. These operational steps and their method of development provide the essential differences between the methods of uneven-aged silviculture (Alexander and Edminster 1977, 1978; Gibbs 1978; Graham 1983; Leak 1978).

PRACTICE AND APPLICATION OF THE SINGLE-TREE SELECTION METHOD

Based upon plans completed during the current episode of forest planning, uneven-aged management will be applied on many National Forests. Hopefully, that choice was based on meeting resource values requiring continuous forest cover, combined with an assurance of a capability to successfully apply the method. Regions generally established through analysis tools standards and guides, which caused the selection of this silvicultural system. Appropriate management application also requires the control of species composition, forest structure and resource yields in the long run, to reach the desired future conditions that are the long term goals. Management objectives and the silvicultural practices and methods that implement those short run changes are the tools of the manager. To make a proper application it is important to understand the method of choice and its practical application (Minckler 1974).

An obvious essential in the choice of applying the single-tree method is a determination that the management objectives and the desired future conditions described for the area to be managed really call for the practice. As will be illustrated later, the method has many more difficulties in its application, suitability, cost, and difficulty to regulate than any other silvicultural method (Marquis 1978; Roach 1974).

Before proceeding with the application of the method, it is essential to assess the forest management goals carefully, assessing current forest structure, species mix, ecosystem circumstances, and general health situation. Apply carefully the prescription tailored to the specific site to achieve the results appropriate to the requirements of the species (Alexander 1977).

Of foremost consideration in applying single-tree selection are the present species mix and present diameter and age distribution of the stand. While the method is said to be applicable to nearly any stand, the conversion process is very difficult if stands are not already multi-aged. Stands should be of good vigor and not highly defective.

In order to assess this, our first actual step in the application process is a stand inventory or examination. This normally entails collecting data to determine basal area, number of trees by size classes and species groups, and assessing each tree's relative health. It is also important to evaluate, over the stand, the arrangement of size classes. By evaluating this data, a determination of suitability for applying the single-tree method can be made.

Following the decision that the stand or area has the suitability and capability for management using the single-tree method, a series of choices must be made to implement the action. It is essential to begin by carrying out the steps mentioned above. I will deal with each of these as if a silvicultural prescription were being made, pointing out some concerns and pitfalls while dealing with practical variations in the application.

The first decision to be made in applying the single-tree selection method to a stand is choosing the residual stocking level to be retained after harvest. A well known yield principle is that stand growth varies only slightly over a moderately wider range of stocking levels (Marquis 1978). If a stand were cut back to within 60 percent of full stocking (obtained from yield tables), total growth will be the same, only it will be concentrated on fewer trees. In order to choose the best level of stocking, species, sizes of trees present, the diameter distribution, crown volume, age relative to senescence, and other tree-within-stand factors should be considered.

Some current residual stocking guidelines exist in the form of basal area for many stands. Unfortunately many are derived from even-aged stands. For the west, special stocking levels developed from uneven-aged stands are not available. This is important and is something that needs future monitoring and evaluation. A range of 70 to 85 square feet of basal area stocking rate is recommended for a variety of central and southern Rocky Mountain types (Alexander and Edminster 1977), and northern hardwoods in New England and the Appalachians (Leak, *et al.* 1969). The range covers fair to good sites. For northern hardwoods in the Lake States, 80 to 90 square feet of basal area residual stocking is recommended (Gingrich 1978). Graham and Smith (1978) have recommended a wide stocking rate range from 60 to 175 square feet per acre for the northern Rockies. It may also be possible to evaluate the range of potential stocking levels by reviewing the habitat type data, available over much of the west, to determine the basal area levels of these stands which are approaching climax. While the data may be from natural stands with less than desired structure and appear questionable, it often is the only thing available. Remember to reduce these upper levels some 50 to 70 percent of the maximum upper limit to allow growth. As Marquis (1978) points out, when a range of values is given, it is often recommended that a high stocking value be used in heavily stocked, previously uncut stands and the lower values be used when some stand management has already been applied.

Another alternative for establishing the stocking level is to utilize the Gingrich (1978) or National Forest format stocking guides. The upper stocking level would be the normal or average maximum density line values depending on tree size. The target could be as low as 70 percent of the AMD line.

In order to maintain any intolerant or evenly moderately tolerant trees in the stand, it will be necessary to maintain stocking rates at a much lower level. Roach (1974) and others have developed stocking guides that consider species in setting a stocking level.

The second decision to be made in the single-tree selection method is in two parts; both must be considered together as they are closely linked. They are also linked with the first decision. One decision to make at this point is the maximum tree size at dbh that will be retained after harvest. This number must be determined to satisfy a couple of considerations, one being biologically defined, the other economically.

The maximum tree size should consider several biological factors. Site quality is extremely important as the rate of diameter growth per unit of time must be considered as a minimum against bio-senescene rate for the species managed. Short lived hardwoods and conifer species may have a maximum size of 16 to 18 inches, while long lived and fast growing trees may be as large as 30 inches or more.

An important economic consideration is the species importance to forest uses other than timber production. In some areas, value is added to the property based upon the size and arrangement of the trees on the site. Very large trees are particularly useful in recreational property, providing a secure or ethereal feeling to the site. Assignment of an economic value is very difficult.

Another excellent guideline for making an economic decision about the maximum size is obtained from financial maturity data. For some eastern hardwoods this data is available in the table.

Table 1.–Maximum size trees for various rates of return, species and site index (from Marquis 1978)

	2 Percent			4 Percent			6 Percent		
Species	Site index for oak								
	80	70	60	80	70	60	80	70	60
Yellow-poplar	26	26	24	20	18	18	18	18	18
Beech	24	22	22	20	18	18	18	18	18
Black cherry	32	30	30	22	20	18	18	18	18
Red maple	32	30	30	22	22	18	18	18	18
White ash	30	28	28	22	20	18	18	18	18
Sugar maple	32	32	30	22	22	18	18	18	18
Red oak	26	26	24	22	22	20	20	18	18
White oak	24	22	20	20	18	18	18	18	18
Chestnut oak	24	24	22	20	18	18	18	18	18
Other long-lived species	26	26	24	20	20	18	18	18	18

Normally, species that have little value added per unit of diameter have small maximum diameters due to exponential form of the rate of return function. However, species that have both grade recovery increases and increased use efficiency with size will often have sizes greater than 20 inches.

Several computer simulations capable of dealing with uneven-aged management and economics are currently available to make that assessment (Hann and Bare 1979). The models, however, are relatively cumbersome to utilize and interpret. For that reason, field useage is expected to remain limited except for broad levels of forest planning.

The last part of the second decision step deals with choosing a balanced diameter distribution goal. The balance in the size (age) class distribution provides the conditions for regeneration growth and individual tree attribute development while sustaining yield rates. The methods are: 1) Weibull distribution—using both flexible form for a variety of diameter distributions or a sigmoid form that is fitted by polynomial or non-linear regressions; 2) empirical form, where numbers over size are built from field data; 3) power function, where number over size is plotted on log/log paper, or the commonly referred to 4) "q" which implies a negative exponential distribution where the logarithm of stem number over size plots as a straight line ("q" being a diminution coefficient).

As indicated, a "q" based diameter distribution is most often used. The common "q" method develops the distribution of size classes using a geometric progression, which is a ratio between number of trees in each succeeding size class. This ratio is "q" or may be referred to as deLiocourt's "q". The number of trees in a size class multiplied by the "q" results in the number in the next smaller size class. The maximum diameter establishes the limit for "q".

An important consideration in setting a "q" is its influence on the number of large and small size classes regardless of the maximum diameter established. For example, setting a "q" (by 2-inch diameter classes) with a small value will cause a large proportion of the growing space to be devoted to larger trees. A high "q" value means that stands will have many small trees.

It is extremely important in management to develop "q's" for stands that fit with their current structure. Establishing a "q" goal such as 1.3 for a developing stand with a current "q" of 1.9, with few large diameter trees, would mean heavy removals of trees with high growth potential and low economic value, plus a non-commercial thinning in the remainder of the stand would usually be needed. The "q" may need to be changed during the time period when a stand is first being brought under management. The stand can then be gradually worked toward a desired "q" with some shortened cutting cycles.

Figure 1 illustrates how an initial target "q" was developed. Three harvest cycles later, the optimum stocking curve is closely approached. Note that a substantial shifting of "q" was not needed (from Daniel, Helms and Baker 1979).

It is pointed out by a number of authors that silviculturists often try to obtain a low "q" of 1.3 to 1.5 (2-inch class) in order to maintain a high proportion of sawtimber. However, it is more important to encourage sawtimber by reducing mortality and increasing growth of smaller and larger sawtimber trees. In some cases it may be appropriate to use a proportionate or dual "q" value for sawtimber sizes while pole through seedling sizes have another. This would allow retaining a "q" of 1.3 for the sawtimber and a 1.5 for the smaller sizes. This could account for logging damage as the regeneration and smaller trees enter the next "q" goal while maintaining high value growth on the sawtimber components.

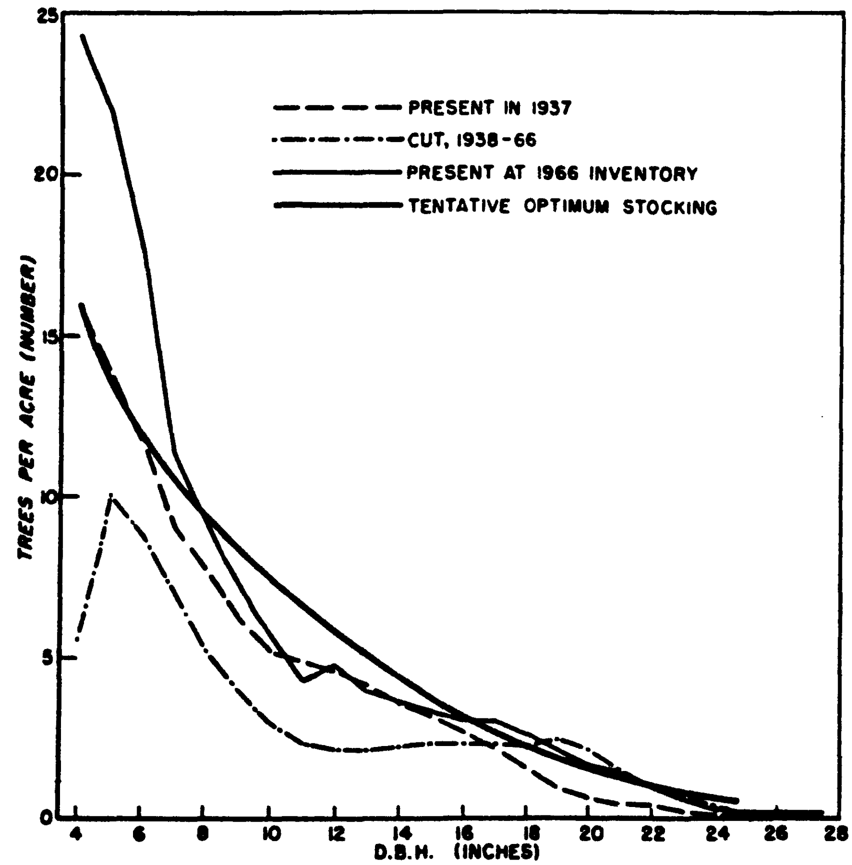


Figure 1. Uneven-aged management of loblolly and shortleaf pine mixture at Crossett, Arkansas, showing the production and change in numbers of trees in the various diameter classes over the 29 years of the study with a "q" value of approximately 1.25 for the optimum stocking curve.

Above all, it is VERY IMPORTANT to remember that all size classes must be controlled to meet their target diameter distribution. This means that regeneration to be added to the seedling portion must be assured to meet the future stand structure size distribution. It may be necessary to perform cultural work in the other size classes to avoid excessive numbers in the diameter distributions. If you assure that the residual growing stock distribution is appropriate on the various areas to be treated each cutting cycle, yields will normally take care of themselves.

A "q" value range has been determined for a number of species in unmanaged forest-cover types. These values will be helpful in setting initial goals for the single-tree selection method.

Range in "q" Values for Various Unmanaged Forest-Cover Types

Type	q Value (approximate)	Author
Ponderosa pine in Southwest (densities from 30 to 100 ft^2 per acre)	1.24	Schubert 1974
Northern hardwoods in New England	1.2-1.8	Solomon 1977
Engelmann spruce-subalpine fir, Utah	1.24-1.54	Moore 1964
Engelmann spruce-subalpine fir, Rocky Mountains	1.3-1.5	Alexander 1977
Loblolly pine-shortleaf pine, Arkansas	1.25	Reynolds 1969
Mixed-conifer type, California	1.3-1.5	Grah 1977
Grand fir-cedar-hemlock (Idaho)	1.1-1.5	Graham-Smith 1983

(From Daniel, Helms and Baker 1979, and others)

The last decision and one unique to the selection system is determination of the cutting cycle. This harvest and stand treatment interval will depend on the degree of management desired and the economics of the operation. A short cutting cycle, in the 10- to 15-year range, usually gives a small periodic harvest, except in very rapidly growing or short-lived tree species. Such an entry usually leaves more residual grow stock, also. The determination of this cycle length is very dependant on the growth projected for the stand as well as how commercial the entry is. Short cutting cycles often allows the capture of almost all mortality, allowing the harvest of poor risk trees before they die. Such a strategy is useful to minimizing the potential for insect or disease epidemics.

Short cutting cycles are often necessary during the conversion period in previously unmanaged stands. Frequent light entries in stands of larger trees reduces the loss to windfall from wide spacings. It also allows the transition and development of leaf and needle components to better tolerate full or partial sunlight, thus reducing sunscald and leaf drop problems from exposure to high levels of sunlight.

Frequency of seed production and regeneration establishment should be a consideration in cutting cycles. The forestation requirement of NFMA on some sites with periodic cone cycles greater than 5 years may require that sufficient regeneration occur prior to harvesting to complete regeneration portion of the diameter distribution.

A cycle length of 40 years is considered long and normally should only be used where a large maximum tree size is established. Long cycles with heavier density manipulation may also be used to help maintain less tolerant species in the stand. The greater harvest volumes, reducing residual stocking, may be the only way to create openings with sufficient sunlight to obtain these species. A rule of thumb to help determine the cutting cycle length is to assure that a minimum of 5 cycles occur over what would be considered a normal even-aged rotation period for that species.

The cutting cycle will obviously have a strong influence on the diameter distribution and residual stocking level established for the stand. Trees must be allowed to grow into the appropriate diameter classes based on the intervals between treatment. A 30-year cutting cycle may require that the stocking reduction be near 60 percent of full stocking while, with a 15-year cutting cycle, 75 to 80 percent of full stocking may be the level maintained. It is important to use growth simulations or projection systems to help establish the growth rates.

An economic assessment that evaluates the break-even point of the harvest practices used will also help establish the economic cutting cycle. This will vary by the "q" or number of trees removed by diameter class. Large trees with large piece sizes (logs) with fixed costs per unit of handle such as skidding, loading, or felling, normally would encourage longer cutting cycles. If, for example, skidding practices can have costs per unit handled reduced, an adjustment could be considered in the cutting cycle if economics was a consideration when it was determined.

So far, any discussion has generally set out the general procedures and practices to be followed in order to implement the single-tree selection method. It has been clear that this method is probably one of the most restrictive regeneration methods available. There are some alternatives that are considered acceptable in applying the decisions outlined above. The common variations have been discussed. There are others.

An alternative method for controlling the stocking level and the diameter distribution is the use of Reineke's Stand Density Index (SDI). Long and Daniel (1990) indicate that the establishment of a "q-factor" with its resultant residual basal area growing stock level has two "major" limitations: 1) excessive number of small trees dictated by strict application of a "q" factor, and 2) difficulty interpreting growing stock and basal across a broad range of diameters.

The relative mean size and density of individuals experiencing self-thinning is predictable and the basis of an index number, such as SDI. The indexes of this relationship are independent of site quality and stand age. Conceptually, the SDI of an even-aged stand is the number of trees per acre (TPA) based on the quadratic mean diameter (Dq) of 10 inches [see (1) below].

$$\text{SDI} = \text{TPA}\ (\text{Dq}/10)^{1.6} \quad (1)$$

The calculation of SDI is independent of species. However, each species has a maximum level. It is very useful to express as a percentage of maximum (%SDI) various values in the development of a stand. For example, 25 percent of maximum is the onset of competition (crown closure), 35 percent the lower limit of full site occupancy, and 60 percent the onset of self-thinning.

These levels are useful to determine target levels for growing stock. When using SDI, it can be assumed that the index is proportional to site utilization. Since the contribution of individual stand components to both SDI, hence site utilization, is additive, SDI can be used to assess control of growing stock in uneven-aged stands. Long and Daniel (1990) suggest the expression as:

$$\text{SDI} = \sum (\text{DBH}_i/10)^{1.6}$$

Where DBH_i is the diameter of the $_i$th tree in the stand.

It is less accurate to calculate component SDI's for larger diameter classes rather than individual size classes, but bias is not a practical concern when the diameter classes are broad and application to strict standards is very difficult. For uneven-aged stands, there are two reasons why it is necessary to estimate SDI by summation of individual tree or diameter class SDI's: 1) Equation (1) is inappropriate for the skewed diameter distribution typical of uneven-aged stands; 2) It is not just the stand level total that is important in uneven-aged stands, but the way the stock is distributed or partitioned among size classes.

Long and Daniel (1990) provided an example of southwestern ponderosa pine from Schuburt managed to a "q" of 1.5 and 80 square feet per acre basal area stocking level. The 2-inch classes were divided into 5 diameter groups. The regeneration group (0 to 1.9 inches DBH) is not shown because it would be regenerated after harvest of the mature crop (Table 2(A) and Table 2(B)).

Table 2(A). Trees per acre and SDI, by 2-inch diameter classes; total basal area is 80 ft^2/ac and the Q-factor is 1.5 [after Schuburt 1974 and Long and Daniel 1990].

DBH class (inches)	By Class		By Group	
	TPA	SDI	BA	SDI
2	92.5	7.0		
4	61.6	14.2	15.5	41.7
6	41.1	18.2		
8	27.4	19.2		
10	18.3	18.3	29.1	54.2
12	12.2	16.3		
14	8.1	13.9		
16	5.4	11.5	22.6	34.8
18	3.6	9.2		
20	2.4	7.3		
22	1.6	5.7	12.8	17.3
24	1.1	4.2		
Totals	275	145	80	148

Table 2(B). Trees per acre and SDI, by 2-inch diameter classes; total basal area is 80 ft^2/ac and the Q-factor is 2.0 (from Long and Daniel 1990).

DBH class (inches)	By Class		By Group	
	TPA	SDI	BA	SDI
2	308.1	23.5		
4	154.0	35.6	35.5	98.7
6	77.0	34.0		
8	38.5	26.9		
10	19.2	19.2	31.5	59.6
12	9.6	12.9		
14	4.8	8.2		
16	2.4	5.1	10.6	16.5
18	1.2	3.1		
20	0.6	1.8		
22	0.3	1.1	2.6	3.5
24	0.2	0.8		
Totals	616	172	80	178

The above Table 2(A) and Table 2(B) illustrates that the diameters are not apportioned relatively equally. Most of the concentration occurs in the small size classes. Choosing a "q" of 2, nearly 88 percent of the trees and 55 percent of the SDI are in the smallest diameter group. The resultant SDI shift from the "q" 1.5 to 2 was a 20 percent increase in total SDI. Long and Daniel (1990) infer a very inefficient financial management situation with a high "q."

Table 2(C). Trees per acre and SDI, by 2-inch diameter classes; total SDI is 149 (approximately that of the stand represented in Table 2 (A)).

DBH class (inches)	By Class		By Group	
	TPA	SDI	BA.	SDI
2	39.4	3.0		
4	30.3	7.0	8.4	22.1
6	24.9	11.0		
8	20.0	14.0		
10	14.0	14.0	22.9	42.4
12	10.5	14.0		
14	8.2	14.0		
16	6.6	14.0	27.6	42.2
18	5.5	14.0		
20	4.6	14.0		
22	4.0	14.0	31.4	42.1
24	3.4	14.0		
Totals	171	147	90	149

Table 2(C) is an alternative for apportioning growing stock among diameter groups on an SDI basis. The maximum SDI for southwest ponderosa pine is 450. Schuburt recommended approximately 33 percent for the lower limit. Note that most of the SDI is allocated between the 8-inch and 24-inch diameter group. However, the submerchantable diameters contain over 50 percent of the trees per acre with less than 15 percent of the total SDI target. This appears to be a sufficient number to ensure against treatment loss. An important consideration in setting the stocking level is the management objectives. The SDI of 149 does not approach full site occupancy, but may be meeting some other resource objectives. A higher SDI could be set if cutting cycles were shorter and the objective was to grow more trees of the diameter groups more slowly. If the diameter objective were lower, it might also be important to shorten cutting cycle length and increase the level of SDI both in the smaller diameters and large diameters to capture growth and insure enough regeneration to cover logging damage.

Leak and Gottsacker (1985) discuss a variety of alternatives in applying the single-tree selection method. They reported that in small sawtimber or cutover hardwood stands that a "q" of 1.3 was "impractical and discouraging." It influenced logging economics and that "q" did not necessarily produce good growth responses in second-growth stands. Stands with 30 to 45 percent sawtimber produced as much or more net growth as 60 percent sawtimber stands. Their recommendations in stands with greater than 20 square feet basal area residual sawtimber was a 60 square feet/30 percent sawtimber relationship in developing the "q."

The same report by Leak and Gottsacker suggests using a range in residual diameter distributions for hardwood stands in terms of basal per acre by 3 diameter groups (See Table 3).

Table 3. Recommended residual diameter distributions for northern hardwoods in basal area per acre* by dbh group, and Q (quotient between number of trees in 2-inch dbh classes).

Dbh group (in)	Q 1.7	1.5	1.3
6-10	40	32	23
12-14	20	21	21
16+	15	22	31
All	75	75	75

*Recommended basal area varies depending on the chosen maximum-size tree.
This table is based on a 20-inch maximum tree size.

A similar approach is used for mixed wood stands, except a higher residual basal areas per acre, was suggested. These flexible guidelines on diameter distribution with less emphasis on percentage of sawtimber in the residual stand was caused by: 1) simulated stand dynamics indicated a sigmoid form of diameter distribution was more natural and economic; 2) diameter growth was found to decline rapidly with increased tree size objectives on mediocre sites; and 3) the diameter distribution is to maintain a sustained flow, but control is really exerted over many stand areas to make up such a sustained yield unit.

While there are several ways to calculate desired diameter distribution based on the residual basal area, maximum tree size, and "q's", Tubbs and Oberg are reported by Graham and Smith (1983) to have the simplest method. They develop a coefficient for 2-inch diameter classes called a "k" factor which depends on the desired "q" and maximum tree size (see Table 4).

Table 4. K-coefficient for a given maximum diameter and q-factor.

Maximum Diameter	Q-factor 1.1	1.2	1.3	1.4	1.5	1.6	1.7
24	18.5	24.8	34.3	48.1	68.0	97.3	139.3
22	14.0	18.2	24.0	32.1	43.4	58.9	80.1
20	10.3	13.0	16.4	21.1	27.2	35.2	45.6
18	7.4	9.0	11.0	13.5	16.7	20.6	25.5

From: Tubbs and Oberg 1978.

The desired residual basal area is divided by the "K" factor to get the number of trees in the largest 2-inch diameter class (N). Each "N" is then multiplied by the applicable "q" to find the number of trees in the next smaller size class, which in turn is multiplied by the "q" to find the number of trees in the next size class and so on, to the smallest class. For example:

q-factor	1.3
Residual basal area	80 sq. ft./A
Maximum tree size	24 inches

Therefore:

K-factor: 34.3 (from Table 4)
N = 2.33 for the 24-inch class
N = 3.03 for the 22-inch class
N = 3.94 for the 20-inch class
N = 5.12 for the 18-inch class

N = 41.78 for the 2-inch class

A method often thrown up as an alternative or comparable to the single-tree selection method is selection cutting or selective logging. It somewhat fits the definition in that a tree at a time is cut but its purpose is mostly economic gain. Primarily the largest and best trees are cut (high grading). Regeneration is not a principal concern or an objective. Many people still use this term interchangeably with the selection silvicultural system. They are not the same or even remotely similar (Gibbs 1978).

Diameter limit cutting is another method that occasionally is identified as a selection silviculture method because only trees to certain size limit are harvested. This emulates the single-tree method only in that it harvests trees to a maximum size level. However, it usually is not concerned about maintaining a diameter distribution and residual stocking level unless the normal practice is dramatically modified. Diameter limit cutting is more apt to fit in the intermediate stand treatments associated with even-aged silvicultural systems. Jim Baker (in the proceedings) explains a diameter limit system that qualifies as a single-tree method selection system because of the structure, stocking, and goals of the treatment.

The single-tree selection method is regarded as the ultimate ideal for the extreme advocates of the naturalistic doctrine of silviculture. As such, the alternatives in the method are quite limited. Only variations to the decision variables are considered acceptable variations.

PRESCRIPTION AND MARKING

If the management objectives indicate the desired future stand conditions could be best met with the selection silvicultural method, a diagnosis of the examined stand will be necessary along with an evaluation of the resource needs, to finalize the decision. The decision should also be based upon an evaluation of the natural processes that govern stand structure and development. As Naumann (1987) has pointed out for ponderosa pine in the northern Rocky Mountains, "in spite of variability in age and stand structure induced by natural disturbances, the trend for uniformity seems apparent." It is possible through management practices to meet many of the vegetation conditions using something other than the single-tree selection method. The stand must be capable of having the method applied and meeting the management goals in the long run.

Following the analysis of the objectives and of the stand structure, a stand prescription and marking guide can be prepared. It is important here to analyze the stand's basal area against residual basal area desired, and the actual diameter distribution against the ideal after harvest to determine if a modification of the distribution is necessary. Next assess the actual diameters and maximum diameter to see if the goal is capable of being met. A marking guide can now be developed that targets the basal area to be retained, the maximum tree size goal, the goals of species composition, tree numbers, and basal area for each diameter class or group that harvesting or stand treatments will influence. It must also be decided how to handle the less than commercial tree portions in the stand. Assess the problem of not treating these non-commercial tree sizes and the influences they will have on the future stands.

It is extremely important to develop excellent marking guides and controls because marking the single-tree method is more difficult than any even-aged system. This is primarily because the markers must continually account for diameter distribution, juxtaposition as well as density, species, quality, spacing, and other prescription requirements in the stand.

In order to maintain control of markers, here are some suggestions:

1) Use a small 2- or 3-person crew for easy communications.

2) Group the diameter distributions into 3 or 4 sections depending on the maximum size objective.

3) Use the prism plot, verify stocking and diameter distribution frequently against the diameter distribution group basal area target or species composition or defective and high risk trees. It is important that marking guides be developed from good stand examination or inventory data to ensure targets can be achieved. This is often a major weakness in applying the method. Examinations are often not done to reduce costs.

4) The markers should check frequently against a basal area standard with prisms, especially when starting.

5) Develop a check card or other tool to allow rapid reference to stocking levels.

6) Develop a few training plots with known inventories and verify marking against prescriptions developed or marking guides made.

Remember that timber markers familiar with marking even-aged stands will have little idea about marking a single-tree selection method stand. They must receive training in this method's application (Marquis 1978).

How should you control the non-commercial diameter distribution portion of the single-tree selection method? In theory all ages or sizes must be controlled just as regeneration attainment must be continuously occurring at each entry. In practice, however, controlling this distribution is a costly and time consuming project. In the past, the lack of control in this portion of the timber stand treatment has been responsible for the lack of success of this method. Optimum spacing is essential for rapid development of crop trees and maintenance of appropriate crown ratios. Equivalence of competition is essential to the production of appropriately proportioned tree boles free of crook, and concentric in form so that quality lumber may be sawn and so trees can withstand winds.

For pole-sized white spruce, optimum growing space is created by releasing trees from competitors on at least three sides. Retention of high numbers of trees in a western hemlock stand could encourage slow healing of shade-killed lower branches, thus leading to a high infection chance by Indian Paint fungus (McCaughey and Ferguson 1988).

Some authors encourage the control of non-commercial sizes with the logging equipment during harvest. Such a non-selective practice may be practical when numbers are extremely high, but provides little toward selection of appropriate future crop trees. Generally, the allowance of loggers to do this type of damage should be discouraged. In general, logging damage is one of the biggest problems in executing the single-tree selection method (Laacke and Fiddler 1986). Much of the current literature indicates that proper choice of leave trees in the stand has a very strong influence on the genetic structure and character of the populations in the stand, greatly affecting the future. It is best to plan, control, and execute a cultural (thinning) treatment following harvest to effectively control the unmerchantable size group developing an appropriate diameter distribution. It may not be necessary to control the less than 2-inch diameter group because of their high susceptibility to loss.

Planning for the logging of the selection-method treated area is very essential to aid in the control of logging damage. It is essential to plan the transportation system including the skid trails and other roads developed to harvest a land area. That planning of necessity will be toward developing the appropriate protection from construction damage. The methodology of logging, equipment, and operator skill will be paramount in effectively carrying out the treatment. Single-tree selection has a high damage potential from logging because of multiple tree sizes located adjacent to each other.

Much of the control of damage potential in the logging operation starts with correcting poor felling practices. Poor practices often accelerate the damage from skidding operations by several times. Controlled, directional felling is often needed. By placing the tree with the proper lead, equipment maneuverings are reduced. Scrapes to the bole and limb breakage must be avoided during both of these operations to reduce future problems with heart and root rot fungi (Laacke and Fiddler 1986; McCaughey and Ferguson 1988).

Steep terrain or rough topography results in severe damage from most logging methods. In such terrain, it is not appropriate to apply such a treatment as the single-tree selection method. Only when specialized equipment, such as helicopters or other aerial skidding and yarding systems, can be used should such a management program be considered. Such systems are very expensive. However, when high value species or special resource values are involved, the expense for protection of other resources may make it worth considering.

REGENERATION

Uneven-aged management, especially single-tree selection, has been used consistently with the regeneration of shade tolerant or moderately tolerant species (Leak and Gottsacker 1985). In many parts of the United States, but especially in the west, the most tolerant species are, unfortunately, often the least desirable from the standpoint of usefulness for forest products and other resource values (Franklin 1978; Tubbs 1978).

Much of the information on the regeneration of species is found in a series of publications, Ag. Handbook 445 [Silvicultural Systems for the Major Forest Types of the United States (USDA 1983)], Silvics of Forest Trees of the United States (Folwells 1965), the Scientific Basis for Silvicultural and Management Decisions in the National Forest System (Burns 1989). A series of "status" publications for several species from the Rocky Mountain Station, plus silviculture guides from Northeastern, Northcentral Stations and several western species symposium proceedings publications have duly amplified the knowledge base for several species and their requirements for successful regeneration.

Unfortunately some of the best regeneration tidbits are often salted away among other information. Gleaning and utilizing the information in its ecological setting is still often difficult to do, but this is the essence of the application of silviculture.

I will not try to assimilate all the U.S. information on regeneration of the species but will simply say it is essential that the silviculturists in their areas do that. Let's face it, there are enough mistakes to learn by if we will but look. Unfortunately, I believe A. P. Mustian (1978) is correct when, in dealing with a historical recounting of the practice of uneven-aged silviculture, he pointed out that "either we cannot or will not learn from history or the experience of others." I echo that.

Numerous authors indicate that most species in the Northern Rocky area developed with frequent low intensity fires and are adapted to that regime (Naumann 1987; Lilieholm, *et al.*, 1990). Those species with that adaptation are very unlikely to succeed in a single-tree selection method where fire seldom is capable of being used. A rating system (Table 5) is provided that was developed by Graham (in process) for many of the northern Rocky Mountain species. The factors are shown that are considered to be important in determining their appropriateness for single-tree selection. The list is very useful in evaluating potential regeneration capability when planning.

Additions to that list taken from Gordon (1978) that add or supplement the elements in the table are:

a) prevent the destruction of healthy seedlings.
b) wind and shade patterns in relation to seed dispersal.
c) potentially competitive plants.
d) seed crop frequency; production may be high only infrequently.
e) seed bed requirements, soil, rotted debris, and allelopathy or similar pathogen reactions.
f) timing of moisture, drought events, is it critical.
g) predation.

Along with the list in Table 5, these factors are nearly all inclusive.

Table 5. Relative rating of species in northern Rocky Mountain forests. A rating of 1 indicates maximum expression of the property (Graham, in process).

	Species[1]									
Property	PP	DF	WL	LPP	GF	WWP	WRC	WH	ES	SAF
Seed Production	10	6	5	3	7	4	2	1	9	8
Seed Size	1	5	8	6	2	3	10	9	7	4
Seed Viability	4	1	5	2	1	8	9	6	3	10
Seed Predation	1	3	5	4	7	2	10	8	9	6
Shade Tolerance	8	6	10	9	3	7	1	2	5	4
Ecological Amplitude	4	1	2	3	6	5	9	10	7	8
Successional Status	CS[2]	CS	S	S	CS	S	C	C	S	C
Initial Growth	3	5	1	2	6	4	10	9	7	8
Volume Growth	7	5	3	6	2	1	10	9	4	8
Mature Height	4	5	1	10	3	2	9	7	6	8
Longevity	4	7	2	10	5	3	1	8	6	9
Resistance To:										
Root Disease	5	8	3	6	10	4	2	1	7	9
Heart Rots	5	7	1	2	9	3	6	10	4	8
Insects	6	10	5	8	4	7	1	2	3	9
Fire	2	3	1	5	4	6	7	9	8	10
Windthrow	3	8	1	9	6	4	2	5	10	7
Value	3	4	5	7	8	1	2	9	6	10

[1] PP=Ponderosa Pine, DF=Douglas-fir, WL=Western Larch, LPP=Lodgepole Pine, GS=Grand Fir, WWP=Western White Pine, WRC=Western Redcedar, WH=Western Hemlock, ES=Engelmann Spruce, SAF=Subalpine Fir.

[2] C=Climax species, S=Seral Species

The learning process by practitioners about factors influencing regeneration is still occurring. For example, Leak and Gottsacker (1985) indicate that regeneration occurrence of tolerant species is strongly influenced by site or habitat. Sandy till soils will, in New England, regenerate abundantly to beech or red-maple under single-tree selection; on fine-textured soils a significant proportion of sugar maple will occur; excessively wet, dry, or shallow soils will regenerate with conifers. Associated understory mosses are considered important to the regeneration of Rocky Mountain Douglas-fir according to Steele and Geier Hayes (1987). The structure of some early seral moss species allow seed to be imbedded and surrounded by a moisture supply taking them away from most predators. However, the moss species changes without disturbance, advancing successionally to a flat mat-form species that almost rejects the seed, making it impossible to reach the soil and an adequate moisture supply. Some alleleopathy by moss and other plants is also suspected. These above examples should make it very clear that the species, amount of regeneration, and long-term success must be specific to each site and an appropriate prescription level. It must be determined in the silvicultural prescription how the site must be prepared and the timing of that treatment.

However, we do run into a problem of varying proportions in some areas in complying with the National Forest Management Act with the single-tree selection method. The regulations, which seemed to be primarily designed to cope with even-aged management, includes uneven-aged management selection silviculture in its 5-year regeneration requirement (36 CFR 219.27[C][3]). Specifically, the act requires that during the planning and implementation of silvicultural practices when trees are cut to achieve timber production objectives, the cutting is to be made in such a way as to assure that the technology exists to adequately restock the land within 5 years after final harvest. Research and experience is the basis for that determination. Adequacy means that the cut area will *contain* "the minimum number, size, distribution, and species composition of regeneration", the standard is found either in the Regional guide or Forest Plan. The 5 years applies to "*selection* cutting," whatever that is. With the increased push toward selection silviculture, most silviculturists have determined how they are going to meet these standards. Your prescription, which develops the stocking level and diameter distribution goal, will need to assess this standard and how it is going to comply with the law.

The determination of the stocking rate for regeneration points put the need for monitoring and evaluation after harvesting the stand and completing the intermediate stand treatments (density control). The monitoring and evaluation process begins with developing the same kind of stand record system that is developed for all even-age stands, including the acreages involved in treatment and the types of treatments. Stocking and the residual diameter distribution is recomputed after the treatments. If logging compliance or other similar problems have not occurred, this survey is made unnecessary if a good inventory is taken before treatment and sampling during marking residual leave trees is checked during sale designation. This is a sufficient stocking survey to deal with future harvest estimates 10 to 30 years hence. Regeneration, however, must be evaluated 3 to 5 years after harvesting is completed to assure compliance with NFMA.

It is very important to evaluate the regeneration diameter group (less than 2 inch dbh). This is to assure that it is meeting prescription and stand structure goals, not to mention the legal constraints.

Following the stocking evaluation and the stand's failure to meet the regeneration stocking goals, artificial regeneration may be an appropriate consideration. Most people do not consider planting a very legitimate practice in a single-tree selection method prescription. Planting is the exception rather than the rule. A series of small openings in a stand are not readily recognizable as planting spots and would probably not be economical for a planting crew. One estimate for planting costs indicated a 20 to 40 percent increase in the bid rate would be experienced. This was in areas adjacent to a road. Scattered planting in single-tree openings where a range of 10 to 40 trees planted per each tree removed would not be economically efficient due to the amount of search time per unit of actual planting. Even though there may be increased costs, planting may be necessary to meet legal considerations under NFMA if the current preoccupation with meeting the arbitrary 5-year regeneration timeframe persists. It would appear that this could become a costly problem. The cost of doing such business may need much consideration by the public.

Another time when artificial regeneration should be considered is when genetically superior stock, such as disease resistant seedlings can be introduced. From all appearances, species of seedlings appropriate for the single-tree selection method are not involved in many tree improvement programs of the Forest Service or its cooperators.

With some species, the technology for nursery production and care and planting of these tolerant species is not well understood. In some situations, additional research may be necessary in order to carry on a successful planting program.

CONCERNS, CONSIDERATIONS, AND OTHER INFLUENCES ON THE METHOD

Any silviculturist involved with the single-tree selection method has numerous concerns and considerations they express and must try to work around. Some of the considerations are of such a paramount level that they often preclude the application of the method. In the following sections, I will try to discuss each of these concerns or considerations that require some review before applying this method.

Insects and Diseases

Numerous insects and diseases are naturally present through the course of years of development of a stand, each potentially influencing several species and size classes of trees. It is of primary importance that the silviculturist deal with those that may disrupt or even preclude the application of the prescription to achieve the management objectives. The arrangement of the single-tree selection stand often provides host material for a wide variety of pathogens simultaneously.

One of the primary pathogens in the single-tree selection method that should be of concern is the wood-decay fungi, principally the butt and heart rotting species. They are of special concern because the frequent stand entries provide a high chance for damage to the bole, breakage of roots and limbs, and enhancement of the soil medium, all of which seem to create the necessary infection courts, additional stress, or attachment and attack points necessary to cause a proliferation of the fungi. The environment for sporialation is often enhanced by maintenance of higher in-stand humidities, temperatures, and low light levels with the single-tree method stands.

Specifically the literature points to these species of diseases, mostly fungi, plus the included insects, as problems on the trees and areas indicated (Blum 1985; Ferrell 1986; McCaughey and Ferguson 1988; Daniel, Helms and Baker 1979).

Table 6. Species of insects and diseases and tree species affected.

Fungi	Species Affected
Poria obliqua	Birches
Polyporous glomeratus	Maples and Beech
Fomes ignarias	Maples and Beech
Fomitopsis spp.	Western conifers
Armellia mellea	Western conifers
Phellinius spp.	Several conifers
Stereum sanguinolehtum	Balsam, subalpine firs
Echonodontium tinctorium	Western conifers
Heterobasidium annosum	Western conifers
Pholiota adiposa	White fir
Amglostereum	Subalpine fir
Inonotus cincinatus	Engelmann spruce

Diseases and Insects	Species Affected
Cryptococcus fugi	Beech
Nectria coccinca v. fuginata	Beech
Glycobius speciosus	Sugar maple
Arecthobium spp. (host specific)	Several western species
Eastern and Western budworm (*Choristeneura* sp.)	True firs, Douglas-fir spruce
Tussock Moth (*Orygia* sp.)	True firs, Douglas-fir
Resinicium bicolor	Subalpine fir
Western pine beetle	Ponderosa pine
Fir-engraver beetle	True firs

Tree, stand, and site factors must be considered in developing the management strategy and silvicultural prescription. When dealing with regeneration or assessing the chance of it performing as a crop tree, this is of paramount importance. As a general rule, our knowledge of the insects and the diseases and their interactions is far from complete. Many function as complexes and often cyclical circumstances help trigger their influence.

It still seems that we know little about the response of the disease or insect with its host and the interactions that are preferred. For example, the interactions between the rot *Heterobasidum annosum* and the fir-engraver beetle (*Scolytus ventralis*) and drought is being reviewed currently (Ferrell 1986). In the grand fir areas of central Idaho where drought has recurred for at least 3 years, the fir-engraver beetle seems to begin its central activity at the "annosum" centers and spreads successfully from there. While research is being carried out in the pathogen-tree-treatment interactions, few scientists seem to be working in this area. If more single-tree selection method is undertaken, this area of research will need substantial expansion.

Some ecological inferences with single-tree selection is cause for some concern. With the application of this method the use of fire is greatly inhibited, usually it's not possible. Early research infers that in several ecosystems, fires and their smoke adversely affect fungal activity. In many cases one or both negatively influenced the sporialation or spore carryover of several fungi. The interactions are not well understood. In addition, the stands maintained under those conditions are far different than the advanced seral-climax type stands maintained by the single-tree method.

All indications are that rot incidences will continue to increase with time in single-tree method application areas and that these long-lived spores may cause responses that are even less palatable to the public. However, this may be changing as the public currently shows little concern with moderate levels of tree deaths. I hear a "So what?" attitude about relatively "dead" forests.

Disease activity and chance for infection seems to be encouraged by resultant tree growth responses with the single-tree method. Oftentimes the fungal infection courts are in the lower limbs and branch scars which occur due to the suppression during the early sapling development of several species of true fir and hemlock (McCaughey and Ferguson 1988). Choosing high residual stocking levels, with short entry cycles would enhance the chance of infection with this host-fungi relationship.

Several diseases such as dwarf mistletoe would essentially preclude the application of the single-tree selection method. The mistletoe would constantly re-infest the understory, dramatically reducing growth and vigor, allowing secondary diseases to cause mortality.

Areas with a high incidence of spruce budworm and Douglas-fir Tussock moth need to be evaluated for the suitability of the single-tree method. In the West and in the spruce-fir belt of the East, budworm activities could eliminate regeneration if a long, low level budworm incidence occurred (Aplet, *et al.* 1988; Blum 1985; Frank and Blum 1978; Graham in process). The losses and reduced budworm mortality is encouraged by the multi-height stand structure.

Most important in dealing with spruce budworm is dealing with the long term vulnerability of stands. With the single-tree method budworm vulnerability is often maintained by the mature and nearly mature trees in the overstory that will "rain" budworm onto the regeneration and smaller, immature trees (Blum 1985). Avoiding a high level of the vulnerable true firs, while ensuring a vigorous, younger tree through reduction of maximum tree sizes, should be one of the considerations in management if the single-tree selection method is necessary to meet management objectives. Another problem of dealing with a budworm is its negative influence on seed production by bud and flower feeding even at very low population levels. This often delays seed crops and reduces regeneration, making planting a potential need.

Water and Soils

It has already been pointed out by Leak and Gottsacker (1985) that soil can be a major factor controlling the establishment of regeneration of some species. Soil texture was tied to the establishment of sugar maple in New England. Other area and site-specific relationships exist. These must be accounted for in developing the suitable prescription.

The major soil consideration to be aware of in the single-tree method is the influence of logging traffic on the soils. Compaction or the change of bulk density and its impacts are a major concern. The concern arises from the frequency of entries plus the potential volume of traffic occurring over such a broad area. This concern is often amplified when the soil texture and character is also evaluated. Good soil information is essential in evaluating the soil's suitability for the method (Jurgensen, *et al.* 1979).

With increased bulk density from compaction or disturbance, root penetration and growth are reduced (Adams and Froelich 1981). Such a reduction reduces the effective root area potential of the tree increasing its risk to windthrow. This reduction also reduces the plant's capability to handle drought, often enhancing the influence of drought, increasing its potential loss to pathogens (Ruark, *et al.* 1982). Soil compaction normally progresses at an increasing logarithmic rate with trips over skid trails or roads. Although use of skid trails may be low per entry with the single-tree method, the trips per unit of removal is higher than most even-aged treatments.

In order to cope with the compaction situation, development of dedicated skid roads and trail systems is very important. Such a system does not encourage highly mechanized harvesting equipment because the equipment often must drive near the tree.

Long term forest productivity should be encouraged. In most cases, this will mean the leaving of tops, limbs, and cull materials on site for re-incorporation. At least 10 tons of material greater than 3 inches should remain well-distributed on site, according to most of the current research (Harvey, *et al.* 1979, 1981). A secondary concern of leaving this debris should be insects. In some cases, such as spruce beetle, leaving large logs and other such debris must be avoided. The shaded environment of the single-tree method encourages retention of moisture sufficient to successfully brood large populations. Large broods can cause very high rates of mortality. Epidemics can even be started.

The single-tree selection system is a very effective way of harvesting timber and retaining snow for later melt. This is accomplished by the reduced insolation levels under the canopy. However, the method does not have much utility for management of water yield increases through snow redistribution and accumulation. The method may reduce sublimation (snow particle evaporation by wind) losses at high elevations (Tabler 1973; Troendle an Meiman 1984).

The method causes little watershed concerns except for the more frequent entries and short cutting cycles on critical soil areas. Here the concern is that frequent disturbances on skid roads and trails may increase the chance of sediment delivery into a water system through erosion.

Wildlife Habitat

In viewing the single-tree selection method for wildlife habitat, it is often evaluated as not having much species richness because few successional stages are created (Thomas *et al.* 1979). The habitat created is primarily a ubiquitous mix of sameness over a large area; there is little contrast at edges and in the structure internal and external to the stand area. The method is normally applied over broad areas; therefore, it typically is not considered as a fragmenter of the ecosystem.

Species that depend on early seral vegetation or conditions don't do well with this silvicultural method because those stages do not exist. The distinct successional stages that ensure successional diversity and a myriad of habitat niches are not available. Thus, edge related species are in lower numbers or not present.

The habitat structure provided is more of a late maturing late succession character, except the large trees, woody debris, snags, or cavity trees are seldom present in any abundance. The habitat situation provided may be very useful to wildlife species that require a broad array of vertical diversity and a relatively closed canopy for security or have a high thermo-regulatory need (Medin and Booth 1989).

Aesthetics

It seems to be almost understood that uneven-aged silviculture, especially the single-tree selection method, is the system of choice for the management of visually sensitive areas. The acceptance or preference for uneven-aged silviculture, especially the single-tree method in particular, appears prompted by a very negative public reaction to even-aged silviculture, which it seems is considered to include only the clearcut method (Robinson 1988).

As a rule, the preservation organizations and other portions of the public will accept single-tree selection without much concern. The concern expressed centers on the harvest practices, application size, and the way it appears immediately following the harvest (Tubbs 1988). The single-tree method of harvest is desired and allowed in very sensitive areas because of the random small scale pattern of harvest. It is much less discernable. The single-tree method leaves the forest character intact. It provides what people construe to be a natural appearance, making it acceptable when viewed from any angle, including an aerial view (Bacon and Twombly 1977).

Species Composition

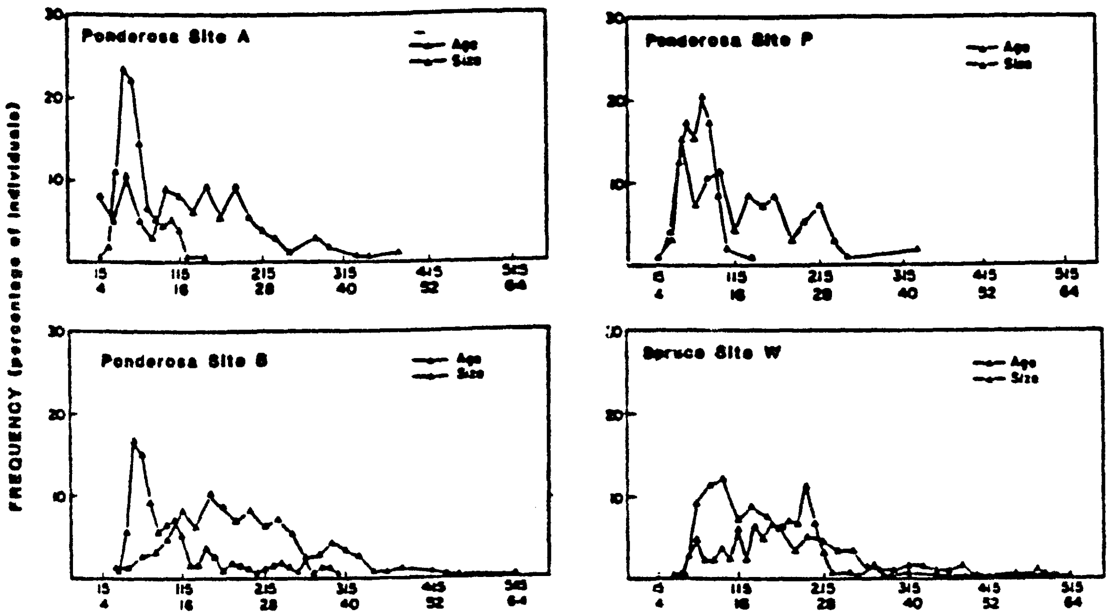
Throughout the west, tree species currently composing the stands where management by single-tree selection method is being proposed are early and mid-seral intolerants, to mid-level tolerants. Applying the method to these species types will cause them to shift to slower growing, lower-valued species that are much more susceptible to diseases and insects (Burns 1989; Franklin 1978).

A similar situations occurs in much of the eastern and southern forests of the United States, except the tolerant species of these forests have values which are often higher. In some areas, the high value hardwood species are perpetuated by this method. As a general rule, values recovered from this method are usually lower as is the volume (Frank and Blum 1978).

In applying the single-tree method the shift in species composition and its influence on values and rates of growth should be one of the principal considerations when the method is chosen. In general, the method has more problems that lie with species preferences than any other method. This means it is the least compatible with management objectives when value of the return from management is the goal (Gingrich 1978).

Age vs. Size

Throughout the discussion, the size of tree has been dealt with as if it were equivalent to the age of the tree. Hence, when discussing the uneven-aged single-tree selection method, we often automatically assume, by implication, that the stand is uneven-sized. Nothing could be further from the truth, as field data indicates.



AGE (Yr)
DIAMETER (cm)

Figure 2. Distribution of ages and diameters at all sites where, within species, curves were significantly heterogeneous among sites.

The faulty assumption that size generally equals age continues to cause people to make some inappropriate choices in the application of the single-tree method. Recently, the reserved J-shaped diameter frequency curve has been shown to be not just an indicator of a balanced distribution of ages in an all-aged stand. The same logarithmically decreasing diameter distribution is also found in mixed species, even-aged stands (Graham, in process). Age and size analysis of Engelmann spruce and ponderosa pine climax stands has also revealed some interesting correlations. In this case, age and size were moderately correlated. Incidences of occurrence, however, on some sites indicated a short span of ages for a broad range of diameters (see Figure 2). Only one of the ponderosa pine and the spruce sites indicates a relatively close correlation between age and size. Two of the ponderosa pine sites show relatively good correlation except in the large diameters (Knowles and Grant 1983). Certainly this lack of correlation and subsequent removal of the best growing trees is one thing to think about when dealing with genetic considerations. In a review of 68 randomly chosen stands of mixed Douglas-fir and ponderosa pine stands from northern Idaho, Graham (in process) found that of the 65 percent with a J-shaped diameter distribution curve, only 30 percent fit that relationship according to age (see Figure 3). He also tested stands containing tolerant species.

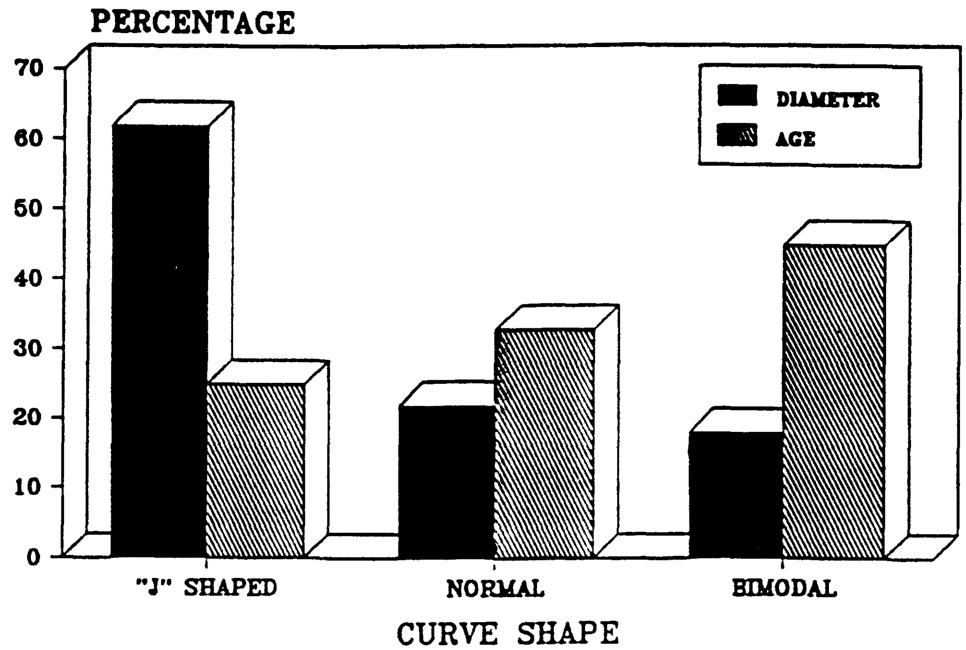


Figure 3. Age and diameter distributions for Douglas-fir and ponderosa pine stands classified as having a "J" shaped curve, normal bell shaped curve, or bimodal (having more than one peak) curve, for 68 randomly selected stands from the Idaho Panhandle National Forest (Graham, in process).

Correlation between age and diameter were made from the more tolerant species, the most suitable for the single-tree method (see Figure 4). Most including spruce showed a poor age/size correlation (Knowles and Grant 1983; Larson 1982). A review of correlations developed in certification prescriptions by Intermountain Region silviculturists also show the poor correlations, corresponding to other authors.

It is imperative that an assessment of age in relation to diameter be made in all stands being managed to determine if the stand is simply uneven-sized, uneven-aged, or both. The genetic implications of the non-correlary stands are very interesting, especially if you consider the long period between seed crops with irregular regeneration establishment. Obviously the slow grower, after reaching sexual maturity, has many more chances of regenerating a site than the rapidly growing young-aged tree. This is especially true because of the dominance position the trees are placed in. This should be a serious concern for this method. In the long run, it could have serious yield and fitness implications (Howe, Proceedings).

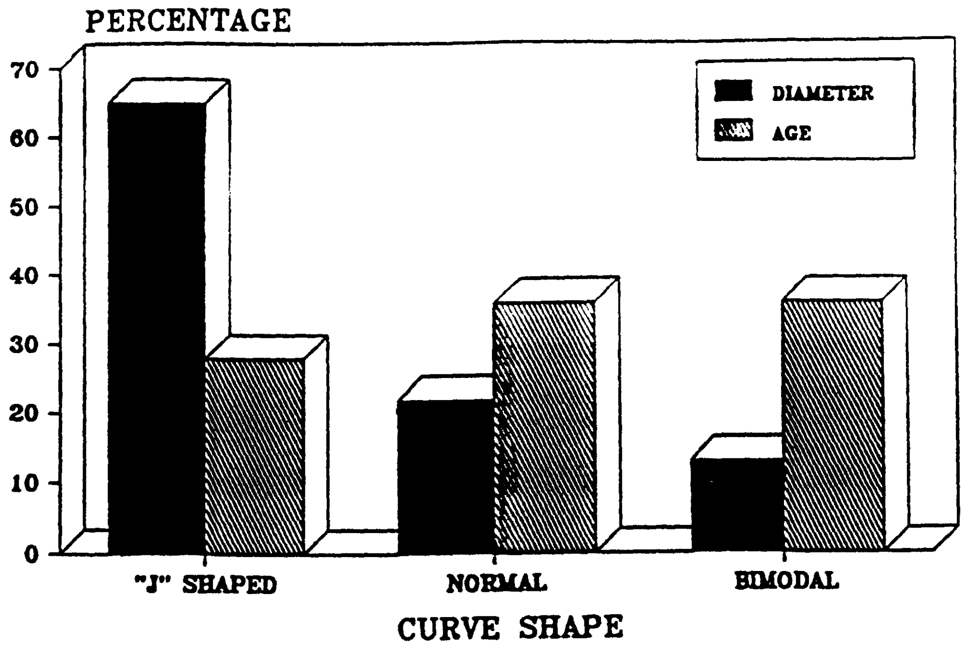


Figure 4. Age and diameter distributions for grand fir and western hemlock stands classified as having a "J" shaped curve, normal bell shaped curve, or bimodal (having more than one peak), for 128 randomly selected stands from the Idaho Panhandle National Forest (Graham, in process).

Skills and Capability to Accomplish

To apply this method requires some of the highest levels of skill and understanding of any of the methods of silviculture. This seems to be a consensus opinion from most authors of silvicultural texts. The high expertise level starts with the silviculturist and is required through to the logger that harvests the stand. The complexity of its application increases with each species which must be considered and dealt with to meet the management objectives.

The method requires a high level of understanding of the silvics and general ecological relationships of the species involved in the treatment. This means that much field time is spent in data collection, interpretation, and validation. That time must be spent by the silviculturist because it requires skill to translate the biological and other management requirements into a set of marking guides and other management instructions. The subtle distinctions to evaluate in determining which trees to mark, while dealing with size, species, and distribution rate over the area, requires highly skilled timber markers with close supervision. The markers must understand the capability of the logger in order to account for possible damage, determining acceptable situations for felling, bucking, and skidding of the trees harvested, and its relationship to other trees (Minckler 1974; Tubbs 1988).

The logger will require both management and equipment skills to protect the leave stand and generally will require close supervision by the sale administrator to deal with problems (Marquis 1978).

The use of the single-tree selection system requires a level of understanding by the line officer to insure provision for the additional time commitments, increased costs of prescription preparation, marking supervision, sale administration, and post-treatment density control problems. All of this additional production cost will occur on stands with less value being returned due to the low value of the species harvested.

In many cases, the single-tree method requires an understanding by other staff specialists of the recurrent treatment needs, road, and other transportation needs. Many forget the recurrent need for treatment, simply wanting the stand's current condition to remain in perpetuity. It requires the commitment of a silviculturist to accomplish the work on the ground, rather than getting exposure for promotional opportunities through meetings and other situations. Field work is not given much capability credit for promotions recently by many line officers.

This method's application will be very difficult to handle with the current personnel ceilings, de-emphasis of timber management (sales preparation) in the budget, and an apparent penchant for having the least-trained person perform the field work. It has a very high chance of not getting performed correctly because of the general lack of capability of having professionals initiate and supervise the field work. This is usually due to their assignment on so many other office tasks of priority that prescriptions will often only receive a rather cursory look. In general, all management actions will be influenced.

The skill level of marking crews to apply the single-tree method is difficult to obtain because of the process used in personnel recruitment. It may require year-long employment at wage rates sufficient for retention to obtain qualified markers. The program must build on skills; therefore, high turnover in the crew is not acceptable because of the poor job accomplished and the time and cost involved in the crew retraining effort by the silviculturist.

The method, if it must be applied, should be done correctly and well. In general, it will require a change in the way many are used to doing business.

A decision that must be made and that should weigh heavily on the implementation of a single-tree selection method is the capability to perform the harvest with the least damage possible. It is important to assess the species and its situation when setting cutting cycles, residual stocking, maximum tree size, and regeneration of class distribution. The suppression rate of regeneration, relative vigor of seedlings and saplings, and inherent damage due to equipment and logging will control the single-tree method application, especially if only species highly susceptible or vulnerable to pathogens are being managed. It may become necessary to qualify operators (loggers) because it is their care and skill that is the most significant in protecting regeneration.

Fire

The use of fire for management of this method is very limited. The fuel ladder configuration of the multi-size classes also may pose a high risk to wildfire. It is imperative that the fire situation be evaluated when this method is being proposed. Where wildfire risk is moderately high, the single-tree method may not be suitable. In some high fire risk corridors, such as along roads, the fire hazard posed by the multi-storied stands developed by the method, may not be acceptable.

It is also difficult to control or reduce the slash hazards in this method. In fire prone ecosystems or in the management of species with a high natural fire correlation the method's use should be questioned. Fire adapted ecosystems like lodgepole, jack and sand pines could not have the method successfully applied.

Ecologically the method does not fit with a fire dependant ecosystem. While the method may be capable of application, an assessment should be made to assure that the frequent fires were not essential to the maintenance or control of other perturbances in the system such as disease. The method often invokes species shifts and with it stand structure, increasing the chance of larger more destructive wildfires.

Ecological Assessment

In order to utilize the single-tree selection method, tools for assessing or evaluating site capability or suitability are often necessary, but there are some problems. For example, site index or site capability data is almost non-existent for most uneven-aged silviculture systems (Curtis 1978). It is important to understand how various early suppression growth delays from overtopping influence the species capablility of utilizing the method. For example, Alexander and Engelby (Burns 1983 p. 60) point out that Engelmann spruce may take 20 years to reach DBH under a light overstory, 40 years under a moderate overstory, and 80 to 100 years under a very dense overstory. Such delays in growth, however, may not be a significant problem on long-lived species such as spruce with a sigmoidal height growth curve form. However, on a short-lived species such as its companion, subalpine fir, it may cause substantial influence in both height and diameter growth prior to biological senescence (Knowles and Grant 1983).

Little data is also available on actual growth rates at various ranges of residual stocking and under varying diameter distribution procedures. Growth projections are not easily made and only a few simulators have sufficient variables influencing growth alogarithms to deal with a range of responses. Residual stocking levels often use a "q" value, but there are indications that this may be inappropriate. Reineke's SDI and other indexes have been suggested as alternative tools to set residual stocking levels. Again, most were developed from even-aged stand situations (Curtis 1978). Are these appropriate for use? Intuitively, they seem acceptable.

Most levels of growing stock research has been abandoned. In the west, little actual research data is available to assess tree and stand growth responses for anything more than a cutting cycle or so. Long term data is needed to assess the method and its growth influences.

Actual validation of various species composition responses to treatment variables are lacking, especially for the west, for periods greater than 15 to 20 years. The degree of species stability and control under single-tree selection is also unknown for many species and ecosystems.

Without much of this information, growth and yield, plus financial simulation models, are not accurate and could lead to an inappropriate conclusion.

Successional response data is only beginning to be developed or assembled which would help in the assessment of site preparation needs appropriate for the species preferred. Habitat types are not available in a number of areas to help catalog vegetation and its responses. Where successional pathway response data is available, inappropriate treatments can be avoided. It is also not possible to assess without successional research the appropriateness of considering single-tree selection to meet a variety of management objectives. In some cases incompatibility with the ecotypes are easily illustrated. Such a classification would allow the ranking by potential productivity and yields.

The frequency, cyclical, abiotic, and other biological influences on seed production and successful seedling establishment is not understood for many species. Determination of this information will have a major influence on meeting the 5-year NFMA regeneration requirement for this method. There is also little experience in applying the method to assure the adequacy of regeneration, especially in the West.

Timber Supply

The ability to predict timber supply from a variety of lands with some variation of the single-tree selection silviculture method is almost as hard to obtain as a feasible FORPLAN solution for Forest Planning. The yield of each stand is controlled by each prescription which is unique to an area it is written for. Although models exist, they are not easily used and the output is very difficult to verify and interpret. However, yield from each site is moderately quantifiable; thus a long-term, broad range supply prediction can be made.

Broad application of the single-tree method to a broad array of management situations may have a very negative effect on the desired industrial species supply throughout the country. The more tolerant species do not have the strength, nail hold, and structural integrity to meet a wholesale application in the building trades. A drop in timber supply could also be expected to occur because of increased loss of growth to diseases and insects. Forest health could be expected to decline. Loss of health and vigor is often the precursor, in the western ecosystems, to large stand-replacing wildfires. The reliance on natural regeneration with this and other methods would substantially reduce long-term seed stores, thus severely limiting the replacement capability of stands after a large fire.

Economic Considerations

The cost to operationally implement a substantial increase in the single-tree method would be substantial. It is difficult to predict if, because of its application, appeals, litigation, and other issue-driven activity, costs would drop, thus having a cost saving. It may also be possible to save on the cost of NEPA documents.

The real cost of the improper application of the single-tree method may not show up for some years, but inevitably a diseased or insect-infested forest that produces little if any resource value has a very high economic cost. The cost of having to replace a diseased stand with a healthy one is probably inevitable when the method is improperly applied, such as when attempting to solve a political dilemma. Unfortunately, most of the lands occupied with the diseased timber have the potential of affecting the more appropriate management species for the situation.

Another relatively long-term influence and potential cost is the loss of the favored species, useful in home and construction building. Tolerant species are usually not highly sought after woods, except for paper materials.

An additional consideration and cost is the increase in professional skills needed to adequately implement the method. The chance of that increase occurring with emphasis on budget reduction and personnel controls is rather remote.

It has been indicated in several recent surveys that the public seems very willing to spend more money to clean up the air and water. Unless this issue can be linked, it is doubtful that budget increases necessary to meet the cost of appropriately applying single-tree selection over more acres would be funded. Unfortunately this simply means more errors and more questions by the public as to the Forest Service's capability to perform the expected management actions.

There would be less monetary return to the treasury from any dramatic increases in single-tree selection method applications. Logging costs would rise, species values would decrease and net income would fall. These items, along with the added burden of extra help for treatment control, would obviously reduce returns to the treasury. A very hard blow to an economy about to bail out several crisis, internal and external.

Socio-Political Concerns

The application of the single-tree selection method and other selection methods must be moved from the level of a cause back to being dealt with as an on-the-ground issue which must be done within appropriate biological limits (Naumann 1987). It has become apparent that the public is suggesting, almost mandating, the use of the selection methods as the method of choice, principally as an aversive response to clearcutting. Many of the publics know little about the method's biological suitabilities. In some recent public meetings, the public indicated that they were really unaware of the differences between the various even-aged silviculture systems which have multiple treatments and canopies, such has in irregular shelterwood with reserves, and how they compare to a single-tree selection method. In many cases, the even-aged methods were much more compatible with the expected outcomes and biological capabilities of the stand. Such a treatment was accepted as long as a link was not made with the even-aged systems which was directly tied to clearcutting, seen as the epitome of dissatisfaction.

It is clear that education is essential for the publics in forestry treatments. However, in a society with too little time, it may be more imperative that we learn to talk their language rather than having them misinterpret ours. I also believe we must make an effort to develop within our own Forest Service employees a similar understanding about forest treatment. It appears that we should use those powerful tools, the video camera and television, to get our points across. There are some excellent show and tell items developed by various Regions, but often they are mostly known in-house. Most importantly, however, the decision process must be brought back to the site where real biological concerns and limits are discussed.

Somehow we must develop with these same publics an understanding of the cost of doing some of our "new" business. "Sloppy forestry" takes much more planning to accomplish and execute. That equates to more people and dollars. This increased cost may mean a cutback somewhere.

It seems inevitable, but somehow we must regain the public's management trust. It must somehow come to fruition that we, the professional land managers, have the best understanding of what works best on the land to accomplish mutually developed objectives. We must apply the single-tree method only where it is best suited or the lack of trust in our ability to manage will grow even faster. A green lie is still a green lie when someone understands what the answer should have been.

The book "Excellent Forestry" (Robinson 1988), touts the use of selective cutting as if it is a surogate for the selection method. Most foresters understand what selective cutting is and how ill-conceived the practice was. Robinson's paradigm seems to lie with always wanting forest lands stocked with trees, without realizing that a tree's life is finite, useful, and controlled by the species' genetics which limits a variety of forestry applications. Basically, his "Excellent" method treats little other than the old large trees in the stand. Regeneration and the diameter class distribution target is not inferred as needing control. Practicing that form of management in times past has resulted in predominately even-aged stands without regeneration, often not of desirable species, and usually with some profound health problems. Certainly succession was accelerated; however, should this be considered success? Did it meet our management objectives at the time? Most will say that it helped the country's development, but many feel not without a high cost.

A last concern. If the single-tree selection method is applied to the extent referred to in some Forest Plans with large grazing and wildlife programs, which program will be successful? If broad application of the single-tree method occurs, grazing will usually need some exclusionary controls, substantial reductions, or all of these. This will be needed to assure regeneration success. Will this be acceptable? Probably not, but in some cases that may meet some group's ultimate objective.

I am aware of some Region's having substantial damage from deer and elk browsing on seedlings. The damage is severe and all protection measures have generally failed or have been thwarted. This problem is obviously one requiring management choices. However, it would not be appropriate or even within the law to practice single-tree selection on areas with these problems.

SPECIES APPLICATION

Some species are incapable of being managed with the single-tree selection method. The very intolerant species, even when grown alone, cannot tolerate being grown in close juxtaposition with crown positions inferior and still survive. The species that fit that standard are:

Aspen	Grey birch
Lodgepole pine	Tamarack
Western larch	Jack pine
Cottonwood	Longleaf pine

The most tolerant through moderately tolerant species will normally handle the single-tree selection method with ease. Table 7, Tolerances of American Forest Trees from Daniel, *et al.* (1979), helps to provide some alternatives.

Table 7. Tolerance of American Forest Trees.

Western Conifers

Very tolerant:
Western hemlock
Subalpine fir
Western red cedar
Pacific yew
California torreya

Tolerant:
Sitka spruce
Engelmann spruce
Mountain hemlock
Pacific silver fir
Grand fir
White fir
Redwood
Incense-cedar
Port Oxford white cedar
Alaska yellow cedar[1]

Intermediate:
Western white pine
Sugar pine
Monterey pine
Blue spruce
Douglas-fir
Red fir[1]

Intolerant:
Limber pine
Pinon pines[1]
Ponderosa pine
Jeffrey pine
Lodgepole pine
Coulter pine
Knobcone pine
Bishop pine
Big-cone spruce
Noble fir
Junipers

Very intolerant:
Whitebark pine
Foxtail pine
Bristlecone pine
Digger pine
Western larch
Subalpine larch

Western Hardwoods

Very tolerant:
Vine maple

Tolerant:
Tan oak
Canyon live oak
Big-leaf maple
Madrone[1]
California laurel[1]

Intermediate:
Red alder[1]
Golden chinquapin[1]
Oregon ash
California white oak[1]
Oregon white oak[1]

Very intolerant:
Quaking aspen
Cottonwoods

Eastern Conifers

Very tolerant:
- Eastern hemlock
- Balsam fir
- Atlantic white cedar

Tolerant:
- Red spruce
- Black spruce
- White spruce
- Northern white cedar

Intermediate:
- Eastern white pine
- Slash pine
- Bald cypress

Intolerant:
- Eastern red cedar
- Red pine
- Pitch pine
- Shortleaf pine
- Loblolly pine
- Virginia pine

Very intolerant:
- Tamarack
- Jack pine
- Longleaf pine

Eastern Hardwoods

Very tolerant:
- Eastern hop-hornbeam
- American hornbeam
- American beech
- American holly
- Sugar maple
- Flowering dogwood

Tolerant:
- Red maple
- Silver maple
- Box elder[1]
- Basswood
- Tupelos
- Persimmon[1]
- Buckeyes

Intolerant:
- Black walnut
- Butternut
- Pecan
- Hickories
- Paper birch
- Yellow poplar
- Sassafras[1]
- Sycamore[1]
- Black cherry
- Honey locust
- Kentucky coffee tree
- Catalpas

Intermediate:
- Yellow birch
- Sweet birch
- American chestnut
- White oak
- Red oak
- Black oak
- American elm
- Rock elm
- Hackberry
- Magnolias[1]
- White ash
- Green ash
- Black ash

Very intolerant:
- Willows (as a class)
- Quaking aspen
- Bigtooth aspen
- Cottonwoods
- Grey birch
- Black locust
- Osage orange

[1] Cases of great uncertainty.

Finally there are the species that fall into the intolerant and intermediate tolerance areas. Maintained in nearly pure species settings, they may accept the single-tree method but only at lower residual stand levels or in situations where they are the climatic climax. Often they are best maintained using the alternate group-selection method. It is imperative in many of these situations to evaluate very carefully the application of single-tree because of the cost in both maintenance, loss of production, and general non-conformance with the past ecological development and maintenance of the species, usually fire or other catastrophic stand replacing events. Each site and species must of necessity be judged on its own for capability and potential success of regeneration.

CONCLUSION

The single-tree silviculture method is, like any tool if inappropriately applied. The tool does not produce the expected outcomes and may even sustain damage. However, when it is appropriately used it accomplishes the job well. The single-tree selection method of silviculture should be viewed as a tool to achieve results. Training may be needed to learn about the tool, its idiosyncrasies, and special approaches. It will take practice to apply the tool inerrantly.

It appears that as we enter into a new era of application strategies in silviculture, we have more and more people with ideas about what they may like, but with less knowledge about the practice or capability to achieve success. In the new era ahead for silviculture, I believe we will come to cope with the "new" like we have the "old" if we will but understand that there are limits in all systems. The successful applicator is the one that finds them, pushes them, but most of all realizes what they are, rather than not exploring them at all.

BIBLIOGRAPHY

Adams, Paul W., and Henry A. Froelich. 1981. Compaction of Forest Soils. PNW217, Pacific Northwest Ext. Pub.; Oregon State University Extension Service, Corvallis, Oregon. 13 pp.

Alexander, Robert R. 1977. Cutting Methods in Relation to Resource Use in Central Rocky Mountain Spruce-Fir Forests, pg. 395-400. Journal of Forestry, Vol. 75, No. 7, July.

Alexander, Robert R. and C. B. Edminster. 1978. Regulation and Control Under Uneven-Aged Management. In: Uneven-Aged Silviculture and Management in the United States, pg. 217-230. USDA Forest Service, Washington, D. C. 234 pp.

Alexander, Robert R. and C. B. Edminster. 1977. Regulation and Control of Cut Under Uneven-Aged Management. Res. Paper RM-182. USDA Forest Service, Rocky Mountain Station, Ft. Collins, Colorado. 7 pp.

Alexander, Robert R. and C. B. Edminster. 1977. Uneven-Aged Management of Old Growth Spruce-Fir Forests: Cutting Methods and Stand Structure Goals for Initial Entry. Res. Paper RM-186. USDA Forest Service, Rocky Mountain Station, Ft. Collins, Colorado. 12 pp.

Aplet, Gregory H., Laven, R. D., and F. W. Smith. 1988. Patterns of Community Dynamics in Colorado Engelmann Spruce-Subalpine Fir Forests, pg. 312-319. Ecology 69(2).

Bacon, Warren and Asa. D. Twombly. 1977. National Forest Landscape Management Vo. 2, Chapter 5, Timber. USDA Forest Service Agricultural Handbook No. 559. Forest Service, Washington, D.C. 223 pp.

Blum, Bart. 1985. Appropriate Silviculture In Spruce-Fir Management and Spruce Budworm Proceedings, Tech. Conf. Region VI, SAF Tech. Conf., pg. 185-191, GTR-NE-99. USDA Forest Service CANUSA Program, Northeastern Experiment Station, Broomall, Pennsylvania. 217 pp.

Burns, Russell M., tech. comp. 1989. The Scientific Basis for Silvicultural and Management Decisions in the National Forest System. USDA Forest Service GTR WO-55. USDA Forest Service, Washington, D.C. 180 pp.

Burns, Russell M., ed. 1983 Rev. Silvicultural Systems for the Major Forest Types of the United States. USDA Forest Service Agricultural Handbook No. 445. U.S. Department of Agriculture, Washington, D.C. 191 pp.

Curtis, Robert O. 1978. Growth and Yield in Uneven-Aged Stands. In: Uneven-Aged Silviculture and Management in the United States, pg. 186-201. USDA Forest Service, Washington, D. C. 234 pp.

Daniel, T. W., J. A. Helms and F. S. Baker. 1979. Principles of Silviculture, 2d Ed. McGraw-Hill, Inc., New York. 500 pp.

Ferrell, George T. 1986. Using Indicator Plants to Assess Susceptibility of California Red Fir and White Fir to the Fir Engraver Beetle. USDA Forest Service Res. Note PSW-388. Pacific Southwest Experiment Station, Berkeley, California. 5 pp.

Frank, Robert M. and Barton M. Blum. 1978. The Selection System of Silviculture in Spruce-Fir Stands Procedures, Early Results and Comparisons With Unmanaged Stands. Res. Paper NE-425. USDA Forest Service, Northeastern Station, Bromwell, Pennsylvania. 15 pp.

Franklin, Jerry F. 1978. Effects of Uneven-Aged Management on Species Composition. In: Uneven-Aged Silviculture and Management in the United States, pg. 169-175. USDA Forest Service, Washington, D. C. 234 pp.

Gibbs, Carter. 1978. Uneven-Aged Silviculture and Management? Even-Aged Silviculture and Management? Definitions and Differences. In: Uneven-Aged Silviculture and Management in the United States, pg. 17-24. USDA Forest Service, Washington, D. C. 234 pp.

Gingrich, S. F. 1978. Growth and Yield. In: Uneven-Aged Silviculture and Management in the United States, pg. 115-124. USDA Forest Service, Washington, D. C. 234 pp.

Gordon, Donald T. 1978. Regeneration. In: Uneven-Aged Silviculture and Management in the United States, pg. 159-168. USDA Forest Service, Washington, D. C. 234 pp.

Graham, Russell T. (In-Process). Uneven-Aged Management: Concerns and Biological Realities. In: Proceedings National Silviculture Workshop, Petersburg, Alaska (1989). USDA Forest Service, Washington, D. C.

Graham, Russell T. and R. A. Smith. 1983. Techniques for Implementing the Individual Tree Selection Method in the Grand Fir-Cedar-Hemlock Ecosystems of Northern Idaho. Res. Note INT-332. USDA Forest Service, Intermountain Station, Ogden, Utah. 4 pp.

Hann, David W., and B. Bruce Bare. 1979. Uneven-Aged Forest Management: State of the Art (Or Science?). Gen. Tech. Rpt. INT-50. USDA Forest Service, Intermountain Station, Ogden, Utah. 18 pp.

Harvey, A. E., M. F. Jurgensen, and M. J. Larsen. 1979. Role of Forest Fuels in the Biology and Management of Soils. Gen. Tech. Rpt. INT-65. USDA Forest Service, Intermountain Station, Ogden, Utah. 8 pp.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1981. Rate of Woody Residue Incorporation Into Northern Rocky Mountain Soils. Res. Paper INT-282. USDA Forest Service, Intermountain Station, Ogden, Utah. 5 pp.

Hawley, R. C., and David M. Smith. 1958. The Practice of Silviculture, Sixth Ed. John Wiley and Sons, Inc., New York. 525 pp.

Jurgensen, M. F., M. J. Larsen, and A. E. Harvey. 1979. Forest Soil Biology - Timber Harvesting Relationships: A Perspective. Gen. Tech. Rpt. INT-69. USDA Forest Service, Intermountain Station, Ogden, Utah. 12 pp.

Knowles, Peggy and M. C. Grant. 1983. Age and Size Structure Analyses of Engelmann Spruce, Ponderosa Pine, Lodgepole Pine, and Limber Pine in Colorado, pg. 1-9. Ecology 64(1).

Laacke, Robert J. and Gary O. Fiddler. 1986. Overstory Removal: Stand Factors Related to Success and Failure. Res. Paper PSW-183, USDA Forest Service, Pacific Southwest Exp. Sta., Berkeley, California. 6 pp.

Larson, Bruce C. 1982. Development and Growth of Even-Aged and Multi-Aged Mixed Stands of Douglas-Fir and Grand Fir on the East Slope of Washington Cascades. Thesis. University of Washington, Seattle, Washington.

Leak, W. B. 1978. Stand Structure. In: Uneven-Aged Silviculture and Management in the United States, pg. 104-114. USDA Forest Service, Washington, D. C. 234 pp.

Leak, W. B., D. S. Solomon, and S. M. Filip. 1969. A Silvicultural Guide for Northern Hardwoods in the Northeast. Res. Paper NE-143, USDA Forest Service, Northeastern Station, Upper Darby, Pennsylvania. 34 pp.

Leak, William B. and J. H. Gottsacker. 1985. New Approaches to Uneven-Aged Management in New England, pg. 28-31. Northern Journal of Applied Forestry.

Lilieholm, R. J., L. S. Davis, R. C. Heald, and S. P. Holmen. 1990. Effects of Single-Tree Selection Harvests on Stand Structure, species Composition, and Understory Tree Growth in a Sierra Mixed Conifer Forest, pg. 43-47. West. J. of App. Forestry 5(2).

Long, James N. and T. W. Daniel. 1990. Assessment of Growing Stock in Uneven-Aged Stands, pg. 93-96. Western Journal of Applied Forestry 5(3).

Marquis, David A. 1978. Application of Uneven-Aged Silviculture on Public and Private Lands. In: Uneven-Aged Silviculture and Management in the United States, pg. 25-62. USDA Forest Service, Washington, D. C. 234 pp.

McCaughey, Ward E. and Dennis E. Ferguson. 1988. Response of Advance Regeneration to Release in the Inland Mountain West. In: Proceedings - Future Forests of the Mountain West: A Stand Culture Symposium 1986, pg. 255-266. GTR-INT 243. USDA Forest Service, Intermountain Station, Ogden, Utah. 402 pp.

Medin, Dean E. and Gordon D. Booth. 1989. Responses of Birds and Small Mammals to Single-Tree Selection Logging in Idaho. Res. Paper INT-408. USDA Forest Service, Intermountain Station, Ogden, Utah.

Minckler, Leon S. 1974. Prescribing Silvicultural Systems. Journal of Forestry, pg. 269-273.

Mustian, A. P. 1978. History and Philosophy of Silviculture and Management Systems in Use Today. In: Uneven-Aged Silviculture and Management in the United States, pg. 1-17. USDA Forest Service, Washington, D.C. 234 pp.

Naumann, John R. 1987. Uneven-Aged Management: Practice, Issue or Cause. In: Ponderosa Pine, The Species and Its Management, Symposium Proceedings, Spokane, WA Ed. Baumgartner, D. M. and J. E. Lotan, pg. 243-245. Washington State University, Pullman, Washington. 281 pp.

Roach, Benjamin A. 1974. Selection Cutting and Group Selection. AFRI Misc. Rpt. No. 5, Applied Forestry Res. Inst. SUNY, College of Env. Sci. and Forestry, Syracuse, New York. 9 pp.

Robinson, Gordon. 1988. The Forest and The Trees: A Guide to Excellent Forestry. Islan Press, Washington, D. C. 257 pp.

Ruark, G. A., D. L. Mader, and T. A. Tattar. 1982. The Influence of Soil Compaction and Aeration on the Root Growth and Vigor of Trees - A Literature Review. Part 1, pg. 251-265. Arborcultural Journal Vol. 6. Great Britain.

Schmidt, Wyman. 1990. personal communication. Uneven-aged Public Meeting, January 17, 1990, McCall, Idaho. USDA Forest Service, Payette National Forest.

Smith, David M. 1988. Even-Aged Management: When Is It Appropriate and What Does It Reveal About Stand Development? In: Proc. New Perspectives on Silvicultural Management of Northern Hardwoods; on the conflicting consequences of practicing northern hardwood silviculture, pg. 17-25, Gen. Tech. Rpt. NE-124. USDA Forest Service Northeastern Station, Durham, New Hampshire. 107 pp.

Smith, H. Clay and Neil I. Lamson. 1982. Number of Residual Trees: A Guide for Selection Cutting. Gen. Tech. Rpt. NE-80. USDA Forest Service, Northeastern Station, Broomall, Pennsylvania. 33 pp.

Steele, Robert and Kathleen Geier-Hayes. 1987. The Douglas-fir/Elk Sedge Habitat Type in Central Idaho: Succession and Management (draft review). USDA Forest Service, Intermountain Research Station and Intermountain Region, Ogden, Utah. 171 pp.

Tabler, Ronald D. 1973. Evaporation Losses of Windblown Snow, and the Potential for Recovery. In: Proceedings Western Snow Conf., pg. 75-79. Grand Junction, Colorado.

Thomas, Jack W., tech. ed. 1979. Wildlife Habitats in Managed Forests in the Blue Mountains of Oregon and Washington. USDA Forest Service, Agricultural Handbook No. 553, Pacific Northwest Experiment Station, Portland, Oregon. 512 pp.

Troendle, C. A. and J. R. Meiman. 1984. Options for Harvesting Timber to Control Snowpack Accumulation, In: Proceedings Western Snow Conference, Sun Valley, Idaho. pg. 86-97.

Tubbs, Carl H. 1978. Stand Composition in Relation to Uneven-Aged Silviculture. In: Uneven-Aged Silviculture and Management in the United States, pg. 88-103. USDA Forest Service, Washington, D. C. 234 pp.

Tubbs, Carl. 1988. Uneven-Age Management: When Do Conditions Require This Approach? In: Proc. New Perspectives on Silvicultural Management of Northern Hardwoods; on the conflicting consequences of practicing northern hardwood silviculture, pg. 27-30, Gen. Tech. Rpt. NE-124. USDA Forest Service Northeastern Station, Durham, New Hampshire. 107 pp.

Author

Ronald C. Hamilton
Regional Geneticist
Intermountain Region
324 25th Street
Ogden, Utah 84401

GENETIC EFFECTS OF SINGLE-TREE SELECTION IN NORTH TEMPERATE FORESTS

George E. Howe
Northern Region
Missoula, MT

GENETIC PRINCIPLES AND PHENOMENA

Principles

Let me review some genetic principles with you. How does man or nature change the genetic constitution of plants or animals? We do so by changing gene frequencies through *selection*, among other mechanisms. Selection is changes in gene frequencies resulting from differential reproduction.

Heritability is a measure of the ability of parents to transmit their genetic constitution to their offspring. I will limit my discussion to transmission via the sexual process. There are strongly, moderately, and weakly heritable traits, and it is important for silviculturists to recognize which traits fall into which categories. Diameter and height growth tend to be moderately to weakly heritable; specific gravity, disease susceptibility, and many insect susceptibilities tend to be strongly heritable; form traits tend to be moderately to strongly heritable.

Phenomena

Asymmetry of response to selection (Libby, 1989). Few researchers have studied the effects of selection for *poor* phenotypes of the traits they evaluated. Bill Libby and others believe that for most of the traits we are interested in, selecting for poor phenotypes probably is not the flip side of the coin for selecting for desirable phenotypes for the same trait. Leaving poor phenotypes is apparently more effective for achieving genetic loss than leaving excellent phenotypes is for achieving genetic gain. Moreover, phenotypes poor in growth traits may be so due to damage in the past which is no longer detectable. The damage may have been from insects or disease and, as we have already said, disease susceptibility and many insect susceptibilities are likely strongly heritable.

GENETIC EFFECTS

Uneven-aged silviculture is single-tree selection and group selection. Smith (1962) describes selection cutting as the harvest of the oldest and largest trees with some predetermined diameter limit taken as the definition of the smallest trees old enough for such cutting. Of course, even if you are trying to do the best job you can, the temptation is always to take the best phenotypes. More frequently, selection cutting has been a euphemism for high grading, particularly in single-tree selection.

Because of the impracticality of ascertaining the age of every tree potentially to be cut, foresters typically substitute diameter-limit cutting as a surrogate, but many authors are unequivocal in their criticism of diameter- limit cutting. Zobel and Talbert (1984) regard diameter-limit cutting as dysgenic and resulting in poorer quality, slower growing stands. They believe that dysgenic selection of even one generation may be undesirable for seed collected from such stands for planting, because nursery practices tend to encourage survival of genetically inferior seedlings which would have perished in nature (supported by Muona, et al., 1988). Maynard, Overton, and Johnson (1987) characterize diameter-limit cutting as follows:

> "In terms of genetic consequences, diameter-limit cutting is like destroying the 1st, 2nd, and 3rd place finishers in every horse race, and putting the last place finishers out to stud!"

In my opinion, single-tree selection cutting can be correctly done only if: 1) your age classes are narrow, 2) you are sure you are cutting the oldest and largest trees within an age class and not cutting outstanding phenotypes in a younger age class, 3) you are also thinning out poor phenotypes in each age class each cutting cycle. The implication is that you need to know the age of each tree potentially to be cut. Is this really practical? Single-tree selection may also provide a great opportunity for inbreeding between a tree and its offspring or other close relative in a younger age class (Ledig and Smith, 1981).

If single-tree selection were ever to successfully be practiced wholesale over large areas for long periods of time, it has the potential for quickly liquidating pioneer and early seral species (Zobel and Talbert, 1984). Single-tree selection of this sort would be inconsistent with the ecology of virtually all Temperate forests, which recycle periodically to even-aged structure, primarily by fire.

There are opportunities foregone by single-tree selection. The first is gain from phenotypic selection. It is very difficult (perhaps impossible) to select superior genotypes by selecting superior phenotypes in uneven-aged stands (Zobel and Talbert, 1984). Also, to whatever extent uneven-aged management relies on natural regeneration, you are foregoing the benefits from planting trees free of natural levels of inbreeding and bred for improved qualities.

Smith (1962) summarizes the genetic consequences of selection cutting by saying, "If there is any method of cutting that is likely to reduce the productivity of the forest by eliminating good genotypes, it is the selection method. It is probably difficult to avoid, even under intensive application of the method."

What do I conclude from all of this? First of all, single-tree selection is much more likely to result in dysgenic selection than even-aged management. Dysgenic selection is certainly more subtle but in the long run much more damaging than the purported "evils" it is intended to replace. Smith (1962, p. 242) states, "The harm that can be done by dysgenic cutting is...greater than the benefits to be gained by eugenic cutting." Second, it is far easier to liquidate species with single-tree selection management because, while a shade-tolerant climax species readily can be a component of even-aged stands, an intolerant pioneer species generally cannot be a component of uneven-aged stands managed with single-tree selection. Third, planting is much less likely to be used in uneven-aged stands, so the benefits of planting, particularly the planting of genetically improved stock, are foregone.

Finally, fire cannot be tolerated in stands managed with single single-tree selection, but the ecological virtue of excluding fire indefinitely in most Temperate forests is highly dubious (Howe, 1976; Habeck and Mutch, 1973).

RECOMMENDATIONS

What are my recommendations from all of this? First of all, we must understand the natural history of the ecosystems we are working with. We must develop a multi-rotation management strategy that mimics this natural history. If we do this, in my opinion, for Temperate forests, single-tree selection will generally be avoided. The exceptions, of course, are those North Temperate forests which have spent the bulk of their evolutionary history in the uneven-aged structure.

LITERATURE CITED

Habeck, J.A. and R.W. Mutch. 1973. Fire dependent forests in the Northern Rocky Mountains. Quaternary Research 3:408-424.

Howe, G.E. 1976. The evolutionary role of wildfire in the Northern Rockies and implications for resource managers. *In*: Proc. Tall Timbers Fire Ecol. Conf. No. 14 and Intermountain Fire Res. Council Fire and Land Mgt. Symp: 257-265.

Ledig, F.T. and D.M. Smith. 1981. The influence of silvicultural practices on genetic improvement: height growth and weevil resistance in eastern white pine. Silvae Genet. 30(1):30-36.

Libby, W.J. 1989. Some tradeoffs among tree improvement, highgrading and genetic conservation. Unpublished manuscript. Univ. Cal. Berkeley.

Maynard, C.A., R.P. Overton and L.C. Johnson. 1987. The silviculturist's role in tree improvement in northern hardwoods. *In*: Managing Northern Hardwoods—Proc. of a Silvicultural Symp. SUNY ESF Faculty of Forestry Pub 13 (ESF-002) and SAF Pub 87-03: 35-45.

Muona, O., A. Haiju, and K. Karkkainen. 1988. Genetic comparison of natural and nursery grown seedlings of *Pinus sylvestris* using allozymes. Scand. J. For. Res. 3:37-46.

Smith, DM. 1962. The Practice of Silviculture 7th Ed. John Wiley and Sons. NY. 578 pp.

Zobel, B.J. and J.T. Talbert. 1984. Applied Forest Tree Improvement. John Wiley and Sons. N.Y. 505 pp.

Author

George E. Howe
Regional Geneticist
Northern Region
P.O. Box 7669
Missoula, Montana 59807

SINGLE-TREE SELECTION METHOD
(A Research Perspective)

James B. Baker
Southern Forest Experiment Station
Monticello, AR

INTRODUCTION

This paper discusses the single-tree selection method from a research perspective and is limited to loblolly-shortleaf pine in the Coastal Plains of the southern U.S. The discussion includes: (1) early research and development of the method, (2) current research, and (3) gaps in knowledge and future opportunities and challenges.

EARLY RESEARCH AND DEVELOPMENT

Research on the single-tree selection method in loblolly-shortleaf pine was first begun by Russ Reynolds in 1937 on the Crossett Experimental Forest in southern Arkansas. During the late 1930's and early 1940's, several studies utilizing the single-tree selection method were installed by Reynolds in cutover, second growth stands to determine the feasibility of the method for rehabilitating and managing these stands (Reynolds 1980).

The second-growth forests that had developed throughout the southern Coastal Plains by the late 1930's, in which Reynolds installed these studies, consisted of remnants of the virgin stands, plus pines and hardwoods that had seeded in over the previous 20 to 30 years. Nearly all acreage, except on abandoned agricultural lands, had overstory and midstory hardwoods and hardwood brush patches intermingled with pine. Many of these stands exhibited uneven-aged characteristics in that they were comprised of pines of various ages and sizes. However, most of the stands had only 25 to 35 square feet of pine basal area and 1,500 to 2,500 board feet (Doyle) of sawlog volume per acre.

Reynolds thought that the stands could be easily improved in stocking and quality through the use of uneven-aged silviculture if pine regeneration was periodically established and allowed to develop at an acceptable rate. Reynolds observed that pine seedlings and saplings were developing rapidly in openings that had been created by harvesting large, overstory pines or hardwoods. However, no pine regeneration existed in the densely shaded areas underneath midstory or overstory hardwoods.

Thus, one of the first silvicultural treatments imposed on these stands was the harvesting of merchantable and girdling of unmerchantable hardwoods that were competing with the intolerant pines for light, moisture, and growing space. Reynolds also began a series of improvement cuts in the pine stands to remove those trees having poor form and quality, low vigor, or evidence of insect or disease infestations. Only a portion of the growth that occurred between cyclic cuts was harvested, thus growing stock volume was improved.

Once the stands reached adequate stocking levels of 60 to 70 square feet of basal area or 4,500 to 5,500 board feet sawlog volume per acre (this generally occurred within 12 to 15 years), Reynolds began regulating stand structure by controlling the volume in the sawlog component of the stand using a guiding-diameter method. Also, after full stocking was reached, all of the growth that occurred between cyclic cuts became the allowable cut for that cycle.

This form of single-tree selection was later employed in additional research studies on the Crossett Experimental Forest to determine its effectiveness in maintaining uneven-aged loblolly-shortleaf pine stands for sustained timber production. The basic silvicultural techniques employed in the "traditional" method included: (1) vigorous hardwood control, (2) frequent periodic cyclic cuts at 3 to 10 year intervals, and (3) stand structure regulation by volume control in the sawtimber component—a subjective regulation method, and (4) cutting the worse pines and leaving the best. These techniques insured the establishment of pine regeneration, the development of that regeneration through a range of size classes through maturity, and the sustained yield of high quality and value forest products. The details and the results of this form of management over a 40-year period is documented in several publications (Reynolds, Baker and Ku 1984; Baker 1986).

CURRENT RESEARCH

During the last decade, research on the single-tree selection method has been intensified in the following areas:

(1) Models have been developed that allow for the prediction and/or projection of merchantable growth and yield of uneven-aged loblolly-shortleaf pine stands (Murphy and Farrar 1982; Murphy and Farrar 1983; Farrar, Murphy and Willett 1984; Murphy and Farrar 1985).

(2) Methods for objectively regulating stand structure have been developed and evaluated (Farrar 1984; Farrar and Murphy 1988).

(3) Methods have been developed for preparing timber-marking guidelines using basal area, maximum diameter, q-factor (BDQ) stand structure regulation. The guidelines are available in a computer software package (Murphy 1989).

(4) The feasibility of precommercial thinning pine regeneration in uneven-aged stands has been evaluated (Cain, Baker and Murphy 1987).

(5) Results of long-term case studies utilizing single-tree selection have been documented (Farrar, Murphy and Colvin 1984; Farrar, Straka and Burkhardt 1989).

(6) Production and financial comparisons between even-aged and uneven-aged management have been made (Baker 1987; Guldin and Baker 1988; Guldin and Guldin 1990; Straka and Baker 1990).

FUTURE OPPORTUNITIES AND CHALLENGES

Even though much progress has been made over the last five decades in the development and application of the single-tree selection method for regenerating and sustaining uneven-aged loblolly-shortleaf pine stands, many gaps in knowledge still exist. The "traditional" single-tree selection method was formulated to insure the establishment and development of intolerant loblolly-shortleaf pine regeneration, and to provide for high and sustained yield of large sawlog-size pines. This assurance was provided through the elimination of the midstory and overstory hardwoods and the vigorous control of the understory hardwood brush with the use of herbicides.

Because of this constrained and somewhat conservative formulation of treatments, little is known about the management of pine-hardwood mixtures and the use of fire for controlling hardwoods under the single-tree selection method. In addition, little is known (or at least documented) regarding the impacts of the single-tree selection method on such non-timber values as wildlife habitat and populations, scenic beauty, recreational opportunities, biodiversity, water quality, or economics. Since many of these non-timber amenities are deemed important under the multiple-use management concept, the method must be evaluated in respect to them.

Research must also be intensified regarding the management of pine-hardwood mixtures and the use of herbicide alternatives. Since many of the non-timber values associated with forest management are often enhanced by the presence of hardwoods, it may become desirable that traditional silvicultural systems—which usually reduce or eliminate the hardwood component—be modified or adapted to include a hardwood component.

Silvicultural systems can often be formulated to provide for multiple resources within the biological constraints of the species under management. One of the most severe biological constraints in pine management, particularly the regeneration of pine, is maintaining adequate quantities of light for the establishment and development of regeneration. Thus, only enough hardwoods can be maintained in uneven-aged pine stands to allow for adequate light to reach the forest floor.

Some of the future silvicultural/genetic challenges or opportunities regarding the single-tree selection method may include:

1. The identification and classification of genetically superior trees in uneven-aged stands to be reserved for seed production.

2. Planting of genetically improved seedlings in uneven-aged stands to supplement insufficient natural regeneration.

3. Develop genetically superior seedlings of intolerant species with attributes of aggressiveness and tenacity, thus making them better able to compete with more shade tolerant hardwoods.

LITERATURE CITED

Baker, James B. 1986. The Crossett farm forestry forties after 41 years of selection management. Southern Journal of Applied Forestry 10:233-237.

Baker, James B. 1987. Production and financial comparisons of uneven-aged and even-aged management of loblolly pine. *In* Proceedings of the Fourth Biennial Southern Silvicultural Research Conference; 1986 November 4-6; Atlanta, GA. USDA Forest Service Gen. Tech. Rep. SE-42. Southeastern Forest Experiment Station, Asheville, NC. pp. 267-273.

Cain, Michael D., James B. Baker and Paul A. Murphy. 1987. Precommercial thinning of pine regeneration in uneven-aged stands. *In* Proceedings of the Fourth Biennial Southern Silvicultural Research Conference; 1986 November 4-6; Atlanta, GA. USDA Forest Service Gen. Tech. Rep. SE-42. Southeastern Forest Experiment Station, Asheville, NC. pp. 419-424.

Farrar, Robert M. 1984. Density control–natural stands. *In* Proceedings of the Symposium on the Loblolly Pine Ecosystem (West Region); 1984 March 20-22; Jackson, MS. Mississippi Cooperative Extension Service Publ. 1454. Mississippi Cooperative Extension Service, Mississippi State, MS. pp. 129-154.

Farrar, R.M., P.A. Murphy and R. Colvin. 1984. Hope farm woodland: 33-year production in an uneven-aged loblolly-shortleaf pine stand. Journal of Forestry 82:476-479.

Farrar, Robert M., Paul A. Murphy and R. Larry Willett. 1984. Tables for estimating growth and yield of uneven-aged stands of loblolly-shortleaf pine on average sites in the West Gulf area. Arkansas Agricultural Experiment Station Bulletin 874. Division of Agriculture, University of Arkansas, Fayetteville, AR. 21 p.

Farrar, Robert M. and Paul A. Murphy. 1988. Objective regulation of selection-managed stands of southern pine–A progress report. *In* Proceedings of the Fifth Biennial Southern Silvicultural Research Conference; 1988 November 1-3; Memphis, TN. USDA Forest Service Gen. Tech. Rep. SO-74. Southern Forest Experiment Station, New Orleans, LA. pp. 231-241.

Farrar, Robert M., Thomas J. Straka and Charles E. Burkhardt. 1989. A quarter century of selection management on Mississippi State farm forestry forties. Mississippi Agricultural and Forestry Experiment Station Tech. Bull. 164. Mississippi State, MS. 24 p.

Guldin, James M. and James B. Baker. 1988. Yield comparisons from even-aged and uneven-aged loblolly-shortleaf pine stands. Southern Journal of Applied Forestry 12:107-114.

Guldin, James M. and Richard W. Guldin. 1990. Economic assessments of even-aged and uneven-aged loblolly-shortleaf pine stands. *In* Proceedings of the Southern Forest Economics Workers; 1990 March 28-30; Monroe, LA. (In Press).

Murphy, Paul A. 1989. UEA TARGET–A computer program for developing a target stand structure using the BDQ regulation method. A paper presented at the Uneven-aged Management Workshop; 1989 November 13-14; Macon, GA. (On file at RWU-4106, Monticello, AR.)

Murphy, Paul A. and Robert M. Farrar. 1982. Interim models for basal area and volume projection of uneven-aged loblolly-shortleaf pine stands. Southern Journal of Applied Forestry 6:115-119.

Murphy, Paul A. and Robert M. Farrar. 1983. Sawtimber volume predictions for uneven-aged loblolly-shortleaf pine stands on average sites. Southern Journal of Applied Forestry 7:45-50.

Murphy, Paul A. and Robert M. Farrar. 1985. Growth and yield of uneven-aged pine stands in the Interior Highlands. USDA Forest Service Res. Pap. SO-218. Southern Forest Experiment Station, New Orleans, LA. 11 p.

Reynolds, R.R. 1980. The Crossett story: The beginning of forestry in southern Arkansas and northern Louisiana. USDA Forest Service Gen. Tech. Rep. SO-32. Southern Forest Experiment Station, New Orleans, LA. 40 p.

Reynolds, R.R., James B. Baker and Timothy T. Ku. 1984. Four decades of selection management on the Crossett farm forestry forties. Arkansas Agricultural Experiment Station Bulletin 872. Division of Agriculture, University of Arkansas, Fayetteville, AR. 43 p.

Straka, Thomas J. and James B. Baker. 1990. A financial assessment of capital-extensive management alternatives for storm-damaged timber. Southern Journal of Applied Forestry. (In Press).

Author

James B. Baker
Research Silviculturist
Southern Forest Experiment Station
P.O. Box 3516
Monticello, Arkansas 71655

OPENING REMARKS FOR THE GROUP SELECTION PANEL

John R. Naumann
Northern Region
Missoula, MT

Group selection is probably one of the most controversial silvicultural methods among Foresters, and one of the least understood by other resource professionals and by the public. At this time there is an appeal on the Shawnee National Forest claiming that a proposed group selection is really a bunch of clearcuts!

A good understanding of uneven-aged systems including group selection suffers from a lack of example. We have a number of first entries, but precious few stands, intentional or otherwise, that demonstrate the viability of this rather theoretical silvicultural system over the long run. Will Rogers is often quoted as having said "all I know is what I read in the newspapers." For Foresters that should read—all I know is what I see in the forest. The trouble is, not enough of us go to the forest these days. And unfortunately the only forestry the public knows is what they read in the newspapers.

If we take our charter from SAF Terminology our task here today is simple and we can make up some time on the program. SAF says group selection is a modification of the selection method in which trees are removed in small groups. We have just reviewed the selection method, so instead of single trees, think of small groups. On the other hand, there is a wide range of thought about group selection and this discussion will explore that range.

One school of thought takes a cue from nature and attempts to limit group selection to openings controlled by their edge. These are the "two tree length" people.

Others would use group selection as a device to simplify uneven-aged management by making it an aggregate of small, even-aged stands offering some hope of promoting seral species that would otherwise be lost in the shade of a single tree strategy.

Still others see group selection as an opportunity to respond to the variability inherent in any forest by removing a single tree here, a small group there, and shifting to microshelterwoods where good leave trees are available. These Foresters are not as concerned about size of openings as much as they are about the other issues associated with timber harvest.

Group selection can be any of these things as long as it meets two criteria.

1. It is managed as an uneven-aged system

2. Its practice assures regulation of yields

Now lets hear from our panel.

Author

John R. Naumann, Group Leader, Silviculture, Northern Region, P.O. Box 7669, Missoula, Montana 59807

THE GROUP SELECTION METHOD

Richard S. Barth
Idaho Panhandle National Forest
Silverton, ID

INTRODUCTION

Lewis Carroll's "Alice in Wonderland" records a very interesting exchange between Alice and the Cheshire cat that should be tucked away in the memory of every forester. Alice has come to a crossroads in her journey through Wonderland and is perplexed as to which road to follow. Spying the Cheshire cat nearby she approaches and asks: "Which way should I go from here, Sir Cat?" "That depends a good deal on where you want to get to" said the cat. "I don't much care where I get to" replied Alice. "Then it doesn't much matter which road you take" said the cat.

It makes good sense to know our destination before we choose which road to take. The choice of any silvicultural system sets the forester on a specific road that will pass by a number of points of interest and come out a specific place. This paper will discuss an endpoint (an uneven-aged stand), a means of getting there (group selection), and some things to watch (out) for along the way.

DESCRIPTION OF THE SYSTEM

Group selection is a silvicultural method that creates small aggregations of relatively even-age/size trees within a stand. Generally 3+ age classes are represented within a given stand in such a manner that the overall character of the stand is uneven-aged (Hawley 1962; Smith 1986). The ultimate intention is to create an optimum distribution of size/age classes in a mosaic of small contiguous groups (Powell 1987).

Size of Openings

One of the most frequently asked questions concerning the group selection method is "How large can I make the openings and still call it 'group selection'?" While the literature contains no clear answer to this question, several guidelines have been developed.

An acreage limitation is probably the simplest to implement with a range of 1/4 to 2 acres in size being most common, although occasionally a 5 acre maximum has been suggested (Blyth and Malcolm 1988).

Relating the size of opening to the height of the surrounding timber is also a common practice with a range of 1 to 2 tree heights up to a maximum of 4 tree heights being considered "normal" (Fisher 1981). For a 150' tall stand, and a two tree height opening size a unit would range from 1.5-2 acres depending on whether it was round or square. A four tree height opening would range from 6-8 acres.

Two other methods of determining opening size take into account its effect on microclimate: One method requires that the entire opening remain under the influence of the adjacent stands as regards its microclimate. This generally means small (less than 1 acre) cutting units. The other method says that units should be of a size that less than 50% of the opening is in full sunlight during those hours critical to the successful regeneration of the site. This can mean openings up to 7+ acres in size depending on slope, aspect, and distance from the equator (Fisher 1981).

In point of fact, administrative decisions concerning aesthetics, economic viability, size/age of harvestable material, and magnitude of the allowable cut often take precedence in determining opening size (Franklin and DeBell 1973; Alexander and Edminster 1977; Boucher and Hall 1989).

Biological considerations including insect and disease activity, the silvics of the individual tree species, wildlife requirements and watershed management criteria may also influence unit design.

Frequency of Entry

Cutting cycles ranging from 10-20 years are most commonly reported in the literature, although this can vary widely with special management needs. Shorter cutting cycles capture more mortality and provide quicker returns on investments, but do so at the cost of larger piece size and volume per acre harvest. Administrative costs are also correspondingly higher. Another trade-off is in timing of thinning; early thinnings produce early sawlogs but at the expense of product quality due to reduced natural pruning (Hensold 1988).

Administrative direction as to the level of management intensity is often the most important factor in deciding frequency of entry. All of the biological considerations mentioned above under "size of opening" are also applicable here.

Once the stand has been brought completely under management, the growth rate of the trees and existing or anticipated merchantability specifications are of increasing importance in timing stand entries. The time frame involved in bringing a stand completely under management varies with stand condition, level of stocking, and intensity of management, but is generally reported in the literature as 60+ years (Blyth and Malcolm 1988; Hensold 1988).

DESCRIPTION OF THE METHOD

Group selection is a regeneration method as well as a silvicultural system. As a method, it works through the creation of small openings in the stand of a size that the regeneration process may begin (Hawley 1962; Smith 1986).

Perhaps the biggest error made in implementing the group selection method is assuming that the regeneration process will occur in a satisfactory manner with little thought or effort on the part of the silviculturist. It is important to note that group selection is a method and not a "happening" to be left to the vagaries of nature. A workable regeneration prescription that takes into account the many factors that impinge on the success or failure of the regeneration process is an absolute necessity:

> The silvical requirements of the species being managed for must be known and accomodated. Shade tolerance/intolerance, degree and type of seed bed preparation needed, and susceptibility to pathogens must all be considered. For example, subalpine fir (*Abies lasiocarpa*) both begins and maximizes its photosynthetic rate at much lower light levels than Englemann spruce (*Picea engelmannii*) thus affording a competetive advantage to the fir under

conditions of dense shade. Subalpine fir's taproot averages 200% longer than Englemann spruce's at age two weeks, again giving an advantage to the fir in areas of deep duff and minimal site preparation (Knapp and Smith 1982).

Desired stocking levels—minimum/optimum/maximum—must be set, along with guidelines for the acceptability of advanced regeneration:

> Stocking levels can be developed using standard, even-aged yield tables or computer programs such as Stages' Prognosis Model (Stage 1973; Wykoff, Crookston and Stage 1982), however reduced growth rates due to proximity of the residual stand need to be taken into account somewhere in the calculations (Graham and Smith 1983).
>
> Radial growth and height growth are generally considered the best predictors of release potential for advance regeneration with the former being considered most diagnostic in some studies and the latter in others (Gravelle 1977; McCaughey and Schmidt 1982; Carlson and Schmidt 1989). Physiological shock, suppression, dwarfed or wrenched roots, broken tops, stem scars, and soil compaction are all factors that tend to prevent satisfactory release (and thus suitability) of advanced regeneration (Ferguson 1984). This can be a very important determination for the manager as research shows that good vigor trees grow 4-6 times faster than their poor vigor counterparts (McCaughey and Schmidt 1982; Cole and Schmidt 1986).

Overwhelming brush response, ingrowth of undesirable tree species and lack of an adequate seed crop have singularly or in combination doomed many group selection efforts to failure and therefore account must be taken of their potential occurrence (Franklin and DeBell 1973; Dale, Hemstrom and Franklin 1983). For example, one study of western hemlock (*Tsuga heterophylla*) regeneration under various light levels, reported up to 212 thousand stems per acre became established under "optimum" conditions, precluding or severely limiting establishment of other more desirable species (Jaeck 1984).

Based on the above considerations, the silviculturist must decide whether natural regeneration will produce the desired target stand or if it must be supplemented by planting or seeding. The composition of a naturally regenerated stand depends on seed bed characteristics, the composition of the seed source, and any advanced regeneration (Franklin and DeBell 1973). Without site preparation and a viable seed source, the group selection method will not produce adequate amounts of the generally more desirable intolerant species; or in some cases not enough stocking at all (Seidel and Head 1983; Ferguson, Stage and Boyd 1986; Smith and Miller 1987; Mosandl 1989; Dale, Hemstrom and Franklin 1983).

Finally the establishment of a monitoring or "feed-back" loop to evaluate post-harvest results is essential to improving our prescriptive abilities for a relatively untried silvicultural method (Ferguson 1984).

ADVANTAGES OF THE GROUP SELECTION METHOD

Given that the desired future condition of the stand/s to be managed includes that they have a multi-storied structure, the group selection method is considered to be easier to apply than the alternative single tree selection method (Haight 1987). This is due, at least in part, to the fact that many of the well understood principles of even-aged management apply with little or no modification (Alexander and Edminster 1977; Graham and Smith 1983).

Perhaps the most significant advantage that group selection has over single tree selection is in the regeneration of shade-intolerant species (Franklin and DeBell 1973; Graham and Smith 1983; Powell 1987). The literature is virtually unanimous that single tree selection generally precludes the establishment of intolerant regeneration at any normally prescribed residual stocking level. Opening size in group selection can be set to allow for or even encourage intolerant regeneration. However, many group selection schemes have failed at this point by not accurately assessing the amount of sunlight needed to successfully regenerate the desired intolerant species i.e. the openings were too small (Minckler 1989)!

The group selection method is also suitable for cleaning up small pockets of beetle or root rot-killed timber especially in areas where aesthetic considerations preclude larger openings.

Group selection also minimizes the dysgenic effect often associated with "selection cutting" or the "economic selection method". In addition, the openings created allow for the outplanting of genetically superior seedlings in an environment suitable to the expression of their full potential (Franklin and DeBell 1973; Bassman and Fins 1988).

Fuels managers generally prefer group selection over single tree because the slash created is concentrated on fewer acres having more treatment options. In addition, the residual stands are not as likely to exhibit the "ladder effect" of fuel structuring, common to single tree selection, and characterized by a contiguous canopy layer from near the ground to tree top levels.

Finally, biodiversity is maintained at a higher level since all phases of plant (and associated animal) succession are provided for. The "edge effect" is maximized under this system—a boon for some (but not all) wildlife (Peterson 1982; Scott and Gottfried 1983; Salwasser 1985).

DISADVANTAGES OF THE METHOD

Costs are generally higher for group selection than for the traditional clearcut, shelterwood, or seed tree methods, although generally lower than for individual tree selection (Powell 1987). Several factors contribute to these increased costs:

> Stand inventories need to be more precise and accurate in order to properly prescribe the management regime for each individual stand. This may require a separate sampling scheme for each size/age class that is being managed. Considerable on-the-ground follow-up is required to be sure the prescription is being correctly implemented through sale layout, administration, and post harvest activities (Alexander and Edminster 1977; Graham and Smith 1983).
>
> The group selection method requires a more intensive job of sale layout often including pre-location of skidding corridors, and locating, marking, and cruising small, elusive cutting units scattered randomly across the hillside (Graham and Smith 1983).
>
> Logging costs can be higher due to increased lateral skidding distances, and protective measures for the residual stand such as requiring locking carriages and intermediate supports on

cable skidding systems. Increases of 20% or more are commonly reported in the literature (Franklin and DeBell 1973; Benson and Gonsior 1981; Kaminski 1975).

Administration of the more complex timber sale contracts requires more on the ground time to ensure protection of residual values, however many failures of the system can be traced to poor administration and/or sale layout (Benson and Gonsior 1981).

Fuels management, reforestation, stand tending operations, and stand record keeping cost more because of the loss of economies of scale and the difficulty of tracking small units scattered over a large area (Carlisle and Chatarpaul 1984).

In addition to increased costs, several other disadvantages have been noted in the literature:

Although juvenile growth rates are usually higher under group selection than individual tree selection or shelterwood, they are less than that attainable by clearcutting (Magnuski 1976; Meldahl 1984; Minckler 1989).

Operations tend to be spread over a larger area to harvest an equivalent clearcut volume leading to increased amounts of road construction, stand tending entries and disturbance to wildlife.

Fragmentation of the landscape is becoming more of a concern. There is a considerable body of literature indicating that the size of cutting units associated with group selection and smaller patch clearcutting may be detrimental to a number of important wildlife species that need larger home ranges in which to operate (Wilson and Peter 1988).

Group selection-sized cutting units are at high risk to become frost pockets if located in the wrong terrain. This is important in selecting the species to be regenerated since, for example, Douglas-fir (*Psuedotsuga menziesii*) and western red cedar (*Thuja plicata*) are notably susceptible to frost damage, while western white pine (*Pinus monticola*) and lodgepole pine (*Pinus contorta*) are relatively resistant (Miller 1984).

Similarly, they can be pockets of extremely high humidity favorable to various disease organisms—especially rusts. Pathogens which transfer readily from mature overstory to newly established understory such as western spruce budworm (*Choristoneura occidantalis*) or dwarf mistletoe (*Arceuthobium* spp.) are particularly favored by uneven-aged management (Carlson and Schmidt 1989). Group selection with regeneration to non-host species is an exception and may even be desirable under certain conditions.

APPLICATION OF THE METHOD

As indicated in the introduction, it is very important to know where you want to "get to" when considering the group selection method. Perhaps the very poorest reason for choosing group selection is that "everyone else is doing it" and if I don't "have one" I'll be thought of as out of step with these rapidly changing times (heaven forbid!). This perceived pressure, along with a general ignorance of correct silvicultural terminology, has led to the fairly common practice of calling small patch cuts "group selection" regardless of their current management regime (Minckler 1989).

It has been noted that the various concerned publics often have their own ideas on how to manage their National Forests. It may matter little (to them) what name we give the silvicultural system that we employ nor how well it "fits" all of our objectives if we produce results (no matter how transitory) that are not acceptable to these publics. This should not be considered license, however for the professional community to play fast and loose with our nomenclature as certain loss of credibility and communicability will result.

There are four main areas that need to be addressed to ensure the success of any group selection silvicultural prescription.

1. You must have an appropriately chosen stand. Although the group selection method is considered by many to be one of the most versatile, there are situations where it is not a viable choice. Some of these are obvious, and some will become obvious as our knowledge/experience base grows. Stands which are too old and are not likely to last long enough (30-60+ years) to be brought fully under management are of course a poor choice as are stands so riddled with disease that large scale type conversion is the only sensible prescription (Graham and Smith 1983).

2. You must have reason/s why group selection is the system of choice e.g. an even-aged stand that must be converted to uneven-age in order to meet some specific management objectives. Accidents of stand history such as multiple light fires, succesive blowdown events, and pathogen attacks can structure the residual stand into small pockets suitable for harvest by this method.

There are not many stand conditions where uneven-aged management is essential to successfully regenerating the site. One example is Ponderosa pine (*Pinus ponderosa*) growing at the limits of its ecological amplitude (Graham and Smith 1983). The above are indicative, not all-inclusive and the creative silviculturist will no doubt think of many other possible applications (Tubbs 1989).

3. You must have a set of objectives for the stand/s that you are trying to attain. Foremost of these objectives will, of course, be to comply with the various forestry laws that have been enacted—Federal, state, and local. The current Forest Plan will also have "Standards and Guidelines" that serve as an overall management framework.

Other resource fields will often have objectives that must be taken into account e.g. the wildlife biologist may want to adjust the amount of "edge effect", the "cover/forage ratio", or the multi-storied nature of a landscape that will be created by a particular harvest plan. The hydrologist may need to manipulate water yields or enhance streamside vegetation and the landscape architect may want to modify the form, line or texture of a viewscape. All of these singly or in concert can often be accomodated by the group selection method (Bityukov 1988).

4. The fourth thing you must have is a written plan (silvicultural prescription) for integrating and achieving all these various management objectives. Several steps are involved in developing this plan:

First the stand data must be analyzed—you have to know what you've got! Silviculturists call this "diagnosis". Some of the more important stand attributes are:

Stand structure including age, size, number of stories, species distribution, and clumpiness or mosaic nature of the area must be analyzed. Modifying size and placement of harvest units to take advantage of existing stand structure as well as patterns of insect and disease activity should be routine.

Habitat type (land capability as expressed by the potential climax plant community) is an excellent indicator of expected brush response, likelihood of reforestation success, and site productivity. Browse species and production rates, best regeneration method, suitability of advanced regeneration, pathogenic response, and growth-triggered harvest intervals may all be at least partially inferred from habitat type.

Physiographic site—Harsh slopes, aspects, or elevations, and shallow or rocky soils are all conditions for which the group selection method may be especially suitable. The microclimate within the harvest units encourages the establishment of the more desirable shade-intolerant species.

Second, the silviculturist must put foot-prints on the ground. There is no substitute for this step! Knowing exactly where the root rot or bark beetle pockets are, or seeing first hand how the fire mosaic lays on the hillside, are essential to developing an attainable target stand, writing an appropriate prescription, and getting it implemented on the ground.

Third, having diagnosed the current stand conditions, the silviculturist must develop a target stand. (You have to know where you want to "get to"). Species to feature, resistance to pathogens, stocking levels, size of end product, and time frames involved must all be specified. In general, uneven-aged management requires more, not less, attention to detail than its even age counterpart (Long and Daniel 1990).

Fourth, close coordination with the sale layout crew is essential to be sure they understand the silvicultural objectives and can recognize the subtle differences in stand structure and pathogen activity that identify areas to be harvested and areas to be retained. This will usually require a whole new set of silvicultural footprints be scattered over the hillside!

Fifth, the silviculturist must specify future management needs and opportunities. Precommercial and commercial thinnings are often necessary to maintain the desired level of intolerant species in the stand or capture mortality associated with high levels of pathogen activity. Neglecting needed stand tending activities is one of the surest ways to doom any uneven-aged management system to failure (Jaeck 1984; Della-Bianca and Beck 1985; Cole and Schmidt 1986; Powell 1987; Smith and Miller 1987; Boucher and Hall 1989; Long and Daniel 1990).

Sixth, establishment of a monitoring/feedback loop to assess results and improve future prescriptive abilities should be an integral part of the process.

ADDITIONAL RESEARCH NEEDS

In doing the research for this paper, several "knowledge gaps" in the literature came to light. Listed below are some areas where additional research is needed if we are to correctly apply uneven-aged management to any significant portion of the forest.

Growth and yield estimates are sadly lacking for uneven-aged management regimes, particularly so in the northwest where even-aged management has dominated since we left off with "economic selection" (read: "high-grade") in the late 1940's—early 1950's. Attempts have been made to modify the Growth Prognosis Model to predict volumes under uneven-aged regimes with mixed results and unknown reliability, especially when dealing with younger stand components (Hensold 1988). A means of determining optimum stocking levels and "best" J-shaped curves needs to be worked out for these regimes over the wide range of stand and site conditions characteristic of northwest forests. Long term growth plots in stands managed under various uneven-aged prescriptions will provide some answers, but the complex interactions between site, stand, and treatment indicate that some kind of modeling will be necessary as it is nearly impossible to have enough long term tests to cover all conceivable situations (Corns and Pluth 1984; Dale, Hemstrom and Franklin 1983).

Our knowledge of silviculture needs to be further refined to indicate such things as how much site preparation, or percent full sunlight is essential to successful regeneration of a particular species or group of species.

A close look needs to be taken at the kind of traits being selected for in our various breeding programs. Will these traits continue to be of value if the "genetically superior" stock is outplanted underneath various densities of overstory or on sites with minimal levels of site preparation (Bassman and Fins 1988)?

It needs to be determined what effects the fragmentation of the landscape that occurs under group selection will have on the methods acceptability to the various other disciplines and publics concerned with managing the National Forests (Wilson and Peter 1988). A prescription cannot be said to be "silviculturally sound" unless it satisfies (to the extent possible) all the applicable management objectives.

EPILOGUE

Can the group selection method be made to "work" in our National Forests? Certainly! Keeping in mind the principles and caveats discussed above, there may be any number of sites and stand conditions where group selection will be optimum.

Can the group selection method be made to "fail" in our National Forests? Certainly! Forgetting the principles and caveats discussed above, there may be any number of sites and stand conditions where group selection will be found wanting.

Alice's question remains appropriate: "Which way should we go from here?" As does the Cheshire cat's answer: "It depends a good deal on where you want to get to!" And may this author add "It also depends a good deal on where you started from!"

BIBLIOGRAPHY

Alexander, R. R. and C. B. Edminster. 1977. Regulation and control of cut under uneven-aged management. U.S.111. Forest Service, Rocky Mountain Forest and Range Expermiment Station Research Paper RM-182.

Bassman, J. H. and L. Fins. 1988. Genetic considerations for culture of immature stands. Proceedings-Future Forests of the Mountain West: A stand culture symposium. U.S.D.A. Forest Service General Techinical Report, INT-243.

Benson, R. G. and M. J. Gonsior. 1981. Tree damage from skyline logging in a western larch/Douglas-fir stand. U.S.D.A. Forest Service Research Paper, Intermountain Forest and Range Experiment Station, INT-268.

Bityukov, N. A. 1988. Water balance of catchments in relation to fellings in beech forests in the NW Caucasus. Lesovedenie:103, 55-65.

Boucher, B. A. and O. F. Hall. 1989. Implementing group selection in Appalachian hardwoods using economic guidelines. Proceedings of the Seventh Central Harwoods Conference, North Central Forest Experiment Station GTR NC-132.

Blyth, J.F., and D.C. Malcolm. 1988. The development of a transformation to irregular forest: 35 years experience at the Glentress trial ares.

Carlisle, A. and L. Chatarpaul. 1984. Intensive forestry: Some socio-economic and environmental concerns. Petawawa National Forest Institute, Canadian Forestry Service information report PI-X-43.

Carlson, C. E. and W. Schmidt. 1989. Influence of overstory removal and western spruce budworm defoliation on growth of advance conifer regeneration in Montana. Intermountain Forest and Range Experiment Station, Research Paper INT-409.

Cole, D. M. and W. C. Schmidt. 1986. Site treatments influence development of a young mixed species western larch stand. U.S.D.A. Forest Service Intermountain Forest and Range Experiment Station research paper INT-364

Corns, I. G. W., and D. J. Pluth. 1984. Vegetational indicators as independent variables in forest growth prediction in West-central Alberta, Canada. Forest Ecology and Management: 9(1984)13-25.

Dale, V. H., M. A. Hemstrom, and J. Franklin. 1983. The effect of disturbance frequency on forest succession in the Pacific NW.

Della-Bianca, L. and D. C. Beck. 1985. Selection management in southern Appalachian hardwoods. Southern Journal of Applied Forestry, Society of American Foresters, August 1985. Vol.9(3) p. 191-196.

Ferguson, D. E. 1984. Needed: Guidelines for defining acceptable advance regeneration. U.S.D.A. Forest Service Intermountain Forest and Range Experiment Station Research Note INT-341

Ferguson, D. E., A. R. Stage, and R. J. Boyd. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystems of the northern Rocky Mountains. Forest Science Monograph 26 supplement to Forest Science Vol. 22, No 1 March 1986.

Fisher, B.C. 1981. Designing forest openings for the group selection method: SHADOS, a computer model. Southern Forest Experiment Station, General Technical Report for the Southern United States. (1981) (34) p 274-277.

Franklin, J. and D. S. DeBell. 1973. Effects of various harvesting methods on forest regeneration. Even-age Management Symposium, Oregon State University.

Graham, Russell T. and Richard A. Smith. 1983. Techniques for implementing the individual tree selection method in the grand fir-cedar-hemlock ecosystems of northern Idaho. U.S.D.A. Forest Service Intermountain Forest Range and Experiment Station Research Note INT-132.

Gravelle, P. 1977. Growth response and logging damage to advanced regeneration following overstory removal: the present state of knowledge. Potlatch Corporation, Lewiston, Idaho.

Green, E. J. and H. E. Burkhardt. 1984. Estimating optimum tree diameter for products with specified size. Northern Journal of Applied Forestry 3:60-61

Haight, R. G. 1987. Evaluating the efficiency of even-aged and uneven-aged stand management. Forest Science Vol. 33 No. 1 (1987) pp 116-134.

Hawley, R. C. and D. M. Smith. 1962. The Practice of Silviculture, John Wiley and Sons

Hensold, T. S. 1988. Evaluating alternative target structures for an uneven-aged ponderosa pine stand using the Stand Prognosis Model. Thesis for M.S. in Forest Resources, University of Idaho.

Irland, L. C. 1983. The new forest: Achieving and retaining favorable public opinion and supportive public policy. Newsweek July 25, 1983.

Jaeck, L. L., et al. 1984. Hemlock regeneration after partial cutting in light, medium, and dense overstory. Forest Science Vol. 30, No. 1, pp 117-124.

Kaminski, P. A. 1975. Silvicultural basis of commercial fellings in scots pine stands in group I forests in Sverdlovsk Province. pp 62-69.

Knapp, A. K. and W. K. Smith. 1982. Factors influencing understory seedling establishment of Englemann spruce and subalpine fir in southeast Wyoming. Canadian Journal of Botany 60:2753-2761.

Long, J. N. and T. W. Daniel. 1990. Assessment of growing stock in uneven-aged stands. Western Journal of Applied Forestry 5(3).

Magnuski, K. 1976. Growth of young Quercus robur under conditions of clear, partial or group fellings. Sylwan 120(7) 49-56.

McCaughey, W. W. and W. C. Schmidt. 1982. Understory tree release following harvest cutting in spruce-fir forests of the intermountain west. Intermountain Forest and Range Experiment Station Research Paper INT-285.

Meldahl, R. S., et al. 1984. Alternative methods for determining edge effect on small sample plots. Canadian Journal of Forest Research 14:874-878.

Miller, D. L. 1984. Survival and growth of containerized western red cedar in north Idaho. Potlatch Corp. Forestry Technical Paper TP-84-2.

Minckler, L. S. 1989. Intensive group selection silviculture in central hardwoods after 40 years. North Central Forest Experiment Station General Technical Report 132 p.35-39.

Mosandl, R. 1989. Group fellings in montane mixed forests. Forstliche, Forshungsberichte Munchen 1989 no. 61.

Peterson, R. M. 1982. Diversity requirements in the National Forest Management Act. Chief, U.S.D.A. Forest Service, Washington, D.C.

Powell, D. C. 1987. How to prepare a silvicultural prescription for uneven-aged management. U.S.D.A. Forest Service, Rocky Mountain Region, Pike and San Isabel National Forests.

Salwasser, H. et al. 1985. Applying the diversity concept to national forest management.

Scott, V. E. and G. J. Gottfried. 1983. Bird response to timber harvest in a mixed conifer forest in Arizona. Rocky Mountain Forest Experiment Station Research Paper NRM-245.

Seidel, K. W. and S. C. Head. 1983. Regeneration in mixed conifer partial cuttings in the Blue Mountains of Oregon and Washington. Pacific Northwest Forest and Range Experiment Station Research Paper PNW-310.

Smith, D. M. 1986. The Practice of Silviculture (eighth edition). John Wiley and Sons, Inc.

Smith, H. C. and G. W. Miller. 1987. Managing Appalachian hardwood stands using four regeneration practices - 34 year results. Northern Journal of Applied Forestry Vol. 4.

Otage, A. R. 1973. Prognosis model for stand development. Intermountain Forest and Range Experiment Station Research Paper INT 137.

Tubbs, C. 1989. Uneven-aged management: When do conditons require this approach? In New Perspectives on Silviculture and Management of Northern Harwoods. Northeast Forest Experiment Station General Technical Report GTR NE-124.

U.S. Department of Agriculture, Forest Service. 1978. Uneven-aged silviculture and management in the United States. General Technical Report WO-24.

Wade, M. J. and D. G. McCauley. 1984. Group selection: the interaction of local deme size and migration in the differentiation of small populations. Evolution Vol. 38 (5) pp. 1047-1058.

Wilson, E. O. and F. M. Peter. 1988. Biodiversity, National Academy Press, Washington, D.C.

Wykoff, W. R., N. L. Crookston, and A. R. Stage. 1982. User's guide to the stand prognosis model. Intermountain Forest and Range Experiment Station General Technical Report INT 133.

Note: While all entries in this bibliography were consulted in the writing of the paper, not all of them are specifically cited within the body of the report. They are included as potential reference material for those interested in a more in depth analysis of the group selection silvicultural system.

Author

Richard S. Barth
District Silviculturist
Wallace Ranger District
P.O. Box 14
Silverton, Idaho 83867

GROUP SELECTION
Genetic Implications

John Murphy, Hyun Kang, John Hazel, and Richard Meier
Eastern Region and North Central Experiment Station
Milwaukee, Madison, and Rhinelander, WI

INTRODUCTION

The previous paper has established the criteria and the silvicultural attributes of the group selection method. This paper is intended to explore the genetic implications of applying group selection. Group selection has not been extensively utilized. It is anticipated that use of the system will increase as a means to reach plan objectives. This being heavily influenced by a desire by some for a perceived gentler form of forest management. Past and present genetic implications of group selection have been masked in the general concept of avoiding dysgenic practices, such as high grading or diameter limit cutting. This dogma has satisfied most people with very little empirical data to substantiate specific genetic impacts. With a greater interest in biodiversity, a greater interest has developed in the genetic implications of management systems and in no management.

We will explore several specific situations of group selection implementation. We will interject some hypothetical situations and resulting genetic implications. We will conclude with some suggested management options that the land manager may want to consider. The intent being to enhance the genetic attributes of managed forests while still meeting a host of other Land and Resource Management Plan objects. It is not intended that enhancement of genetic attributes be considered just bigger and better veneer trees, but is the enhancement of the genetic attributes to reach the planned objectives.

CRITERIA FOR STAND REGENERATION

In looking at the various facets of regeneration that could have an influence on the genetic status of a stand over some given time period, we developed a flow chart, Figure 1, to display the arrangement of the regeneration parameters.

The figure represents two paths. The first being from the initial state of the stand which is solely influenced by natural factors to arrive at a final state for the assigned values. The other path from the initial state to the final state is influenced by the factors of the management practices applied and the natural fa^tors which may also be influenced by the management practice (group selection). The final states are in terms of the assigned values.

The following is a discussion of what could be considered the primary factors pertaining to the genetic implications of natural regeneration for each of the criteria segments.

Initial State (1)—This represents a view of the existing resource that is being addressed. The factors include the specie or species present, age of trees (even-age or uneven-age), an assessment of the genetic and phenotypic attributes of the trees, and stand history (high graded or not). Physical considerations such as slope, soils, aspect, proximity to like stands or species in conjunction with the basic silvics of the species could have a bearing on the final state.

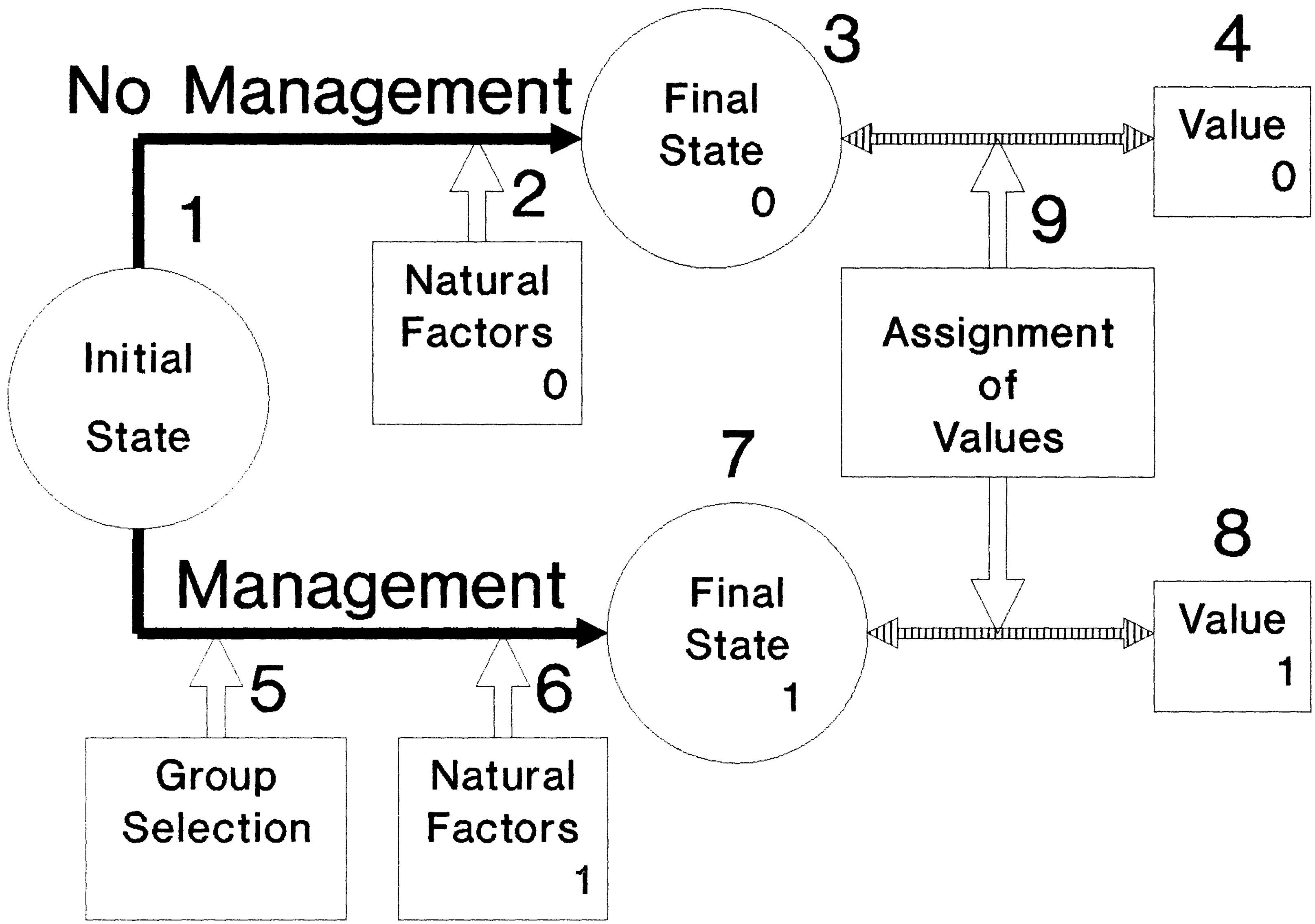


Figure 1. Criteria for regeneration.

Values (4)—In addressing the genetic implications of group selection, a key value is the time frame being considered. This simply translates to the genetic implication after a single entry or time period may be vastly different than the implications after several entries and time periods. Another key value is the management objectives or complex of objectives such as maximum or minimum genetic or species diversity. Are the objectives high quality large veneer trees, or small burly trees for wildlife or both.

Natural Factors (2)(6)—Many natural factors come into play on the initial state condition. The basic reproductive regime (seeding or sprouting) for the stand may be influenced by the environmental factors present during the reproductive phase (moisture, temperature, insects, disease,etc).

Group Selection (5)—The application and implementation of this system can influence both the basic biological factors of the initial state as well as how the natural factors influence the process. In group selection two primary thoughts prevail. The first being that the groups can be in the realm of two trees in size to two acres or even up to five acres in some minds. The other thought is that group selection is applied to reach a reversed J curve that plots the number of stems over diameters and reflects an ideal uneven-aged management condition. In either case the objective is to reach or maintain an uneven-age condition. Likewise in either, the size and configuration of the openings created can have a dramatic effect on the reproduction produced. If some degree of age distribution is desired, the ability to discern the ages of the trees is imperative to prevent the potential of creating and uneven sized but even-age stand. To some, making the proper selection is difficult to simulate on paper, and may be virtually impossible in the field.

Final State (3) and (8)—The culmination of the thought process is an evaluation of the conditions in terms of the assigned values resulting from the management and natural factors applied. As an example the value assigned may be a twenty year period or 100 years. Based on that value the final state at 20 years could be very different than the state at 100 years.

HYPOTHETICAL (POTENTIAL) CASE RESULTS

The following discussion is divided into two section (A) Artificial Selection Influence, and (B) Computer Simulation. Both are intended to demonstrate potential results given situations where some of the factors discussed above are incorporated. The flow from initial state to final state can be viewed as trying to assemble a very large complex jigsaw puzzle. The following examples are an attempt to separate out some of the pieces such as the boarder pieces and put them together. The thinking being that if all the pieces are tried at once, the faint at heart may give up. Completing the boarder may allow a basic view of the problem with the potential for filling in the center as time progresses.

ARTIFICIAL SELECTION

In the previous sections, we have assumed that group selection will significantly influence the final state of the forest stand being manipulated—i.e., F(0) is different from F(1). If F(0)=F(1) regardless of how group selection is applied, then this will lead to the trivial conclusion that there is no need for management, or to be concerned about different group selection applications.

We indicated that few empirical examples are available to guide us in answering various questions in group selection. We need to note that we do not have well defined measures to be used in determining the nature and magnitude of differences, although we assume some differences might (or must) exist in the final states depending on the group selection methods used. Therefore, to determine the measures to compare the final states, we must first define the variables and values assigned to the variables. We also need to determine when the observed differences may be considered significant.

Despite the difficulties in determining the measures and their significance, we ask: Will group selection seriously influence the genetic properties of naturally regenerated forest tree populations? Traditionally, the answer to this question has been assumed to be "yes". With this assumption, silviculture books (Daniel et al. 1979, Smith 1962) intuitively described genetic consequences of various reproduction methods. Many forest geneticists also have assumed that an intense selection in natural population could be effective in obtaining genetic gain (Zobel and Talbert 1984, Ledig 1974), and compared efficiencies of using different selection techniques (Ledig 1974). The above geneticists' assumption can be translated into saying that intensive selective harvesting or regeneration methods that leave a small number of extreme individuals could significantly influence the genetic structure of the naturally regenerated populations.

Currently available research results, however, offer mixed conclusions. Pitcher (1982) and Neale (1985) indicated that selective harvesting and/or regeneration methods have little impact on the genetic properties of naturally regenerated populations, while Wilusz and Giertych (1984) and Yazdani et al. (1985) offered the opposite conclusion. Roberds and Conkle (1984) observed in a pair of loblolly pine populations–parent population and its naturally regenerated progeny population–that although allele frequencies did not differ, the genetic substructures (F-statistics) differed between successive generations. Therefore, we may at best conclude that the results are mixed in these empirical experiments.

It is apparent from the above literatures that the criteria of measurements varied and the significance equalled "statistical significance". We will not judge the value of different selection criteria. However, we will attempt to point out that the statistical significance of a quantitative trait is quite conservative representation of significant difference. To make this point clearer, we will use another means of defining "seriousness" or "significance". Most geneticists agree that the changes in peppered moth in response to the progressive pollution of the environment by coal soot during the industrial revolution in Manchester, England (Industrial melanism) would represent a dramatic evolutionary change observed (Hartl 1980). Therefore, if the changes in a quantitative trait in response to a group selection is greater than that observed in Industrial Melanism, we may say that the selection significantly influenced the naturally regenerating populations.

Table 1 shows results of comparing the statistical significance and Industrial Melanism on the per generation basis. Many different assumptions are made in developing the assumptions (See Kang 1989 for detailed discussions). From the columns headed by letter "s", which means selection coefficient, we can see that the s values of statistical significance could be 2 to 4 times greater than that of Industrial Melanism. Therefore, if we observe statistically significant differences between two populations with respect to a quantitative trait at 5% level, then this means that the selection pressure from group selection was 2 to 4 times greater than that observed in Industrial Melanism, indicating that artificial selection could be much stronger than a strong natural selection. The difference with respect to heritability is much greater between the two types. However, heritability does not have as significant role in this comparison. It shows that heritability as small as .003 could have an important evolutionary meaning.

Table 1. Comparison of strengths of Statistical Significance and Industrial Melanism with respect to heritability, average effect of allele substitution, and Selection coefficients (Single generation of selection, p: Proportion of individuals selected in the population, i: Selection intensity, h^2: Heritability, a: Average effect of allele substitution, and s: Selection coefficient).

		Statistical Significance at 5% level			Industrial Melanism		
p	i	h^2	a	s	h^2	a	s
4/400	2.621	0.045	0.300	0.786	0.003	0.076	0.2
20/400	2.051	0.057	0.338	0.692	0.005	0.098	0.2
40/400	1.749	0.067	0.366	0.64	0.006	0.114	0.2
100/400	1.268	0.092	0.429	0.544	0.012	0.158	0.2
200/400	0.796	0.147	0.542	0.431	0.031	0.251	0.2

When Pitcher's data (1982) was reexamined with this in mind, we find that the null hypotheses regarding differences with respect to height among different select groups (good, average, and poor) were not rejected at 5% level, because the mean differences (0.11) were slightly less than the significance values (0.117). Therefore, pitcher concluded that selection in natural populations may not be of great importance. However, if we accept the difference between populations 0.11 as the true difference, then this still would indicate that the artificial selection was quite strong.

We need to make many more empirical experiments designed to measure the strength of artificial selections in naturally regenerated populations. However, it is useful to keep in mind that (1) The meaning of significance could be defined in different ways; (2) statistical significance is a conservative means of defining significant differences between population mean; and (3) Artificial selection tends to have a stronger impact on the population than natural selection in naturally evolving populations.

COMPUTER SIMULATION

A computer program of limited scale has been developed to attempt to simulate the sexual reproduction of natural regeneration. The following is a discussion of how the systems operates and the results of four scenarios.

Basic Assumption:

A stand is created which is assumed to be an even-aged stand with various genetic attributes. The stand (or portion of a stand) is located within a large area of the same single species (See Appendix). The area being considered has fixed site factors forming a diagonal valley. The bottom being a higher value than the sides. The site factors are intended to represent some factor such as slope or moisture. The stand is assumed to be of a single species, reproduced sexually, and that trees within the stand contribute pollen to surrounding trees within range and all trees receive background pollen from outside the area.

Genetic Values:

Each tree has a genetic value, female value, and male value. The female and male genetic values initially are in the range of 2-12. Genetic value is calculated by adding the female and male value divided by 2 (rounded down to a whole number).

Each tree can produce eight seeds. Female value for the seed is selected at random from the male or female of the mother tree. Self pollination is not allowed. Each seed can receive up to ten pollen from surrounding trees within range, plus a background pollen. In addition, there is a background pollen consisting of the male genetic values one through ten. Pollen is dispersed at random to all sites within the pollen distribution range.

Seed (seedling) genetic value is calculated as stated above. The pollen being selected at random from the number of pollens (up to ten) that are present on the seed site. If the last pollen number is selected then the male value will be selected at random from the background pollen.

Seed is disseminated to points selected at random within the same range from the mother tree that pollen is disseminated.

The stand is then grown to reproductive stage again with appropriate phenotypic values assigned by adding the site value to the genetic value or existing phenotypic value if a tree was designated for retention. The phenotypic value is consider to be a character such as visible diameter.

In the transition from seedlings to trees, the original seeding trees are removed and the volume is accrued.

Options are then available to designate trees to be retained through the next generation or trees that are to be removed. Trees can be removed by designating leave trees or by diameter limits from above and/or below. The phenotypic value is accrued for the cut trees as the volume removed. This cut can be perceived as a preparatory cut for regeneration.

All of the above process is carried out without being aware of the genetic values of the trees. A summary indicates the total value of average genetic value of the trees and the number of trees.

Four scenarios have been developed. All start from the same basic stand. All are subject to the 1-10 background pollen. All go through the same time period (reproductive cycles). In each scenario, there are two trees at the top and four at the bottom of the area that are retained through all cycles, thus they provide pollen and seed to the area being manipulated (see appendix).

The following are descriptions of the four scenarios A1, A2, A3, and A4:

A1 Reverse J—In this case it was assumed that after the base stand was regenerated, it would be attempted to cut the stand to obtain the following distribution of diameters:

DBH	07	08	09	10	11	12	13	14
# trees	05	04	03	02	01	01	02	02

In some instances the number of desired trees in a dbh class were not present, so substitutes were made from a higher or lower class. Each time 18-19 trees were retained in the area.

A2 Larger Group—The area was divided into 4 cells of 5x5 units. All trees in two units (top left and bottom right) were designated to be retained. In the other two units 4 trees were retained as evenly spaced as practical without regard for diameter (phenotypic value). Each generation the process was reversed for the units.

A3 Diameter Limit Above—In this situation all trees that had a diameter limit of 10 or above were cut in each cycle.

A4 Diameter Limit Below—All trees that had a diameter of 10 or below were cut in each cycle.

Results—The results for each cycle of all scenarios is shown in Table 2.

Table 2. Scenario Results.

Title: A1-Rev J

Cycle	Start	1	2	3	END*
Average Genetic Value	7.0	6.3	6.0	5.8	6.26
Count	10	24	25	24	56
Volume Removed	-	261	303	281	-
Seed Tree Volume	-	98	174	180	170

Title: A2 Group

Cycle	Start	1	2	3	END*
Average Genetic Value	7.0	6.4	6.1	6.2	5.9
Count	10	33	37	37	75
Volume Removed	-	170	342	443	-
Seed Tree Volume	-	98	88	78	85

Title: A3 Diam Plus

Cycle	Start	1	2	3	END*
Average Genetic Value	7.0	5.2	4.5	4.4	4.5
Count	10	21	44	36	55
Volume Removed	-	314	153	105	-
Seed Tree Volume	-	98	121	290	223

Title: A4 Diam Minus

Cycle	Start	1	2	3	END*
Average Genetic Value	7.0	7.3	7.2	7.4	6.7
Count	10	23	23	24	64
Volume Removed	-	231	206	202	-
Seed Tree Volume	-	98	204	207	221

* Results after regenerating and before removing any trees except the seed trees.

Table 3. Volume Removed

Case	A1	A2	A3	A4
Cut Vol	845	785	572	639
Seed Vol	622	349	732	509
Total	1467	1134	1304	1148

Results: It is sometimes difficult in working with this type of program, to remember that only some of the total factors of reality are being looked at in a very simplified fashion. However, there may be some inferences that can be observed in the single examples of the various scenarios.

Genetic Value: The implication is that the genetic value for the desired trait has a slight downward tendency in the J curve and group selection. The diameter limit trend is as expected, take out the big trees and the genetic value goes down, leave bigger trees and the value rises.

Volume removed: Assuming one has markets for all diameter classes, the removal of all size classes in the Reversed J case produced more volume in the long haul. The other three examples are very close.

Spacing: A subjective observation of the distribution of leave trees appears to indicate better spacing in the group selections case (A1 and A2). In the diameter limit cases there is a tendency to distribute trees along the site values depend on whether thinning above or below. This could have significant importance if other non desirable species filled in the voids, thus perhaps reducing the overall population frequency over time.

DISCUSSION OF BIOLOGICAL IMPLICATIONS

Based on the hypothetical examples it would appear very unlikely that the PROPER application of group selection would adversely effect the genetic resource over time. This is with the assumption that stands are being regenerated sexually with sufficient variety and diversity from surrounding trees and areas.

The primary concern would be in not being able to economically apply the system properly, or trying to apply the system where the silvics of the species would not lend itself to proper species population maintenance. It is imperative that sufficient data on the stand, such as diameter distribution, be collected prior to implementation of group selection with properly skilled personnel.

MANAGEMENT IMPLICATIONS

When group selection is to be implemented in an attempt to obtain many Land Management practices, higher skill levels may need to be in place. Special care must be exercised in determining the status of the existing stand and the silvics of the species involved in order to meet the desired objectives over the long run. Particular care must be exercised to insure that age distribution is being maintained, not just diameter distribution. All factors must be completely evaluated in order to be sure the puzzle can be put together.

It is evident that additional studies in the field along with advanced simulation models are necessary to obtain a greater understanding of the long term genetic implications of group selection.

CONCLUSION

Group selection, like other practices such as shelter wood or clear cutting, is a viable tool for the land manager. Prudent use of the system considering all the factors can result in meeting the objectives of Land Management Planning.

LITERATURE CITED

Daniel, T.W., J.A. Helms, and F.S. Baker. 1979. Principles of Silviculture. McGraw-Hill, New York.

Hartl, D.L. 1980. Principles of Population Genetics. Sinauer Associates, Sunderland, MA.

Kang, H. 1989. Population Genetics Theory in Managing Naturally Regenerated Forests. Proceedings of the Thirty-first NEFTIC and the Sixth NCTIA. pp. 48-62.

Ledig, F.T. 1974. An analysis of methods for the selection of trees from wild stands. Forest Science 20:2-16.

Neale, D.B. 1985. Genetic implications of shelterwood regeneration of Douglas-fir in Southwest Oregon. Forest Science 31:995-1005.

Pitcher, J.A. 1982. Phenotype selection and half-sib family performance in black cherry. Forest Science 28:251-256.

Roberds, J.H. and M.T. Conkle. 1984. Genetic structure in Loblolly pine stands: Allozyme variation in parents and progeny. Forest Science 30:319-329.

Smith, D.M. 1962. The practice of silviculture. John Wiley & Sons.

Wilusz, W. and M. Giertych. 1974. Effects of classical silviculture on the genetic quality of progeny. Silvae Genetica 23:127-130.

Yazdani, R., O. Muona, D. Rudin, and A.E. Szmidt. 1985. Genetic structure of a Pinus sylvestris L. seed-tree stand and naturally regenerated understory.

Zobel, B.J. and J.T. Talbert. 1984. Applied Forest Tree Improvement. John Wiley & Sons, New York.

Authors

John D. Murphy
Regional Geneticist
Eastern Region
310 W. Wisconsin Avenue
Milwaukee, Wisconsin 53203

Hyun C. Kang
Population Geneticist
North Central Forest Experiment Station
1630 Linden Drive
Madison, Wisconsin 53706

John W. Hazel
Regional Silviculturist
Eastern Region
310 W. Wisconsin Avenue
Milwaukee, Wisconsin 53203

Richard J. Meier
Zone Geneticist
Eastern Region
68 S. Stevens Street
Rhinelander, Wisconsin 54501

APPENDIX 1

SITE MAP

		1	2	3	4	5	6	7	8	9	10
1	AA	1	1	1	2	2	3	3	4	4	5
2	AB	1	1	2	2	3	3	4	4	5	5
3	AC	1	2	2	3	3	4	4	5	5	5
4	AD	2	2	3	3	4	4	5	5	5	5
5	AE	2	3	3	4	4	5	5	5	5	4
6	AF	3	3	4	4	5	5	5	5	4	4
7	AG	3	4	4	5	5	5	5	4	4	3
8	AH	4	4	5	5	5	5	4	4	3	3
9	AI	4	5	5	5	5	4	4	3	3	2
10	AJ	5	5	5	5	4	4	3	3	2	2
11	AK	5	5	5	4	4	3	3	2	2	1
12	AL	5	5	4	4	3	3	2	2	1	1
13	AM	5	4	4	3	3	2	2	1	1	1

APPENDIX 2

REPRODUCTION EXAMPLE

		1	2	3	4	5	6	7	8	9	10
1	AA	P	P	P	P	P	P	P	-	-	-
2	AB	P	P	P	P	P	P	P	-	-	-
3	AC	P	P	[S]	[S]	[S]	P	P	-	-	-
4	AD	P	P	[S]	T2	[S]	P	P	-	-	-
5	AE	P	P	[S]	[S]	[S]	P	P	-	-	-
6	AF	P	P	P	P	P	P	P	-	-	-
7	AG	P	P	P	P	P	P	P	-	S1	-
8	AH	-	-	-	-	S1	-	-	-	-	-
9	AI	-	-	-	-	-	-	-	-	S1	-
10	AJ	-	-	-	-	S1	-	T2	-	-	-
11	AK	-	-	-	S1	-	-	-	-	S1	-
12	AL	-	-	-	-	-	S1	-	-	S1	-
13	AM	-	-	-	-	-	-	-	-	-	-

Tree T2 has Genetic Value (GV)
GV = (Male Value + Female Value) / 2
GV of Seed: (MV^1 + FV^2) / 2

[1] Female: Selected at random from MV or FV of T2
[2] Male: Selected at random from up to 10 pollens from other T2 trees

S1 = random placement of S from T2

☐ = Range of Dispersal

APPENDIX 3

PHENO MAP

A1: 10-1 [ ] = Trees to be held, no cut.

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[9]	-	-	-	[10]	-	-
2	AB	-	[9]	-	-	-	-	[14]	10	-	-
3	AC	[6]	-	[8]	-	-	11	-	-	[8]	-
4	AD	-	[10]	-	10	-	[9]	11	-	-	-
5	AE	10	-	9	10	10	14	-	11	-	-
6	AF	-	-	-	-	[13]	12	[12]	10	-	-
7	AG	[9]	-	-	12	-	10	9	-	-	-
8	AH	8	-	-	-	11	-	[8]	-	-	-
9	AI	[8]	12	-	[14]	-	11	[10]	-	-	10
10	AJ	-	-	10	[13]	9	-	-	-	-	[11]
11	AK	-	-	11	9	-	[6]	[6]	11	-	-
12	AL	-	-	-	-	-	-	[9]	-	[5]	-
13	AM	-	-	-	[11]	-	[9]	-	-	-	-

APPENDIX 4

PHENO MAP
A1: 10-2

		1	2	3	4	5	6	7	8	9	10
1	AA	7	6	10	[11]	-	8	-	[14]	-	13
2	AB	-	-	6	12	6	-	-	10	-	-
3	AC	-	[8]	-	-	-	-	-	[13]	-	-
4	AD	[6]	-	[10]	[8]	13	-	10	[7]	12	-
5	AE	6	-	[7]	10	[9]	[12]	-	10	-	-
6	AF	-	[9]	-	-	-	-	-	-	-	-
7	AG	-	10	-	12	-	11	12	10	-	-
8	AH	-	[12]	-	12	10	[13]	-	[8]	[10]	10
9	AI	-	-	-	-	10	6	-	[9]	-	-
10	AJ	[14]	-	[11]	-	12	-	5	[7]	5	-
11	AK	-	-	-	-	-	-	-	[7]	-	-
12	AL	-	-	-	-	-	10	[11]	9	[6]	7
13	AM	-	-	7	[14]	-	[11]	6	-	-	-

APPENDIX 5

PHENO MAP
A1: 10-3

		1	2	3	4	5	6	7	8	9	10
1	AA	-	3	-	[13]	-	5	7	[18]	-	-
2	AB	-	-	-	5	[13]	-	[8]	6	16	-
3	AC	[6]	-	-	-	[7]	-	-	-	-	-
4	AD	-	6	-	-	10	[7]	[11]	-	-	-
5	AE	-	[7]	-	[10]	-	-	-	[7]	-	13
6	AF	[5]	-	-	-	10	10	[9]	13	[10]	-
7	AG	-	-	-	10-	[14]	-	-	-	-	
8	AH	-	-	-	[13]	13	-	-	-	-	-
9	AI	-	[13]	-	12	-	12	10	-	[12]	6
10	AJ	-	14	-	13	-	9	[9]	-	10	-
11	AK	-	-	-	11	[9]	5	11	-	-	-
12	AL	-	-	-	-	-	10	[13]	6	[7]	-
13	AM	10	-	-	[17]	-	[13]	3	5	7	-

APPENDIX 6

PHENO MAP

A1: 10-4

		1	2	3	4	5	6	7	8	9	10
1	AA	3	-	7	[15]	8	-	-	[22]	10	-
2	AB	6	6	9	-	-	-	-	109	-	
3	AC	-	-	-	11	-	11	10	-	-	10
4	AD	-	6	-	11	13	-	-	11	-	11
5	AE	-	-	-	-	8	-	-	-	11-	
6	AF	-	11	-	9	-	-	-	13	-	12
7	AG	9	-	-	-	-	-	14	-	-	8
8	AH	-	-	12	-	13	10	11	6	-	-
9	AI	-	-	11	9	-	10	13	-	11	
10	AJ	-	-	-	-	-	8	-	10	-	7
11	AK	-	12	-	13	-	-	-	9	-	-
12	AL	-	-	-	11	11	8	[15]	10	[8]	-
13	AM	10	-	-	[20]	9	[15]	-	-	7	-

APPENDIX 7

PHENO MAP
A2: 10-1

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[9]	-	-	-	[10]	-	-
2	AB	-	[9]	-	-	-	-	[14]	10	-	-
3	AC	6	-	[8]	-	-	11	-	-	[8]	-
4	AD	-	[10]	-	[10]	-	9	11	-	-	-
5	AE	[10]	-	[9]	[10]	[10]	[14]	-	11	-	-
6	AF	-	-	-	-	[13]	12	12	[10]	-	-
7	AG	7	-	-	[12]	-	[10]	[9]	-	-	-
8	AH	8	-	-	-	11	-	[8]	-	-	-
9	AI	[8]	12	-	[14]	-	[11]	[10]	-	-	[10]
10	AJ	-	-	10	13	9	-	-	-	-	[11]
11	AK	-	-	[11]	9	-	[6]	[6]	[11]	-	-
12	AL	-	-	-	-	-	-	[9]	-	[5]	-
13	AM	-	-	-	[11]	-	[9]	-	-	-	-

APPENDIX 8

PHENO MAP
A2: 10-2

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	8	[11]	-	-	11	[14]	8	-
2	AB	-	[10]	8	10	-	11	-	-	-	-
3	AC	7	-	10	[10]	10	-	-	-	-	8
4	AD	8	12	-	9	12	12	9	11	-	13
5	AE	12	9	12	[14]	14	-	9	-	-	-
6	AF	-	[9]	-	8	18	-	8	-	10	-
7	AG	-	8	10	15	11	[15]	14	-	-	[7]
8	AH	-	-	10	9	9	10	12	6	-	-
9	AI	-	-	-	-	-	15	14	9	-	12
10	AJ	-	-	12	11	13	-	[10]	-	-	[13]
11	AK	11	14	-	6	11	9	9	13	-	9
12	AL	-	-	11	5	10	-	[11]	-	[6]	-
13	AM	-	-	-	[14]	-	[11]	-	-	-	5

APPENDIX 9

PHENO MAP
A2: 10-3

		1	2	3	4	5	6	7	8	9	10
1	AA	-	6	-	[13]	-	-	-	[18]	-	-
2	AB	-	-	10	6	9	[14]	8	10	9	-
3	AC	-	12	10	-	-	8	12	13	[11]	13
4	AD	6	9	9	10	-	16	14	16	-	18
5	AE	10	-	-	-	-	-	[14]	-	8	-
6	AF	-	-	-	7	-	-	13	14	[14]	-
7	AG	-	[12]	14	20	16	-	-	-	-	9
8	AH	-	-	15	14	[14]	-	-	13	6	9
9	AI	10	-	11	-	13	8	-	-	-	8
10	AJ	-	8	17	16	[17]	10	-	7	-	-
11	AK	16	[19]	13	10	15	-	7	10	10	5
12	AL	11	-	-	11	-	6	[13]	6	[7]	-
13	AM	-	-	-	[17]	9	[13]	-	5	9	-

APPENDIX 10

PHENO MAP

A2: 10-4

		1	2	3	4	5	6	7	8	9	10
1	AA	5	7	-	[15]	-	-	-	[22]	-	10
2	AB	-	-	12	8	12	-	9	-	12	-
3	AC	-	14	12	12	-	7	13	11	-	-
4	AD	8	11	12	13	9	-	10	13	-	-
5	AE	12	-	-	8	8	14	-	-	11	-
6	AF	-	8	13	11	11	-	-	11	-	-
7	AG	7	-	-	-	10	10	-	5	-	12
8	AH	8	-	9	12	-	12	-	17	9	12
9	AI	-	13	7	-	-	12	9	-	7	10
10	AJ	13	13	-	14	-	14	-	10	-	6
11	AK	-	-	-	14	-	-	10	12	12	6
12	AL	11	-	11	6	13	10	[15]	-	[8]	-
13	AM	-	10	-	[20]	10	[15]	3	9	-	-

APPENDIX 11

PHENO MAP

A3: 10-1

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[9]	-	-	-	[10]	-	-
2	AB	-	9	-	-	-	-	14	10	-	-
3	AC	6	-	8	-	-	11	-	-	8	-
4	AD	-	10	-	10	-	9	11	-	-	-
5	AE	10	-	9	10	10	14	-	11	-	-
6	AF	-	-	-	-	13	12	12	10	-	-
7	AG	9	-	-	12	-	10	9	-	-	-
8	AH	8	-	-	-	11	-	8	-	-	-
9	AI	8	12	-	14	-	11	10	-	-	10
10	AJ	-	-	10	13	9	-	-	-	-	11
11	AK	-	-	11	9	-	6	6	11	-	-
12	AL	-	-	-	-	-	-	[9]	-	[5]	-
13	AM	-	-	-	[11]	-	[9]	-	-	-	-

APPENDIX 12

PHENO MAP

A3: 10-2

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[11]	6	9	8	[14]	-	7
2	AB	-	-	7	10	10	-	-	9	13	-
3	AC	-	-	-	11	7	-	7	-	-	-
4	AD	-	9	7	9	12	-	-	-	-	-
5	AE	-	-	-	8	-	11	-	9	-	10
6	AF	-	-	-	9	9	-	-	11	-	-
7	AG	-	-	8	-	-	9	-	-	-	6
8	AH	-	9	-	8	-	9	-	6	4	-
9	AI	-	-	10	11	-	7	8	-	-	-
10	AJ	-	-	12	8	-	10	-	9	-	7
11	AK	-	9	11	-	8	-	-	-	4	9
12	AL	11	8	-	9	-	-	[11]	7	[6]	4
13	AM	-	-	-	[14]	-	[11]	8	-	-	6

APPENDIX 13

PHENO MAP
A3: 10-3

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[13]	-	-	-	[18]	5	-
2	AB	5	-	-	-	6	-	-	-	-	-
3	AC	6	-	9	-	-	-	-	10	8	9
4	AD	-	-	-	-	6	7	7	-	-	-
5	AE	-	8	7	-	-	-	-	-	13	-
6	AF	6	-	-	-	-	-	11	-	8	-
7	AG	10	8	-	-	-	-	10	9	9	-
8	AH	-	-	-	-	11	-	-	-	-	9
9	AI	9	10	9	-	-	-	-	6	6	-
10	AJ	10	-	-	-	-	6	8	-	6	-
11	AK	9	-	8	-	-	-	-	-	-	-
12	AL	10	-	-	-	-	-	[13]	-	[7]	-
13	AM	10	9	-	[17]	-	[13]	-	8	7	-

APPENDIX 14

PHENO MAP
A3: 10-4

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	7	[15]	-	-	4	[22]	-	-
2	AB	-	-	-	4	-	11	9	5	11	6
3	AC	-	-	-	6	6	-	6	-	-	-
4	AD	-	-	-	5	-	-	-	-	-	12
5	AE	8	-	-	9	-	8	8	-	-	-
6	AF	-	9	-	-	9	9	10	10	-	9
7	AG	-	-	-	-	11	-	8	-	-	-
8	AH	8	-	-	-	9	8	9	10	-	-
9	AI	-	-	-	7	11	-	-	-	-	5
10	AJ	8	11	-	11	12	-	-	-	-	-
11	AK	-	10	-	10	6	6	11	-	8	4
12	AL	-	8	-	7	-	7	[15]	-	[8]	5
13	AM	-	-	7	[20]	-	[15]	-	-	-	-

APPENDIX 15

PHENO MAP
A4: 10-1

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[9]	-	-	-	[10]	-	-
2	AB	-	9	-	-	-	-	14	10	-	-
3	AC	6	-	8	-	-	11	-	-	8	-
4	AD	-	10	-	10	-	9	11	-	-	-
5	AE	10	-	9	10	10	14	-	11	-	-
6	AF	-	-	-	-	13	12	12	10	-	-
7	AG	9	-	-	12	-	10	9	-	-	-
8	AH	8	-	-	-	11	-	8	-	-	-
9	AI	8	12	-	14	-	11	10	-	-	10
10	AJ	-	-	10	13	9	-	-	-	-	11
11	AK	-	-	11	9	-	6	6	11	-	-
12	AL	-	-	-	-	-	-	[9]	-	[5]	-
13	AM	-	-	-	[11]	-	[9]	-	-	-	-

APPENDIX 16

PHENO MAP
A4: 10-2

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[11]	10	-	10	[14]	-	12
2	AB	-	9	9	-	-	8	-	8	14	11
3	AC	-	-	-	6	-	-	8	-	-	-
4	AD	-	8	-	-	-	8	-	-	10	13
5	AE	8	-	8	-	9	-	-	-	11	-
6	AF	6	10	-	-	-	-	-	-	-	-
7	AG	-	-	-	-	8	-	13	10	12	-
8	AH	-	-	12	-	-	12	-	-	-	-
9	AI	10	-	12	-	13	-	11	-	-	5
10	AJ	9	-	-	-	11	-	-	-	-	-
11	AK	13	12	-	-	12	-	6	-	8	-
12	AL	-	-	-	10	-	-	[10]	-	[6]	-
13	AM	-	13	-	[14]	-	[11]	-	-	-	5

APPENDIX 17

PHENO MAP
A4: 10-3

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	4	[13]	-	-	-	[18]	-	-
2	AB	-	-	9	-	-	-	-	12	-	-
3	AC	-	-	-	-	8	9	9	9	14	12
4	AD	-	-	10	-	11	-	-	-	-	-
5	AE	-	-	-	-	9	11	13	-	-	-
6	AF	-	-	-	11	-	-	13	-	12	-
7	AG	13	10	-	11	12	-	-	10	-	-
8	AH	9	-	-	-	-	-	-	11	-	-
9	AI	6	9	-	-	-	11	-	10	8	6
10	AJ	15	10	9	11	-	9	8	7	-	-
11	AK	-	-	-	-	-	-	8	5	-	9
12	AL	-	14	-	-	-	-	[13]	-	[7]	2
13	AM	14	-	-	[17]	-	[13]	-	-	-	-

APPENDIX 18

PHENO MAP

A4: 10-4

		1	2	3	4	5	6	7	8	9	10
1	AA	-	-	-	[15]	-	11	10	[22]	-	-
2	AB	8	-	-	-	10	8	-	-	-	12
3	AC	-	9	-	10	-	-	10	9	-	-
4	AD	-	-	11	11	-	-	-	13	-	-
5	AE	-	-	10	10	-	-	-	-	14	12
6	AF	-	-	11	-	12	12	-	12	-	9
7	AG	-	-	-	-	-	13	12	10	13	10
8	AH	-	10	-	13	11	11	-	-	11	-
9	AI	11	-	15	-	12	-	12	-	11	9
10	AJ	-	13	9	-	14	11	9	11	11	10
11	AK	12	-	8	12	-	5	5	5	-	8
12	AL	-	-	-	-	10	-	[15]	8	[8]	5
13	AM	-	10	-	[20]	-	[15]	-	7	-	-

GROUP SELECTION METHOD
Hazards and Case Studies

Robert J. Laacke
Pacific Southwest Experiment Station
Redding, CA

INTRODUCTION

The central purpose and philosophy of forest management is changing in response to continuous public pressure. This is certainly true on public lands and possibly on private industrial lands as well. That change is the reason for the topics covered and backgrounds of the people at this workshop—on both sides of the podium or word processor. My background is research and my topic is Group Selection, one of the many silvicultural methods (approaches, techniques) that constitute the conceptual toolbox of the professional forester and forest manager.

Does Group Selection work? I will get to that shortly, but before I do, I feel it necessary to sound a warning or at least a cautionary note.

Solving forestry's problems by cutting trees in small groups rather than large or very large groups is appealing, and so simple in concept that it is bound to be implemented. For this reason I will spend a little space dealing with what is a philosophical issue.

I suggest, to you, that Group Selection is potentially the most dangerous term and idea in the practice of public forestry, at least in the Forest Service at this time. The hazard is created by a combination of factors. First, the concept of Group Selection has the following "social" and technical characteristics:

1. It has been around long enough to have a definition called "classical". (And what could be wrong with a classic?)

2. All of us know the word "group" and that, applied to silviculture, it means small rather than large. We can cite an unimpeachable source (Ford-Robertson 1971) without having to read it again, which is handy.

3. It falls under the general category of uneven-aged management. (If even-aged is unacceptable then uneven-aged must be good.)

4. It provides a "cross walk" from even-aged to uneven-aged management. (Even-aged ideas, techniques, and consequences can be applied to uneven-aged objectives.)

Now, to be honest, there is nothing particularly dangerous about any of the above, taken singly or together. What makes Group Selection a potentially dangerous term is its application in the context of long standing and institutionalized pressures ON and WITHIN the organization.

The relevant pressure ON the organization has been to produce wood from an ever-shrinking land base and be cost effective in doing so. This pressure has been (and is) applied by the forest products industry as well as legislative and administrative branches of the Federal Government.

Pressures WITHIN the organization are expressed in the performance traits most valued and rewarded. Kennedy and Quigley, in their 1989 study of Forest Service Values and Rewards, questioned entry level employees, Forest Supervisors, Regional Foresters and Chiefs. The survey found that all three levels rated the meeting of targets in the top three performance traits most rewarded by the Forest Service. All three levels of the organization placed targets ahead of professional competence, teamwork, and following rules and regulations.

At the risk of being both pedantic and grizzled (perhaps even hoary), I feel that some definitions are necessary.

From Webster's Unabridged Dictionary (1976 edition).

PERFECT (per'fect)
#4. Without reserve or qualification pure.

PERFECT (per fect')
#2. To make perfect or more nearly perfect according to a given standard.

OPTIMUM (op ti mum)
#1. Most favorable or most conducive to a given end, especially under fixed conditions.
#2. Greatest or best possible under a restriction, expressed or implied.

NOMINAL (nom' i nal)
#4a. Existing or being something in name or form but usually not in reality, distinguished from reality.
#4b. Being so small, slight, or negligible as scarcely to be entitled to the name.
#5a. Approximate, rated

From the Terminology of Forest Science (Ford-Robertson 1971):

"GROUP SELECTION–A modification of the selection system in which trees are removed in small groups at a time."

"SELECTION CUTTING–The annual or periodic removal of trees (particularly the mature), individually or in small groups from an uneven-aged forest in order to realize the yield and establish a new crop of irregular constitution. Note: The improvement of the forest is a primary concern."

PERFECT (per'fect) adherence to the definition of group selection is perhaps impossible. The obvious conclusion is that to apply group selection we will have to exercise some approximation of the approach (see nominal and optimum above). Note that if NOMINAL (#4b. above) is taken to mean "no difference from the ideal" by one person (they) and "no difference from current practice" by another (us), TROUBLE IS CERTAIN.

Which leaves us in the uncertain position of coming up with and defending an optimum definition of group selection, one that changes from site to site and District to District.

We should not worry too much because, although the shape of forestry with our new (or expanded) perspective is not yet clear, it is likely that "classical" silvicultural concepts will be of value primarily (if at all) for their intermediate consequences rather than their originally designed and defined purpose. And those intermediate objectives will provide us the rationale for designing, and defending, definitions that vary from place to place.

So what is dangerous? The danger to forest management lies in is the "cross walk" of ideas, concepts, and application. A group selection cut looks and acts like a clearcut (as well it should). This simple condition is dangerous because of the combination of factors cited above and the resulting, predictable tendency to use the "crosswalk" and invoke the "nominal change from current practice" definition. If GROUP SELECTION is prescribed with CLEARCUT and TARGETS in our frontal lobes (or wherever it is we make our decisions) we will end up with egg on more than our faces. We cannot afford a reflexive anencephalous application of any silvicultural prescription, especially group selection. Anencephalous management is as hard to swallow as it is to say.

On the other hand, group selection obviously has some intermediate consequences of real value to forest management. These include open habitats for intolerant trees and plants other than trees, "edge" for wildlife, species diversity for the ecosystem, preservation of gene pools, the ability to mimic age class patterns created by natural fire, and many other concerns (including, at some point, age structure, species composition, and growth of trees for wood production).

Group selection potentially has an immense number of reasons to be used. It also has a large potential to be misused.

Now to the initial question, "Does group selection work?".

At the Pacific Southwest Station we have explored group selection in a variety of places and with a variety of objectives since the late 1930's. The early work was done on the Stanislaus-Tuolumne Experimental Forest by such luminaries as Fowells and Dunning. The Station changed the emphasis of its work following World War II, and, with the passage of time, these early plots have disappeared into the general forest and the records into the archives.

However, we do have the information gained from tests of group selection done in two forest types beginning in the early 1960's. They are presented separately below.

CHALLENGE EXPERIMENTAL FOREST

Studies of group selection (or group cutting) were installed on the Challenge Experimental Forest in 1964.

Where

Challenge Experimental Forest is located on the western slope of the central Sierra Nevada in California. At an elevation of between 2500 and 3500 feet the Forest lies in a "rain belt" and receives more than 68 inches of precipitation per year.

Significant Features

Productivity: Site quality is high to very high, ponderosa pine reaching more than 6 ft in 9 years, 140 ft in 100 years.

Mixed species/characteristics: The forest is young growth mixed conifer, composed of Douglas-fir, white fir, ponderosa pine, sugar pine, incense-cedar, and the hardwoods California black oak and Pacific madrone. It is classified as SAF type Pacific ponderosa pine/Douglas-fir.

Shade tolerance of the conifers differs significantly and cover the range from the intolerant ponderosa pine, through increasing levels of tolerance with sugar pine and Douglas-fir, to the very tolerant white fir and incense-cedar.

Early growth rates of the species also differ. Initial growth of ponderosa pine is the greatest, followed by sugar pine, then Douglas-fir and white fir, with the slowest being incense-cedar.

Regeneration ease: Regeneration is easy to obtain, natural regeneration is usually copious.

Competing vegetation: Competing vegetation is impressive. The brush species (largely whiteleaf manzanita and deerbrush) reaching 8 feet in 9 years in the open. Black oak and madrone achieve 13 feet in nine years.

Questions asked in studies: There were several purposes to this set of research cuttings. First, to determine what size openings in the effectively even- aged forest would promote the regeneration of the more tolerant species. And second, what was the growth of the species relative to growth in the open (clearcut). This was not an attempt to test or demonstrate a silvicultural system.

Openings varied in size; minimal (single tree selection), small to moderate groups, shelterwoods and clearcuts. The group cuttings were circular and 30-, 60-, or 90-feet in diameter (0.06-, 0.26-, and 0.58-acre) in a stand with average canopy height of 125 feet. Groups were located to include seed sources for the other species in addition to ponderosa pine.

RESULTS

After nine years the results were a combination of surprise and expected.

Surprise

None of the intolerant, sun requiring, species died out, even in the single tree openings. Ponderosa pine was the most numerous conifer at all levels of opening. Black oak and the woody shrubs (whiteleaf manzanita and deerbrush) remained at all levels of cutting.

Expected

Ponderosa pine growth was severely suppressed in the single tree cutting and increased steadily as the opening size increased.

The shade intolerant woody shrubs did not become a major component of the regeneration community except in the clearcut.

Sugar pine, Douglas-fir, and white fir all grew half again as much as ponderosa pine in the group cuttings.

Growth in the group cuttings was about one third to one sixth that for the species as they grew in the clearcut.

SWAIN MOUNTAIN EXPERIMENTAL FOREST

Group cuttings were instituted on the Experimental Forest beginning in 1970.

Where

The Experimental Forest is located in the southern Cascades of northeastern California. It occupies a volcanic cone with an elevations between 5700 and 7200 feet and receives an average annual precipitation of 45 inches, almost all of it as snow.

Significant Features

Productivity: Site quality is high, average 60 feet in 50 years

Mixed species/characteristics: The forest is mixed California red fir and California white fir with scattered sugar pine, western white pine, incense-cedar, and lodgepole pine in wet areas.

Shade tolerance of the conifers of interest differs little, with white fir being slightly more tolerant than red fir. Early growth of the two species is very similar and slow. Sapling growth of both can be quite rapid.

Regeneration ease: Natural regeneration is relatively easy to obtain, at least in openings narrower than twice the surrounding tree height.

Competing vegetation: Competing vegetation is initially slow to develop in new openings under virgin old-growth forests but, once seed sources are established, grass and lupine invasion of second and third generation cuttings is rapid. Woody vegetation is slow to develop except following fire and is composed of mountain whitethorn, ribes, and varnishleaf manzanita.

Questions asked in studies: The purpose of this series of cuttings was to determine natural regeneration requirements and alternatives for the commercial true fir forests in California. This was not an attempt to test or demonstrate a silvicultural system.

Openings were rectangular: squares of 0.4, 0.9, and 1.6 acres; strips of 0.6, 1.2, and 1.8 acres. The openings had minimum dimension of 66 ft and a maximum dimension of 264 ft. and were placed in a closed true fir forest with a canopy height between 165 and 200 feet.

RESULTS

Regeneration was rapid and within 3 years all openings supported more than 2500 seedlings per acre. Both species were represented although red fir dominated in numbers.

Fifteen years after cutting, seedling numbers had fallen to the point that only 10 of 70 openings remained stocked with regeneration. Grasses and gopher damage appears to have accounted for most of the mortality. The square openings, because they provided the opportunity for tractors to turn around, sometimes suffered the additional impact of deep soil disturbance.

Growth of regeneration remaining within the small openings is generally less than one third that of the seedlings on the 3.6 acre shelterwood cuttings installed at the same time (even when the overwood remained for the full 15 years).

CONCLUSIONS

Group selection is a difficult management tool when wood production is the primary purpose of forest management. It has all the advantages of clearcutting without the advantage of efficiency. The requirement to apply the same vegetation management treatments and care to scattered small openings as is required of plantations in even-aged management is a scheduling and record keeping nightmare.

However, group selection has a real place in forest management and its potential usefulness is increasing as new perspectives are incorporated in the operations of public forests. Only now, the intermediate consequences of cleared openings are the reasons for cutting and the value to group selection.

LITERATURE CITED

Gordon, Donald T. 1979. Successful natural regeneration cuttings in California true firs. Research Paper PSW-140. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, U. S. Department of Agriculture. 14p.

McDonald, Philip M. 1966. Seed fall and regeneration from a group selection cut...first year results. Research Note PSW-113. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, U. S. Department of Agriculture. 6p.

McDonald, Philip M. 1976. Forest regeneration and seedling growth from five cutting methods in north central California. Research Paper PSW-115. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, U. S. Department of Agriculture. 10p.

Laacke, Robert J. Data on file at PSW Redding.

Laacke, Robert J.; Tomascheski, Jeanne H. 199_. Effects of residual trees on height growth of natural true fir regeneration. Manuscript in editing. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, U. S. Department of Agriculture.

Author

Robert J. Laacke, Research Forester, Pacific Southwest Forest Experiment Station,
2400 Washington Avenue, Redding, California 96001

CLEARCUTTING - AN INTRODUCTION

Walter H. Knapp
Pacific Northwest Region
Portland, OR

Ask the (wo)man on the street about timber harvest: Chances are that you will hear about clearcutting. Many people perceive that clearcutting is the dominant management practice on public and private timberlands.

But what is the real situation? Statistics for the Pacific Northwest Region (R-6) of the U.S.D.A. Forest Service show that over the last 17 years only about one-tenth (11%) of the area harvested by timber sales was clearcut. Other methods such as shelterwood, selection, and intermediate harvests accounted for the remainder of commercial treatments. Yet by its nature, clearcutting receives dramatic attention from all segments of the public.

We silviculturists have generally looked at the major harvesting techniques, particularly those designed to regenerate a new stand, from a technical point of view: What are the physical, biological, and economic results of our treatments? But the public brings still another consideration: the aesthetic. The concerns of society are, in the final analysis, the strongest determinant in our decision process.

The following papers give useful perspectives on clearcutting: why we do it, where it is applicable, what we gain from it, and what we lose. First, we examine the silvicultural research on clearcutting and discuss its applicability (**Shearer**). Next, we look at the role of genetics. How do our tree breeding programs interact with the use of clearcutting to provide healthy, productive forests (**LaFarge**)? These papers look at yield, stand development, stability, and other physical and biological attributes, and provide valuable insights into silvicultural practices and the status of our knowledge.

Finally, we look at the use of clearcutting, both from an historical and an operational point of view. Here we consider the role of economics. And it is here that we recognize the message from the public: the continued reaction against what silviculturists see as a useful, desirable, and—sometimes—essential tool for the management of the forest (**Boughton**).

Today, many forestry professionals recognize that we are actively redefining silviculture. We are searching for new tools, alternative methods which do a better job of meeting the demands and desires of society on all levels. Clearcutting will continue to be an important silvicultural tool, but the balance will shift from economic and operational efficiencies, and even biological considerations, to what people want.

In some cases, that may be new adaptations of old silvicultural methods. But new approaches also show promise. For example, landscape level analysis and planning techniques are allowing us to better integrate a wide range of objectives into forest management.

Silviculturists and geneticists would do well to look at our histories, to review what is written today in another ten years. Only then will we see how the practices have been redefined.

Author

Walter H. Knapp
Regional Silviculturist
Pacific Northwest Region
319 S. Pine Street
P.O. Box 3623
Portland, Oregon 97208

CLEARCUTTING: OVERVIEW OF A THREATENED AND ENDANGERED SILVICULTURAL METHOD

Jerry L. Boughton
Alaska Region
Juneau, AK

INTRODUCTION

In United States Forestry, clearcutting gained notoriety as an unacceptable management technique in the 1970's with the Monogahela and Bitteroot controversies. This forest management tool continues to be plagued with controversy and criticism into the 1990's from congressional interest, to within Agency alternative system searching in California, to essential elimination on the Ouachita. Whether the method is biologically or managerially correct is not the issue, public opinion and acceptance is.

Manipulation of forest vegetation to yield mans' desired outputs has been happening for centuries. The activity was first haphazard and short-term single product oriented. Planned forest management can be traced back to the early Greeks and Romans (Troup). Manipulation of forests to accomplish a variety of identified resource objectives implies the application of a variety of harvest techniques or "tools".

The "tool" of clearcutting with artificial seeding or planting emerged in Germany about the middle of the eighteenth century. Clearcutting was developed at that time to "clean up" past forestry practices and to increase forest wood product outputs when it was recognized the selection (highgrade) or shelterwood methods that had been taking place since the middle ages would not fulfill the long-term demands for wood products.

It was here the first controversy over clearcutting developed in the nineteenth century with excessive conversion of hardwood, scotch pine, spruce and European silver fir stands to monocultures of Norway spruce.

Clearcutting has ridden the rollercoaster of application and controversy ever since. Why does clearcutting elicit both professionally supported application and public criticism? The answer is possibly too obvious—the method can be biologically applied to regenerate desired tree species in most forest ecosystems. Additionally, there are economic and managerial advantages to the method. With managers keying on these advantages and not looking past regeneration and product development, the method has been widely applied in an array of circumstances. This array has even at times strained the regeneration threshold. Coupling this with little more explanation to the publics than "trust me", there is little wonder the method is viewed with a critical eye. Often the method itself has not been misapplied but associated treatments such as tractor piling oversteepened slopes or terracing have focused public rath. This was the case in the Bitteroot controversy that sent considerable shock waves through the American Forestry ranks.

Proper application of any silvicultural system requires a site specific evaluation, considering the systems advantages, disadvantages and site specific objectives. Public acceptance and long-term health of the ecosystem are legitimate objectives that must be considered.

DEFINITION

Clearcutting is one of 5 major regeneration harvest methods used in the United States (Figure 1). Clearcutting is defined as the harvesting, in one operation, of all trees in a stand or on an area, with the expectation that a new even-aged stand will become established.

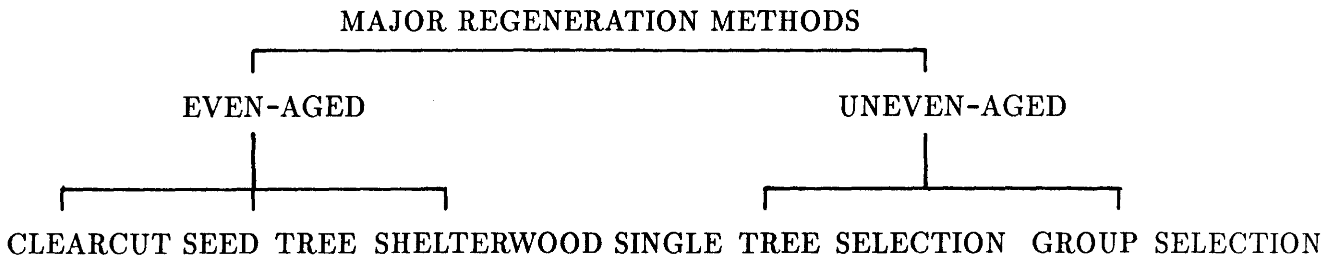


Figure 1. Major regeneration harvesting methods.

Some traditional textbook (Daniel, Helms, and Baker 1979) clearcut method advantages and disadvantages are:

Advantages:
1) Lower logging costs.
2) No logging damage to standing timber.
3) Less skill is needed to implement than other reproduction systems.
4) Introduction of improved stock is possible.
5) Sanitation problems such as dwarf mistletoe can be solved.
6) Grazing is possible after seedlings are beyond damage size.
7) Decadent over-mature stands can be dealt with.
8) Narrow clearcuts favor big game.

Disadvantages:
1) Species must survive in open conditions.
2) Species control is not complete when using natural regeneration.
3) Seedling distribution can be uneven.
4) Erosion and site-deterioration hazard may be high.
5) Regeneration may be delayed and growth conditions may deteriorate rapidly.
6) Seeds must be light enough to have a satisfactory seeding distance.
7) Unprofitable trees may have to be cut.
8) It is aesthetically displeasing, at least until seedlings become saplings.

As "professionals" we have reiterated these axioms of forestry for decades. When reading through the list, the focus is clearly trees and the span of time is short (regeneration-saplings). In times past it was acceptable to think in these terms, and the public accepted our advice and leadership. It is unfortunate we as professionals did not recognize the need to maintain the long-term ecological functions of the ecosystem we were managing, especially as individuals like Leopold were pointing it out to us. Instead we have held tightly to the axioms and allowed our publics to surpass us in considering forestry for the long-term, and now they are providing us direction through the courts and legislation.

TRADITIONAL METHOD VARIATIONS

There are several traditional variations of clearcutting using either natural or artificial regeneration. These are:

Alternate strip—The stand is arranged into a series of strips. The first strip is cut, the second left standing, the third is cut, and so on throughout the stand. Within a few years regeneration is established and the leave strips are then cut to maintain the even-aged character of the stand. The cut strips may utilize natural seeding from the uncut strips. When the original uncut strips are harvested the method may utilize a seed tree or shelterwood method for natural regeneration or clearcut with artificial regeneration.

Progressive strip—The stand again is arranged into a series of strips. The strip cuttings are made at short intervals of time starting at one side of the stand and advancing progressively across to the other side. If an even-aged stand is to be created, the entire series of cuttings must be finished within a period of 10 to 20 years, depending on the length of the rotation. Again the cut strips may utilize natural seeding for the uncut portion of the stand.

Continuous or stand—The entire stand or a group of stands is clearcut. These cuts are generally large (greater than 100 acres) and may be several thousand acres in size. This type of cutting is generally artificially regenerated. Due to law (NFMA) and other resource values managed for on federal holdings, this type of clearcut application is generally restricted to private land ownerships.

Patch—A portion (or all if it is small) of a stand is harvested in the first entry. This newly created stand is allowed to regenerate and provide desired resource values such as hydrologic recovery, wildlife cover, etc., before cutting adjacent to it is done. Size of these patches depends on topography, logging systems, and resource values being managed for. In recent decades patch clearcuts in the range of 20-40 acres have commonly been applied on federal holdings. This has often resulted in a patchwork landscape. If average patch clearcut size applied in a stand is two acres or less, this is generally considered to be application of the uneven-aged Group Selection method.

Commercial clearcutting—Only material meeting identified merchantability specifications is harvested. Material left after the harvest operation may or may not receive followup stand tending. This method variation has potential for drastic long-term results. It is likely material left will be suppressed, damaged, diseased, dysgenic, or of improper species for future management.

TRADITIONAL METHODS OPPORTUNITIES OR EFFECTS

Locations of Applicability

Many forest species owe their survival to natural disruptions in the trend of plant succession. Nature regularly creates these disturbances, both micro and macro, with events such as wildfire, insect epidemics and disease, storms and seismic upheaval. These disturbances alter not only the species composition of an area but the pattern of vegetation on the landscape over time. For instance, the existence of Douglas-fir in the west and many oak types in the Northeast are the result of wildfire. Clearcutting can be applied to simulate these natural disturbances. Clearcutting also traces it's roots, and is useful today, in converting tracts of undesirable vegetation, from past natural or man caused disturbances, to desired forest conditions.

Fifty-one major forest types are identified in *Silvicultural Systems for the Major Forest Types of the United States* (USDA 1983). Twenty-eight of these list clearcutting as the most consistent or desirable method to apply based upon desirable species silvics. Another twenty list clearcutting as an acceptable method to use. This would seem to support a strong case for clearcutting application. However, virtually all of these types listed other silvicultural methods that could biologically be used to manage them.

Extensive clearcutting where environmental conditions are limiting, especially moisture and temperature, may aggravate these conditions and can result in unsuccessful regeneration. Traditionally, regulation of clearcut size and shape has been done to ameliorate these effects on most forest types. Only two western and one eastern forest type do not list clearcutting as a viable option for management within the type.

Franklin & DeBell (1973) pointed out there is no ecological necessity for large patch or continuous clearcuttings to regenerate most forest types. Biologically, the majority of species can be regenerated and managed with small openings (Group Selection method). Further, on the majority of productive forest sites, other than ecological limitations appear to be primary in the choice of selecting even-aged silvicultural methods. Considerations include administrative and economic advantages, efficiency in logging, growth rates, and other vegetative effects such as wildlife habitat and insects and disease.

Species Management

As stated above, the majority of major U.S. forest types are or can be prescribed to be managed for the desired commercial tree species using the clearcut method. This is generally a function of successional species dominating the commercially important list in most of the United States timber producing regions. Most notably are Douglas-fir, ponderosa pine, and sugar pine in the west, and black cherry, white ash and poplar in the east. Not only are these species generally more valuable, but management of the seral tree species (through clearcutting) usually favors increased yields which further increases the projected timber value returns. The focus on this single commodity value and how it has helped lead us into our present quandary with clearcutting, was well expressed by J.W. Duffield (1973) "Under present market and social conditions, little evidence suggests any realistic alternative to our highly effective practice of substituting man-caused for natural catastrophic disturbances in producing economically valuable forest crops. So long as the management of forests, public and private, is compensated largely or exclusively for it's effectiveness in production of wood, there seems little prospect for change. Yet, as we broaden the bases of our cost-benefit analysis, enhance public understanding of the forest resource, and increase our knowledge of forest biology, we may look forward to a silviculture that will be tuned more finely to complexity of forest ecosystems and the many resources they offer."

Disease

Throughout their lives trees are subject to a variety of foliage, root and stem insects and diseases. Natural old forest stands contain endemic levels of these agents. The timing and type of silvicultural system we apply will induce various reactions from these agents. A few of the more recognized agents and their relation to the clearcut method are discussed.

Girdling Stem Disease

Most notable in this category is white pine blister rust. A long standing breeding program capitalizing on identified resistance mechanisms has produced disease resistant reforestation stock. However, clearcutting favors large increases in *Ribes* populations (Quick 1954) which can substantially increase the risk of infection. Therefore, alternatives for silvicultural method application range from shelterwood to clearcut (Tyron 1966) and must be site specific.

Crown Disease

Sporadic foliage diseases such as most needle and leaf rusts, needle casts, leaf spots and blights, fluctuate greatly and even in particularly heavy infection years are rarely serious enough to affect decisions on silvicultural systems (Parmeter 1972). Unlike sporadic diseases, some diseases build steadily additive effects. Classic examples are the dwarf mistletoes. Without control, infested stands can have significant reductions in timber production. This parasite spreads from the upper canopy to the lower with slow lateral movement of seeds. Thus forest management with a single canopy, as opposed to multiple canopies, is an effective method for controlling spread of this disease. Clearcutting in large blocks to minimize edge inoculation is generally recommended.

Root Rots

Major root diseases include *Fomes annosus*, *Phellinus weirii*, and *Armellaria Mellea*. These diseases possess the capacity to spread from tree to tree via roots, causing enlarging pockets of infection. Centers generally originate in stumps or leave trees with basal wounds. Clearcutting, of at least the identified infection centers, with conversion to non-susceptible species is suggested as a control strategy. If one had the objective of maximizing infection and disease spread, silvicultural methods that leave infection, new stumps, and live host trees (possibly wounded) in the closest proximity will maximize the disease potential. Due to reforestation ease or economic considerations, traditional clearcutting has moved stands towards single species management. If a disease were to establish itself in this type of stand now or in the future, severe damage may result. This increased likelihood of significant disease damage in monocultures is a factor that must be considered in establishing proper species composition and density management.

Wildlife

It is widely recognized that clearcutting can increase forage for a host of wildlife species. The removal of the forest canopy, permitting light to strike the forest floor, results in production of herbaceous and shrubby forage in greater amounts, and possibly higher nutritive value, than in a canopied forest.

This relationship of providing increased forage for a variety of wildlife has been the major support that clearcutting provides multi-resource benefits. While this increased food relationship unquestioningly exists, it has also been recognized that juxtapositioning of that food is critical to take advantage of the relationship. Bethel (1971) pointed out that while clearcuts located in big game summer range are used for forage, to be effective in raising overall range carrying capacity they must be located where it is possible for the animals to winter.

Production of understory seeds and fruits is increased when the forest is opened. This generally causes an increase in small mammal populations, and provides an increased food base for other forest residents such as bear and bird populations. A study of wildlife food plants in clearcut pine stands in the Piedmont of South Carolina showed that the areas clearcut and prepared for regeneration of pine "had more than twice as many legumes and other game-bird foods as did the control areas nearby." Predation due to increased visibility also increases in a clearcut situation. The predation factor coupled with the dramatic environmental change from closed canopy to clearcut can have clearcuts act as barriers to migration of some animal species.

Stream flow, Water quality

Numerous models have been developed across the country to assist forest managers in assessing the effects of applying the clearcut method on the landscape to the water resource. Some models are programmed with the thought that clearcutting will increase overall water yields, others that water yields will remain generally constant but the timing and quantity of peak flows will change. Bethel (1971) determined that clearcutting of Pacific Northwest forests offers a means of augmenting the summer low-flows and increasing total annual water yield from forested watersheds.

Regardless of which of these approaches is applicable in a given area, the focus of conversations regarding water resource impacts usually revolve around temperature and sedimentation.

Effects of clearcutting on salmon habitat in Alaska showed no influence of clearcutting on the relationship between rainfall and peak flows. There were no apparent adverse effects on the salmon spawning habitat in the logged watersheds.

Major impacts from sedimentation are not the harvest units but the roads. Clearcutting will generally require the same amount of road building as other harvest methods over the entire management period, yet may reduce the amount during a given period and thus reduce initial sedimentation potential.

Water temperature can be increased by opening the canopy and allowing increased solar input. This has potential to be either a positive or negative effect depending on specific circumstances. Research at Carnation Creek, British Columbia showed that logging of coastal watersheds can cause a shift in temperature regimes that results in a complex chain of physical and biological effects. Stream systems with exceptionally low temperatures have the potential for overall productivity to be raised from increased solar input.

Soils

The prime source of sediment under normal application of a clearcut harvest method is related to the access road rather than disturbance in the harvest unit itself. Copeland (1958) states "About 90 percent of the total watershed damage impact to forested areas can be attributed to poor road design, location, construction and maintenance." Clearcutting adjacent to streams on soil systems with high overland sediment transport potential is a high risk for sediment delivery to the stream. Forest buffers to act as sediment traps may be desirable. Soils systems that retain substantial duff and litter, have a low overland sediment transport potential provided this layer is maintained.

Any harvest method applied to a unit of land will have an effect on the soil through additional solar input, duff reduction, litter input changes, mechanical disturbance or compaction. Whether these changes are positive, detrimental or significant depend on the amount of change and the ecological system in which they take place.

Solar input is obviously increased by clearcutting. The amount of change depends upon size, shape, slope, position on slope and aspect of the unit. In systems where soil surface temperature and soil moisture are limiting, too much increased solar input can restrict establishment of desired regeneration through stem heat lesions or excessive transpiration. Conversely, Gregory and James (1955) indicated clearcutting in Southeast Alaska raised average soil temperatures 6-9 degrees F. In this cool system with typically low decomposition rates, warming will likely increase microbial activity and potentially increase available nutrients. Clearcutting eliminates the annual recycling of forest floor material accomplished through litterfall from trees. This phase of recycling is not fully restored until crown closure of the new stand is attained. In the interim, grasses, forbs, shrubs and other vegetation enhance nutrient recycling. There is no question that clearcutting results in a temporary reduction of forest floor litter. With effective reforestation this is considered insignificant, however, on fragile slopes it may last long enough to expose bare soil and induce accelerated erosion (Maki 1972).

Mechanical disturbance and compaction are a function of application of a particular logging system. With a single entry, clearcutting provides less potential for these soil structure alterations than other harvest methods that require multiple entries.

Need for continuous input of large organic material to maintain soils processes and site productivity over time has been well established. Traditional clearcutting without reserve trees could impact on site delivery of this material over time, and potentially effect site productivity in subsequent rotations.

Recreation, Visuals, Landscape Patterns

Significant recreation management and clearcutting rarely mix well. Dispersed recreation for activities such as berry picking and hunting have been coordinated with harvesting using the clearcut method. Clearcut followed with limited access through road closures has been specifically prescribed to meet quality hunt recreational objectives. Harvesting that may change the recreation experience of a developed recreation facility is generally achieved with other than the clearcutting method.

Immediate unsightliness of a clearcut to the general public until trees are well established, is a major disadvantage of the method and contributes to public concern regarding the method. In other than immediate foreground viewing situations, variation to clearcut size and shape are frequently used to produce irregular harvest patterns that simulate natural stand losses from fire, windthrow, or insects.

The importance is recognized for animals and plants to be able to move freely across a landscape. Whenever the forest is fragmented, by clearcutting or large scale natural disturbances, this freedom of movement can suffer. To avoid creating fragments with harvesting, consideration of juxtaposition and harvest scheduling to facilitate "travel corridors" has been used. Additionally, consideration must be given to leaving stand components or "biological legacies" within the harvest units to allow this movement. This is a basic concept to the growing desire to consider leaving reserve trees when applying the clearcut method.

NON-TRADITIONAL CLEARCUT METHODS

A variation that is gaining popularity under the auspices of "New Perspectives In Forestry" is clearcutting with reserve trees. This modification is intended to provide the biological and economic advantages of the even-aged clearcut method, while retaining sufficient reserve material to provide for on site wildlife structural diversity, maintenance of riparian areas, long-term site productivity, species diversity, and other resource needs. Groups of hardwood trees, snags, and green replacement trees are retained to achieve these objectives. Regeneration options are planting or natural regeneration with reserve trees providing a boost to the natural seeding process. This variation has been described as "units containing a well distributed mosaic of residual reproduction or other stocking, essentially eliminating the appearance and effects of a clearcut" (USDA FS 1989).

Figures 2-5 provide a visual concept of application of this method variation in a western conifer forest (Shasta Costa planning area).

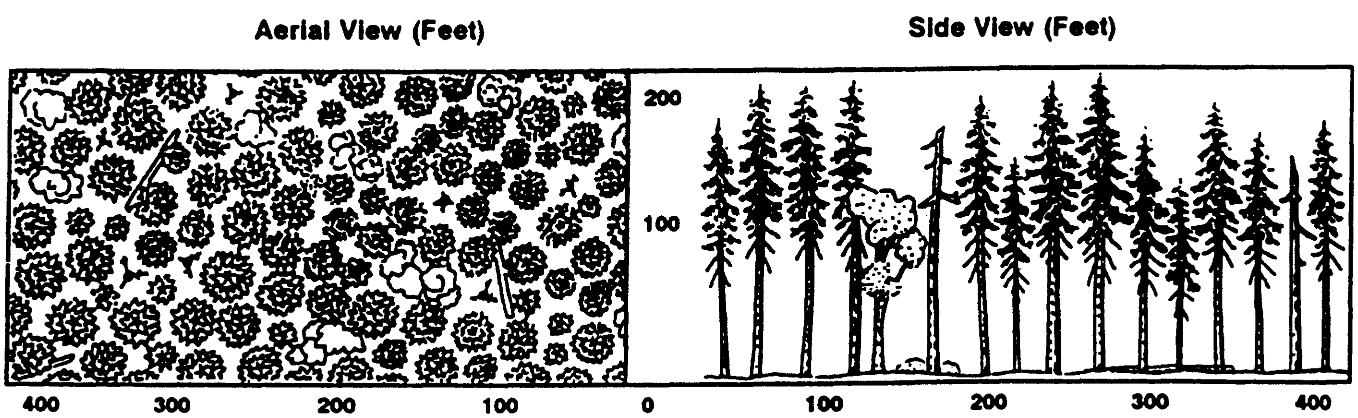


Figure 2. Stand is even-aged and mature to overmature. Many trees are becoming decadent, individual trees are showing thinning crowns and broken tops. There is some individual tree mortality.

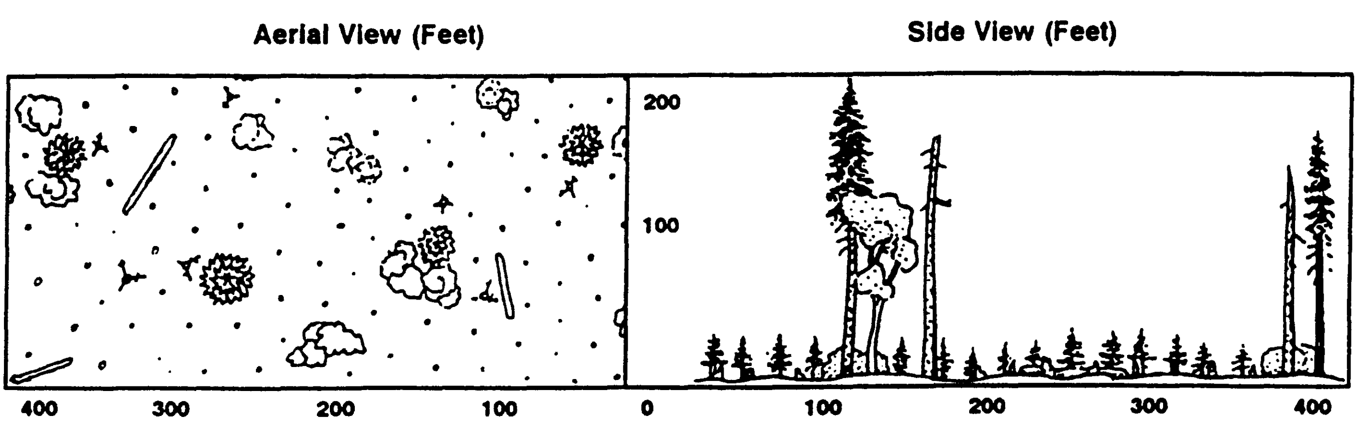


Figure 3. Clearcutting has removed nearly all merchantable trees in the stand. Groups of green trees and snags are reserved for wildlife, riparian protection, long-term productivity, and species diversity.

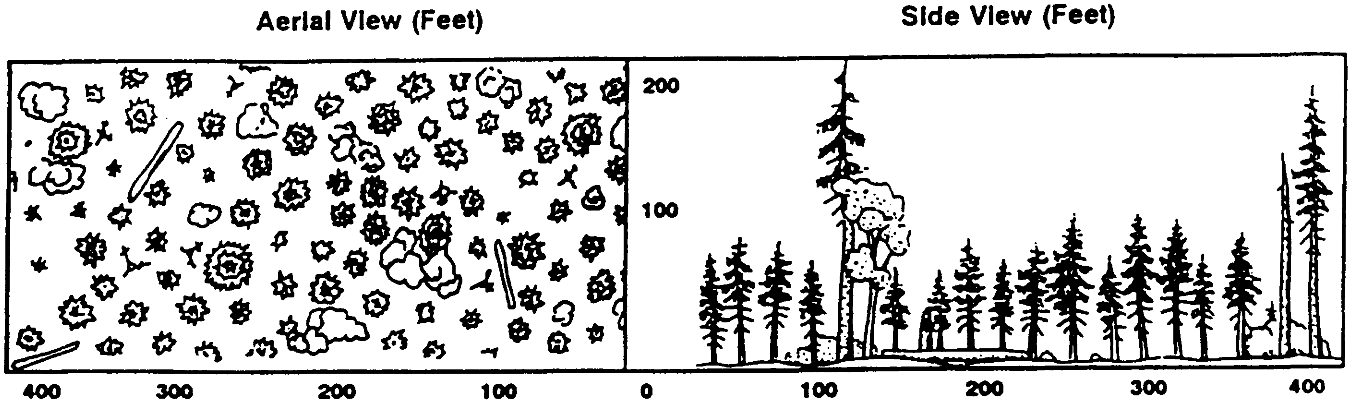


Figure 4. Thirty years after clearcutting, reserve trees are aging and are serving as replacements for those snags which have fallen during the previous three decades. Younger stand vigor is maintained by management activities during the past three decades that may have included release from competing vegetation, precommercial thinning, and fertilization.

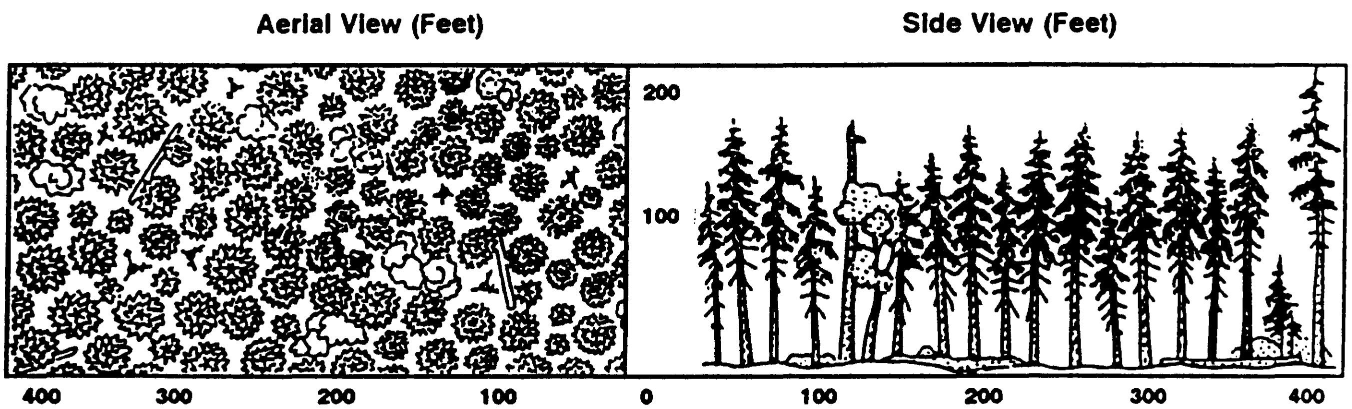


Figure 5. Sixty years after clearcutting, the stand canopy is closing, individual tree growth is beginning to decline and commercial thinning may now be appropriate.

NON-TRADITIONAL CLEARCUT ACTUAL APPLICATION

Disease

Traditional clearcutting is supported as an effective method to manage existing or potential disease situations. The primary benefits are removal of existing infection and/or conversion to non-susceptible host species.

Clearcutting with reserve trees has a potential negative effect to maintenance of a healthy ecosystem by providing, through retention of diseased or potentially diseased trees, the components necessary for an explosion of disease populations. Is this silvicultural method variation a viable option to apply when disease conditions exist? My thought is YES. However, this is qualified by the statement that this is precisely why the definition of silviculture begins with "the *art* and *science*". The scientific concepts supporting clearcutting to deal with disease problems are valid. The art must rely on sound site specific application. Rote application of traditional methods has us in trouble, and rote application of method variations could become even worse. Site specific analysis to determine location and species of reserve trees, proper regeneration and future stand management is a must to avoid future disease problems with application of this method variation.

Timber Supply, California

As previously discussed, clearcutting is an extremely effective and efficient method of maximizing both wood fiber yield and value. Because it removes all the overstory it is the most versatile to apply from an operational standpoint. Depending on the site and the product to be removed it can be applied with a variety of operational systems from helicopter to cable to tractor to only felling with site prep.

How would a switch from traditional clearcutting to clearcutting with reserve trees effect timber supplies or value? In December 1989 an ad hoc team in Region 5 evaluated the effects for that Region a reduction in traditional clearcut acres would have (USDA FS 1989). The results are summarized below:

-A 20% reduction in current amount of traditional clearcutting (replaced with clearcutting with reserve trees) could be accomplished at the current budget level with no effect on the Allowable Sale Quantity (ASQ).

-Reductions above this level would result in a decrease in ability to sustain current timber supply levels and/or require additional funding to implement. Greater than a 30% shift from traditional clearcut application would have an effect on ASQ regardless of increased funding levels.

-Reducing clearcutting by 85% with no increase in budget would result in an estimated 27% reduction of that Regions ASQ (mostly in the Douglas-fir forest types).

If the "tool" of clearcutting was managerially dictated to be reduced by 85%, the report states the concern that this would "result in biologically inappropriate prescriptions just to meet ASQ or clearcutting reduction targets". If clearcutting is to be reduced managerially, the ASQ should be managerially adjusted accordingly.

SUMMARY

Clearcutting has long been recognized as an easy to apply cost efficient method that favors the generally higher valued and desired tree species. This relatively narrow forest management scope of concentrating on desired tree species coupled with the economic and administrative advantages has resulted in wide application of clearcutting. New Perspectives approaches to forest management stresses recognition and maintenance of all ecosystem functions. This concept is indeed important as forest managers are increasingly coming to appreciate the concepts of ecosystem processes that maintain long-term forest health while public disdain with the clearcut method persists.

When considering the variety of shapes, sizes, reserve trees and post harvest treatments that can be applied, clearcutting is actually a very flexible silvicultural method. Therefore, with creativity, this silvicultural method can be varied such that application is specifically designed to maintain all the on site components for ecological processes to continue (soil, down material, duff, standing material, etc.), and thus truly emulate the forest types natural disturbance pattern. If this is accomplished, and the silvicultural method is truly emulating the natural disturbances, it will maintain the natural landscapes and forest health over time. When application of silvicultural methods is based upon this thought process, clearcutting application will become the end (ecologically healthy forest management with timber output as a by product), as opposed to the means to an end (a cost effective method of growing and removing trees).

Aldo Leopold once wrote,

> "Conservationists are notorious for their dissensions. Superficially these seem to add up to mere confusion, but a more careful scrutiny reveals a single plane of cleavage common to many specialized fields. In each field one Group(A) regards the land as soil, its function as commodity-production; another Group(B) regards the land as a biota, and its function as something broader. How much broader is admittedly in a state of doubt and confusion. In my own field, forestry, Group(A) is quite content to grow trees like cabbages, with cellulose as the basic forest commodity. It feels no inhibition against violence; its ideology is agronomic. Group(B), on the other hand, sees forestry as fundamentally different from agronomy because it employs natural species, and manages a natural environment rather than creating an artificial one. Group(B) prefers natural reproduction on principle. It worries on biotic as well as economic grounds about the loss of species like the chestnut, and the threatened loss of the white pines. It worries about a whole series of secondary forest functions: wildlife, recreation, watersheds, wilderness areas. To my mind, Group(B) feels the stirrings of an ecological conscience."
>
> Aldo Leopold
> Circa 1948

Forty years ago Leopold did not have a high regard for "Group(A)" forest managers. Through the 1980's and into the 1990's the public is rapidly coming to share his views. Forest management has been applying the clearcut method in a manner that the public is associating this method with Group(A) forestry. So much so, that the continued existence of the method as a management tool on public lands, regardless of its biological basis or merits, is questionable.

If we are astute, and grasp Aldo's 40 year old "New Perspectives" concepts of matching silvicultural methods to the long-term natural ecological functions that are in place, not only will we display wisdom as professional managers, but we will be able to proudly display our actions and again provide leadership to a critical and demanding public, and just possibly be able to maintain a complete set of forest management tools—including clearcutting—into the future.

LITERATURE CITED

Barrett, J. W. ed. 1962. Regional Silviculture of the United States. p. 334-591. Ronald Press, N.Y.

Bethel, J. S. 1971. Clearcutting as a Forestry Practice with special reference to its use by the U.S. Forest Service and the Bureau of Land Management in Alaska, Washington and Oregon. Report to the Presidents Council on Environmental Quality. Univ. Wash. Coll. For. Resour., Seattle.

Copeland, O. L., Jr. 1958. Soil-Site Studies of Western White Pine in the Northern Rocky Mountain Region. Soil Sci. Soc. Amer. Proc.

Daniel, Helms, and Baker. 1979. Principles of Silviculture 2nd. ed. pp. 436-455. McGraw-Hill series in Forest Resources.

Duffield, J. W. 1973. Physiological characteristics of trees and their relation to even-age management. In: Even-Age Management, Proceedings of a Symposium held August 1, 1972. Oregon State University, School of Forestry, March 1973. pp. 21-28.

Franklin, J. F. and DeBell, D. S. 1973. Effects of various harvesting methods on forest regeneration. In: Even-Age Management, Proceedings of a Symposium held August 1, 1972. Oregon State University, School of Forestry, March 1973. pp. 29-57.

Gregory, R. A., and James, G. A. 1955. The Effect of Clearcutting on Air and Soil Temperatures in Southeast Alaska. Technical Notes of the Alaska Forest Research Center. No.23.

Hermann, R. K., Lavender, D. P., 1973. Even-Age Management, Proceedings of a Symposium held August 1, 1972. Oregon State University, School of Forestry, March 1973.

Maki, T. E. 1972. Does Clearcutting Practice Accelerate Soil Depletion? For. Ind. June 1972. Pulpwood Ann. pp. 4-5.

Parmeter, J. R. 1973. Ecological considerations in even-age management. In: Microbiology and Pathology. pp. 113-136.

Quick, C. R. 1954. Ecology of the Sierra Nevada Gooseberry in Relation to Blister Rust Control. U.S. Dept. Agric. Circ. 937.

Society of American Foresters, with cooperation of the Wilderness Society. 1981. Choices in Silviculture for American Forests.

Society of American Foresters. 1971. Terminology of Forest Science, Technology Practice and Products.

Sigman, M. J. 1985. Impacts of Clearcut Logging on the Fish and Wildlife Resources of Southeast Alaska. Alaska Department of Fish and Game, Habitat Division. Juneau. Technical Report 85-3.

Tryon, E. H. 1966. Implications of Even-Aged Management on Protection. In: Trends from Selection Cutting to Even-Aged Management. Allegheny Section, Soc. Am. For.

USDA Forest Service. 1983. Silvicultural Systems for the Major Forest Types of the United States. USDA Agricultural Handbook 445. Washington D.C.

USDA Forest Service. 1989. Region 5 Ad Hoc committee report. Effects of Proposed Very Large Decrease of Clearcutting in Region 5.

USDA Forest Service. 1990. Shasta Costa Integrated Resources Project Draft Environmental Impact Statement. Siskiyou National Forest, Region 6. Appendix B, Silvicultural Systems.

Author

Jerry L. Boughton
Regional Silviculturist
Alaska Region
P.O. Box 21628
Juneau, Alaska 99802-1628

CLEARCUTTING: THE REGENERATION METHOD OF CHOICE WHEN MANAGING FOR GENETIC DIVERSITY

Timothy La Farge
Southern Region
Atlanta, GA

INTRODUCTION

". . . contrary to a myth whose history and functions would repay further study, truth isn't the reward of free spirits, the child of protracted solitude, nor the privilege of those who have succeeded in liberating themselves. Truth is a thing of this world: it is produced only by virtue of multiple forms of constraint. And it induces regular effects of power. Each society has its regime of truth, its "general politics" of truth: that is, the types of discourse which it accepts and makes function as true; the mechanisms and instances which enable one to distinguish true and false statements, the means by which each is sanctioned; the techniques and procedures accorded value in the acquisition of truth; the status of those who are charged with saying what counts as true."

From "Truth and Power" by Michel Foucalt, 1926-1984, French philosopher.

It is commonly accepted among forest geneticists and tree improvement workers that clearcutting is the regeneration method of choice when planting genetically improved material. Yet it is a common perception among environmentalists and other segments of public opinion that clearcutting is harmful to the environment in general and to biodiversity in particular. For example, at first glance it would appear that clearcutting and genetic diversity are mutually exclusive concepts, i.e., the genetic diversity of a stand that has been clearcut has been reduced to zero, at least for the moment. However, I will attempt to show that, in a number of ways and for a number of reasons, clearcutting is also the method of choice if we are to manage for genetic diversity. Indeed, the degree of diversity that may be attained is only limited by the availability of the material used for stand regeneration, be it advanced reproduction, seed from neighboring stands, the diversity of seed lots or stand collections suited to the site, or the diversity among groups of selections developed for intensive breeding programs.

Although the main focus of this paper will be on genetic diversity, species diversity is itself a form of genetic diversity. Also, species grown in mixtures may result in different selection pressures on the genotypes of each species in the mixture than are likely to occur when each species is grown in pure stands. Obvious examples would be the mixtures of tolerant and intolerant, or early seral and late seral species. Hence, this paper will also consider pertinent aspects of species diversity.

The primary concern will be the potential effects of clearcutting on genetic diversity, but it should also be acknowledged that clearcutting is only one of several regeneration methods that are available for managing forests both spatially and temporally, and that the use of all methods may contribute to diversity.

EFFECTS OF NATURAL REGENERATION METHODS ON DIVERSITY

Ostensibly natural regeneration offers the least opportunity to manage for genetic diversity when a clearcut is implemented. However, natural regeneration should not be overlooked as a potential source of certain kinds of genetic diversity, not the least of which is its potential for favoring genotypes that are adapted to the local environment (Theisen 1980; Friedman 1986).

Namkoong (1990 personal communication) defined two kinds of genetic diversity: alpha diversity and beta diversity. Alpha diversity represents the richness of a sample of a large number of genotypes which might occupy a zone, such as the reforestation of a geographic zone by seed collected from a clonal seed orchard. Such a seed orchard contains a great deal of genetic diversity because most of the clones originate from separate stands and hence are unrelated. Beta diversity is exemplified by many small breeding populations, each occupying a small breeding zone. Alpha diversity has high diversity initially because of the unrelatedness of genotypes obtained from many stands, but, when a geographic zone is reforested with seed from such an array of genotypes, two things happen: (a) we create a new homogenized gene pool, since many of the offspring are more or less related; and (b) all genotypes do not necessarily contain alleles that are adapted to each local environment within the large geographic zone. Rare alleles may be lost from the gene pool, which may prove significant in the future if there is an environmental change to which such rare alleles could provide a unique adaptation. Beta diversity provides an opportunity to sample local gene pools that are adapted to local environments to a much greater degree than does alpha diversity.

Namkoong's definitions appear to be modifications of similar definitions used in ecology to describe species diversity. Whittaker (1970) defined alpha diversity as ". . . richness in species of particular community samples," and beta diversity as " . . . the degree of change in species composition of communities along a gradient." If we substitute "genotypes" and "genotypic" respectively for the word "species" in these definitions, we arrive at the essential concepts outlined by Namkoong. Such analogies illustrate the close similarity between genetic and species diversity.

For species in which natural regeneration commonly occurs after clearcutting, either by means of advanced reproduction or from seed blown in from adjacent stands, natural regeneration provides an optimum source of regeneration which encourages beta diversity, i.e., a set of genotypes that are adapted to the environmental gradient. However, seed from local seed sources also carries with it a degree of inbreeding, due to both crossing among close relatives and to selfing (Squillace and Kraus 1963). We can ameliorate such potentially negative effects by means of breeding and artificial regeneration.

Before we consider the artificial regeneration alternatives, we need to review some studies of the effects on gene frequency and genetic structure that may occur when harvested areas are regenerated naturally with the seed of neighboring stands. Although little or no research has been done on the effects of clearcutting on genetic diversity in natural regeneration as such, we can perhaps make some inferences from studies that have been done on the effects of other regeneration methods or on old-field pine populations.

Roberds and Conkle (1984) reported a study which perhaps best represents what we might expect in the case of natural regeneration of clearcut stands. They analyzed the allozyme variation and genetic structure of two adjacent old-field loblolly pine (*Pinus taeda* L.) stands of different ages in which the younger stand represented the offspring of a portion of the older stand. Two of their conclusions are pertinent to our concern about the effects of clearcutting on diversity. One is that there were low levels of inbreeding obtained in both stands, this despite the probability that these stands were derived from trees in fence rows or in some way having low effective population size. These low inbreeding levels also seemed consistent in all age class groupings and in all spatial groups, and they did not depart significantly from expected Hardy-Weinberg proportions. The second conclusion dealt with the genetic structures of both populations. Significant differentiation was found among age classes for four of the eight electrophoretic loci studied. However, differences were not found among spatial groups, and the differences obtained in the parent stand were not found in the progeny stand. Also, gene frequencies did not differ between parent and progeny stands. The authors concluded that the progeny stand was derived from "random mating of the genotypes in the parental generation and random dispersal of progeny genotypes throughout the site."

Heterogeneity and a predominance of outcrossing may also be the rule rather than the exception in many other pine species. Linhart et al. (1981), studying protein polymorphisms in ponderosa pine (*Pinus ponderosa* Laws.), found very high rates of outcrossing (between 95 and 99 percent). They concluded that these trees are pollinated mostly by pollen clouds representing allele frequencies characteristic of the greater population rather than only close neighbors. Also, despite patchy allelic frequencies suggesting a population composed of family groups, there was no evidence of inbreeding either in the established trees or in their seedling progenies. Similar findings were obtained by Mitton et al. (1981) for ponderosa pine and by Guries and Ledig (1982) for pitch pine (*P. rigida* Mill.). These studies of protein polymorphisms produced heterozygosities of 12 and 14.6 percent respectively, which are high when compared with those of other plant species (e.g., Hamrick and Godt 1989).

On the other hand, Neale and Adams (1985), in a study of mating systems in old-growth and shelterwood stands of Douglas-fir (*Pseudotsuga menziesii* var. 'menziesii'), found evidence of inbreeding due to related matings in uncut old-growth stands but not in adjacent shelterwoods. However, the rate of outcrossing in both types of stands was high.

All of these studies suggest that, so long as a sufficient supply of natural regeneration can be obtained from adjacent natural stands in these species, high levels of outcrossing will be maintained associated with little or no inbreeding. In at least two of the species, ponderosa and pitch pines, there appeared to be considerable panmixia, perhaps because fertilization was supplemented by occasional or frequent pollen clouds. Yet in these same species there was evidence of either spatial or family groupings, suggesting adaptations to local environments. Trees containing such adaptations could increase in frequency due to natural selection occurring at the seedling stage.

CONTROLLING DIVERSITY BY ARTIFICIAL REGENERATION METHODS

Tree improvement programs traditionally limit their regeneration methods to clearcutting and planting, since this method allows strong control of the sources of genetic material and maximizes genetic gain. However, if genetically improved material is available, silviculturists may use it for any regeneration system, such as shelterwood and planting or group selection and planting. The populations within which we make selections are chosen because they have substantial genetic variability, or diversity, so that we can be assured of strong selection differentials which will result in ample genetic gains, even with traits having weak or moderate heritabilities,

Effects of Tree Improvement Programs on Diversity

Many segments of the public, including environmental groups and even some foresters, seem to make the tacit assumption that all forest genetics practices necessarily lead to a reduction in genetic diversity. I contend that, not only are we not reducing genetic variability, but because genetic variation is essential to the productivity of our forests, our practices are in the long run actually enhancing the diversity and vigor of our forests and the tree species with which we are working.

However, if not carefully planned, certain program practices can lead to reductions in genetic diversity. Such activities include progeny testing and roguing our clonal seed orchards (backward selections), or thinning our seedling orchards, or selecting the best individuals in the best families with which to establish advanced-generation orchards (forward selections). Without proper safeguards, we will gradually reduce the genetic base and increase the potential for inbreeding with resultant reductions in genetic diversity in our production orchards. Various strategies have been devised and discussed for coping with or avoiding such dangers, such as introducing new wild and unimproved stocks, maintaining large breeding populations separate from smaller, intensively selected production populations (Namkoong et al. 1980), or managed multiple populations developed by means of mass selection without testing (Friedman 1989; Namkoong and Bishir 1989). Yet, even when we include the full range of techniques available for breeding trees and managing and conserving gene resources, clearcutting and planting remain high on the list of regeneration methods available for implementing these strategies.

Regeneration from Seed or Seedlings

Clearcutting imposes no limits on the numbers or kinds of seed sources we establish in any given stand or geographic zone. Neither does it require that we plant. For species and/or sites for which direct seeding is appropriate and manageable, clearcutting with appropriate site preparation allows us to regenerate a stand with seed of known genetic quality on which natural selection can operate, thereby combining some of the advantages of both alpha and beta diversity.

The potential for pollen contamination of small, isolated populations, such as seed orchards, has been reported (Friedman and Adams 1985), and, while there is legitimate concern about the obvious seed orchard management implications and problems that such contamination presents, others are very concerned about the potential contamination of natural, locally adapted populations by means of their proximity to commercial "domesticated" forest plantations. Because many studies, especially in the Pacific Northwest, have indicated adaptive patterns of variation in a wide variety of traits, it is feared that the integrities of co-adapted gene complexes will be violated by mixing with gene complexes from other adaptively different populations (Adams 1981; Ledig 1986a, 1986b). It is possible, however, that selection pressures of the local environment would help maintain the needed diversity and integrity of the population, both at the genic level and at the gene complex level. Such would seem to be the evidence provided by the studies reported above for natural stands of ponderosa and pitch pines. In fact, a worthy research study would be to determine what might be the proportion of surviving seedlings planted to naturals over large reforested areas, given the small size of seed orchard populations relative to the large sizes of natural populations.

We may also argue that, if mixing is a potential threat to locally co-adapted gene complexes, then so also are pollen clouds, over which we have no control. Yet co-adapted gene complexes seem to have persisted despite recurring pollen cloud contamination. There are valid theoretical reasons why such contamination may not occur. Co-adapted gene complexes, also known as "supergenes", are clusters of genes that have been locked into the genome as the result of chromosomal inversions (Hartl and Clark 1989). At least in *Drosophila*, the species in which most of the work on supergenes seems to have been done, only nonrecombinant gametes are recovered, so that inversions seem to have the effect of suppressing recombination. In forest trees it would seem that such co-adapted complexes would not be altered easily by pollen contamination of any sort, whether from distant or neighboring populations. What could remove them might be mass extinctions, such as very hot wild fires over very large areas or intensive agriculture, for example cotton farming during the 18th and 19th centuries in the pine belt in the South.

We know very little about local adaptations in general and co-adapted gene complexes in particular. One study of differences in migration or dispersal of male gametes and seed found that ". . . differential sex migration tends to protect polymorphisms" (Gregorius and Namkoong 1983). The authors' modelling showed that conditions of single demes (locally adapted subpopulations) and multiple demes affect protectedness of polymorphisms differently in each sex. Protection by means of single deme protection is strong because, if this occurs when the allele is rare and present only in heterozygotes, it is even more certain to be protected when favored as a homozygote and occurring at a higher frequency in any single deme. Hence, the authors conclude that, in plant species for which migration is wide for male gametes but not wide for seeds, there is a strong mechanism for protecting alleles. Since many commercially important tree species produce seeds which are not dispersed nearly as widely as their pollen, it would seem that locally adapted gene complexes within such species would tend to remain protected and stable, at least when these conditions hold true.

Use of Clonal Material

A discussion of clearcutting and genetic diversity would not be complete without consideration of the implications that clonal forestry has on genetic diversity. By planting clonal material, we can achieve greater genetic diversity in combination with more precise control of the genetic material (Libby and Rauter 1984). The authors support this contention by stating that the important variables which determine diversity are not the numbers of genotypes in a stand so much as the degrees of genetic differences among the genotypes or individuals comprising the stand and the frequencies of those individuals. Again, an intensive method such as clonal forestry makes no sense if it is not implemented by means of clearcutting and planting. Yet, if we accept Libby and Rauter's definitions and standards of genetic diversity, clonal forestry provides an opportunity to maximize genetic diversity in intensive commercial forest management. Needless to say, it is probably not realistically possible to implement such an intensive management method on National Forest System lands.

MANAGEMENT OF THE ECOSYSTEM FOR GENETIC DIVERSITY

As I have already suggested, there is a growing concern among foresters, ecologists, and resource biologists in general over the long-term conservation of gene resources in forest trees (Adams 1981; Ledig 1986a; Ledig 1986b; Namkoong and Bishir 1989; Namkoong 1989a; Namkoong 1989b; Stettler 1986). The conservation methods proposed include managing the genetic diversity of the populations considered, especially of those species being commercially exploited. They include taking consideration of the integrity of the ecosystem in which these forest tree populations are included. The methods for conserving or preserving the genes and gene complexes include both *in situ* and *ex situ* methods. I will limit this discussion to the former, since *in situ* methods usually involve clearcutting and planting.

In the process of trying to understand ecosystem dynamics, we will also need to develop better measures of genetic diversity. Muller-Stark and Gregorius (1986) attempt to define the most useful parameters for measuring diversity. In measurements of a set of Scots pine (*Pinus sylvestris* L.) populations, they found that the conditional heterozygosity, which is calculated as a percentage of the total heterozygosity possible, is a better measure than is actual heterozygosity. When conditional heterozygosity is combined with values obtained for genic diversity and for population differentiation, the reliability of interpretations of genetic diversity can be increased considerably.

Whatever methods we decide to use in the process of fine-tuning our techniques for measuring diversity at the enzyme level, managing the gene resource and the ecosystem for genetic diversity presents other dilemmas for tree improvement program managers and geneticists. On the one hand it is an opportunity to exercise their skills to the fullest and to utilize the full array of techniques and strategies available to them. On the other hand, cautionary and conservative concerns suggest to some that certain techniques for achieving genetic gain may be hazardous to the genetic health of the population. It is also not always clear what sources of variation are important or of use, since studies of genetic diversity at the enzyme level often produce results which contradict those at the whole organism level. Adams (1981) and Ledig (1986a, 1986b) cite electrophoretic studies which indicate much greater genic variation at certain selected loci within populations than between populations. Yet Adams (1981) also cites several common garden tests of growth traits which indicate considerable variation among populations of several conifers of the Pacific Northwest. Similarly a study of loblolly pine (*P. taeda* L.) indicated considerably more variation among than within stands for survival, height, diameter, volume per tree, percentage of trees free of fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*), and an index of stem crook (La Farge 1974). Further, a provenance test of loblolly pine by Kraus (1967) showed that faster growing southern sources of loblolly pine outgrew more northern sources on sites located at least 200 miles north of their origin. Such findings, which are not uncommon in the literature, offer the opportunity of obtaining significant genetic gains for growth and other traits. Yet, increasingly we are cautioned about contaminating the integrity of co-adapted gene complexes when reforesting areas with nonlocal seed.

If such contamination really is a threat to genetic diversity and ecosystem stability, then research needs to be directed toward determining the degree to which mixing of populations does or does not damage the adaptive integrity of locally adapted gene complexes. Such research must include data from studies in the field. The most efficient methods for implementing such studies are clearcutting and planting, since control of spacing and of local and nonlocal genetic material is made possible most efficiently by such methods.

Perhaps the threat to ecosystem stability is much greater in the Pacific Northwest than in the Southeast because of sharper environmental gradients or dissection of the landscape. In Region 8 geographic zones have been defined by the Southwide Pine Seed Source Study for loblolly pine (Wells and Wakely 1966). They are large enough to allow considerable movement within zones without noticeable growth loss or other evidence of declines in adaptation to local environments.

If contamination of locally adapted races is not a problem, then clearcutting offers a great opportunity to combine the genetic gains that can be obtained by planting the most vigorous and often the best adapted sources (Namkoong 1969; Howe 1989; Stettler 1986;) by means of planting with the adaptability of the local population. The natural regeneration is allowed to occur simultaneously with the introduced material. When advanced regeneration is present or seed from light-seeded species is available from contiguous stands, the clearcutting method can enable such a strategy.

Another issue often raised by those who are concerned about genetic diversity and ecosystem stability is density-dependent natural selection. According to Hartl and Clark (1989), models concerned with population dynamics, such as density-dependent selection, provide a kind of forum in which ecologists and geneticists could bring "ecological time" and "evolutionary time" into phase with each other. Until recently the former was thought to occur in short term contexts and the latter in long term contexts, but experiments with *Drosophila* showed that some chromosome inversions sometimes change in frequency in annual cycles. Another example of the poor distinction between ecological and evolutionary time scales was provided by observations in England of the rapid evolution of the pigmentation of certain moth species, termed industrial melanism. In any case, one measure of density-dependent selection is "r-selection", which involves selection favoring certain genotypes at low population densities. The converse of this form of selection is "k-selection" favoring certain genotypes at high population densities. Hartl and Clark go on to observe that these concepts are useful to the extent that they describe extreme modes of selection. As an example, weedy plants are primarily (but not exclusively) r-selected because their life cycle is adapted to rapid reproduction in disturbed environments. The authors also warn that some experiments indicate that models showing differences between reproductive success at high and low densities may be ill-founded.

However, in forest practice the control of stand density is critical in the proper management of stands and forests. It follows that different genotypes, whether locally adapted or not, may vary in their survival or growth rates according to the densities at which they are established. Namkoong and Bishir (1989) considered the dynamic complexities created when certain assumptions are made about different density situations. They cited modelling experiments which indicate, among other things, that certain genotypes or species that usually are of rare occurence may thrive in marginal environments and form stable communities. But, if management practices are undertaken to "protect" them, population density in that community may rise until they are excluded. They concluded that such protective management of certain kinds of patches may unintentionally decrease genetic diversity. Hence, conservation programs should perhaps consider multiple management plans to create an array of protected and unprotected patches. They also stressed the use of multiple populations to increase the probability of adaptations to multiple densities and environments.

Such strategies do not necessarily require clearcutting, but it can be one of several management strategies employed. Clearcutting also is the management technique which allows the greatest control of the species or genotypes to be established (Smith 1986). Hence, clearcutting can be used to establish most effectively and efficiently mass selection plantations in which to select and collect seed from multiple populations (Friedman 1989) when those are called for.

Density-dependent selection may also be a factor when natural regeneration from adjacent stands is relied upon to regenerate clearcut areas. Smith (1986) has shown how the density of seedlings obtained from seed disseminated from adjacent stands decreases along a gradient perpendicular to the effective (rather than prevailing) wind direction. If density dependent selection is a factor, then the genotypes favored close to the adjacent stand would be "k-selected" and those further away in the clearcut would be "r-selected". Although there do not seem to be any electrophoretic studies of such an effect as yet, Marquis (1966) demonstrated that control of the width of clearcut strips can favor which of three species of birch (*Betula* Spp.) will form the dominant regeneration in the management of certain northern hardwood forests. If studies could be designed to show genetic variation among seedlings in a single species of such varying densities, then regeneration of clearcuts from seed disseminated from adjacent stands might be one more method of managing for genetic diversity in natural stands.

Effects of Silvicultural Practices on Genetic Diversity

It would seem that almost any silvicultural practice will have an effect on genetic diversity. Wilusz and Giertych (1974) compared diameter growth and basal area of the progenies derived from stands of mother trees of different ages but of comparable provenance and site. In early years best growth was obtained from the progeny of younger mother stands, but at age 59 the progeny of older mother stands grew best. This indicated that traditional thinning practices had produced genetic gain.

Thinning treatments were also compared in a study of white pine (*Pinus strobus* L.) by Ledig and Smith (1981). Artificial and natural selection, plus a reduction in inbreeding improved height growth, and removal of weeviled parents appeared to result in improved weevil resistance of the progeny. The results suggested that use or abuse of genetic principles in silvicultural operations can promote genetic improvement or deterioration respectively.

Clearcutting has been shown actually to increase species diversity, at least in the early stages of succession. Swindel et al. (1984) defined species diversity as an average property of a community in such a way as to be related to species rarity. They computed indices of species diversity from abundant empirical data obtained under two management regimes followed by clearcutting and site preparation and then for three years after planting of slash pine (*Pinus elliottii* Engelm. var. *elliottii*). These treatments resulted in increased species diversity for the three years following planting. They were predicted by a model which indicated that increases in species diversity can be expected whenever site disturbance reduces but does not eliminate abundant late-successional species and permits the reappearance of native early-successional species, such as forbes and grasses.

Species Diversity and Ecosystem Management

Perhaps the effect of clearcutting, or any form of intensive management, on diversity is best illustrated by examining and comparing an old growth forest with a disturbed forest. Middleton and Merriam (1985) compared an old growth "virgin" forest undisturbed for over 200 years with 17 younger forests having various degrees of disturbance. The uncut, undisturbed forest had by far the fewest plant and animal taxa of all forests examined, and it included no rare species not found in the forests having greater degrees of disturbance. Their's was a study of species diversity, not genetic diversity within species, but we can, I think, consider species diversity as genetic diversity in the broad sense for the purpose of this discussion. In any case, their findings directly contradict the claim by The Ecological Society of America (1986) that plant species diversity increases in old growth forests, a claim supported by no specific data.

As Shugart and West (1981) have shown in a series of gap modelling experiments by means of computer simulation, the focus of forest management should be on the whole ecosystem, including interactions among species within the ecosystem. They compared the data generated by their simulated gap models with an array of data sets from real ecosystems and found their predictions to be very accurate, thereby giving them credibility. Their results also suggest that we should consider interactions among species within the ecosystem and that unstable or undesirable landscapes, whether arrived at by incorrect management decisions or by accidents of nature, will not revert to their former states until appropriate management strategies are actively employed to that end. Their studies also indicated that ecosystems are not really static or unchanging. Evidence of great change over the past several thousand years supports a concept of ecosystems not of great antiquity but rather of considerable dynamics. To understand forest ecosystems, we need to understand their present dynamics.

It seems to me that such reasoning does not need only to be applied at the ecosystem level, but also at the level of genetic variation within species. If we can capture and, in appropriate instances, restructure the genetic diversity and dynamics of the tree species we work with, in terms of both adaptation and utilitarian needs, then we can manage the ecosystem for genetic diversity. Any such system of ecosystem management will need to include clearcutting as one of its primary strategies.

CONCLUSIONS

Despite concerns about inbreeding and limitations on outcrossing in populations that have been restricted by various kinds of major disturbance, and despite modelling experiments which suggest reductions of genetic diversity, studies of diversity *in situ* indicate that in several species high levels of outcrossing associated with little inbreeding are maintained. Some of these studies also suggested that the genotypes sampled in these naturally regenerated populations were adapted to the local environments. Such adaptations would seem to be favored by means of natural selection occurring at the seedling level.

The literature also includes certain kinds of contradictory evidence. For example, electrophoretic studies of most species indicate much greater variability within populations than among populations, yet studies of growth traits tend to show greater variation among than within populations. The fact that both kinds of variation can be tapped to obtain genetic gains in important traits does not seem to reduce the concerns in some quarters that we may be contaminating the integrity of co-adapted gene complexes when reforesting areas with nonlocal seed. To alleviate such concerns, research needs to be directed toward that end. Although modelling experiments help to show all of the possibilities, field studies should be included and even emphasized. Such field studies must inevitably include clearcutting and planting. Not only is this method an important silvicultural method which should be included as a variable, but it is also the most effective method of controlling and designing most of the genetic variables that would need to be included in such an experiment.

There are several reasons why co-adapted gene complexes may resist contamination. Selection pressures may resist contamination by maintaining local adaptability. Further, since such "supergenes" are chromosomal inversions which resist recombination, it seems unlikely that such complexes would be altered by pollen contamination from distant or neighboring populations. However, mass extinctions could pose a threat. Finally, at least one modeling experiment shows that, for species in which male gametes have wide dispersal (as in wind disseminated pine pollen) but female gametes do not (seed of pines and even more so of oaks), there exists a form of single deme protection which tends to protect polymorphisms. In such species it seems that locally adapted gene complexes tend to remain protected and stable.

Clonal forestry in intensive forest management can be applied in such a way as to promote genetic diversity. This argument is based on the realization that the important variables which determine genetic diversity are not so much the numbers of genotypes in a stand as the degrees of genetic differences among the genotypes or individuals comprising the stand and the frequencies of those individuals.

If contamination of locally adapted races proves not to be a problem, clearcutting offers an opportunity to combine the genetic gains obtainable by introducing the most vigorous (and even best adapted) seed sources in plantations together with adaptedness of the local population by allowing natural regeneration to occur simultaneously. In the presence of advanced regeneration or seed from light-seeded species in adjacent stands, the clearcutting method makes such a strategy possible.

Density-dependent selection among genotypes is another factor which may possibly be utilized and exploited in any attempt to manage for genetic diversity. A multiple-populations approach to management practices designed to protect marginal biotypes has been suggested to offset the potentially damaging effects that uniform methods of protection can have on the genetic diversity and survival of such genotypes. Such multiple management plans can be utilized to create an array of protected and unprotected environments and to increase the probability of adaptations to multiple densities. Because it is the management technique which allows the greatest control of species or genotypes to be established, clearcutting should be included as an important tool in such a management system.

In stands naturally regenerated after clearcutting, there is evidence that variable stand densities may favor a diversity of species in such stands. It seems logical to expect that genetic diversity within species is also obtainable by manipulating the sizes and shapes of clearcuts. If such a source of genotypic variability can be verified, then we will have found another tool for managing genetic diversity in natural stands.

Other studies demonstrate that almost any silvicultural practice can have an effect on genetic diversity. Traditional thinning practices have been shown to produce genetic gain. Yet, if not properly applied, such practices can also result in dysgenic selections. Clearcutting has been shown to increase species diversity (i.e., genetic diversity in the "broad sense"), at least in the early successional stages.

In at least one study, species diversity was found to decrease in an old-growth, "virgin" forest relative to similar younger forests having various degrees of disturbance. This analysis directly contradicts claims of increasing diversity in old-growth stands by The Ecological Society of America.

Modelling experiments show that forest ecosystems which have undergone severe changes in the past will not revert to their former "pristine" states if left unattended. Re-establishment of vigorous ecosystem dynamics seems to require some form of intensive management to that end. In many cases clearcutting, which often simulates wildfires, will need to be included in any system of strategies designed to enhance genetic diversity, which must be included in turn as part of the ecosystem dynamic. Obviously, in any of these strategies much more needs to be learned about ecosystems, locally co-adapted gene complexes, and genetic diversity. Although clearcutting is certainly not the only management technique available, it has many applications in the management of and research on genetic diversity. Like any other technique, it can be misapplied in such a way as to reduce genetic diversity and weaken or do harm to the ecosystem. But there is no reason why such mistakes need to be made if we consciously work toward avoiding them. Indeed, clearcutting is the regeneration method of choice when managing for genetic diversity.

Since its inception, the Forest Service has had the authority and power to make its own management decisions based on the most recent research and technology available. We must somehow convince our publics that our actions are based on sound principles. I hope that the evidence I have presented in support of clearcutting as a management and research tool will help to alleviate any doubts our critics may have concerning the truths of our methodology, so that we may continue to exercise intelligently our power to manage the forest resources at our disposal.

LITERATURE CITED

Adams. W. T. 1981. Population genetics and gene conservation in pacific northwest conifers. In: Evolution Today (Scudder, G. C. E. and J. L. Reveal Eds.); Proc. Secd. Intl. Cong. Syst. and Evol. Biol., pp. 401-415.

Ecological Society of America, The. 1986. Conserving Biological Diversity in Our National Forests. The Wilderness Society, Washington, D.C. 116 pp.

Friedman, S. T. 1986. Natural regeneration - genetic and seed aspects. U.S.D.A. Forest Service, Region 6, Area 4 Technology Transfer in Natural Regeneration. 20 pp.

Friedman, S. T. 1989. Appropriate technology in tree breeding: gain with less pain. Proc. 31st Northeast. For. Tree Imp. Conf. and 6th North Cent. Tree Imp. Conf., Univ. Park, PA, 1988.

Friedman, S. T. and W. T. Adams. 1985. Estimation of gene flow into two seed orchards of loblolly pine (*Pinus taeda* L.) Theor. Appl. Genet. 69: 609-615.

Gregorius, H. R. and Namkoong, G. 1983. Conditions for protected polymorphism in subdivided plant populations: 1. uniform pollen dispersal. Theor. Pop. Biol. 24(3): 252-267.

Guries, R. P. and F. T. Ledig. 1982. Genetic diversity and population structure in pitch pine (*Pinus rigida* Mill.). Evolution 36(2): 387-402.

Hamrick, J. L. and M. J. W. Godt. 1989. Allozyme diversity in plant species. In: Plant population genetics, breeding, and genetic resources (Brown, H. D., M. T. Clegg, A. L Kahler, and B. S. Weir, Eds.); Sinauer Associates, Inc., Sunderland, Massachusetts; pp. 43-63.

Hartl, D. L. and A. G. Clark. 1989. Principles of Population Genetics. 2nd Ed. Sinauer Associates, Inc. Sunderland, Mass. xiii+682 pp.

Howe, G. E. 1989. Genetic effects of even-aged and uneven-aged silviculture. National Silviculture Workshop, Petersburg, AK, July, 1989.

Kraus, J. F. 1967. A study of racial variation in loblolly pine in Georgia, Tenth-year results. Proc. Ninth South. For. Tree Imp. Conf., Knoxville, Tenn., pp. 78-85.

La Farge, T. 1974. Genetic variation among and within three loblolly pine stands in Georgia. Forest Sci. 20(3): 272- 275.

Ledig, F. T. 1986a. Heterozygosity, heterosis,, and fitness in outbreeding plants. In: Conservation biology: the science of scarcity and diversity (M. E. Soule, Ed.); Sinauer Associates, Inc., Sunderland, Massachusetts; pp. 77-104.

Ledig, F. T. 1986b. Conservation strategies for forest gene resources. For. Ecol. and Mgt., 14: 77-90.

Ledig, F. T. and D. M. Smith. 1981. The influence of silvicultural practices on genetic improvement: height growth and weevil resistance in eastern white pine. Silvae Genet. 30(1):30-36.

Libby, W. J. and R. M. Rauter. 1984. Advantages of clonal forestry. For. Chron. 145-149.

Linhart, Y. B., J. B. Mitton, K. B. Sturgeon and M. L. Davis. 1981. Genetic variation in space and time in a population of ponderosa pine. Heredity 46(3): 407-426.

Marquis, D. A. 1966. Germination and growth of paper and yellow birch in simulated strip cuttings. U.S.D.A. For. Serv. Res. Paper NE-54. 19 pp.

Middleton, J. and G. Merriam. 1985. The rationale for conservation: problems from a virgin forest. Biol. Cons. 33: 133-145.

Mitton, J. B., Y. B. Linhart, M. L. Davis, and K. B. Sturgeon. 1981. Estimation of outcrossing in ponderosa pine, *Pinus ponderosa* Laws., from patterns of segregation of protein polymorphisms and from frequencies of albino seedlings. Silvae Genet. 30: 4-5.

Muller-Starck, G. and H. R. Gregorius. 1986. Monitoring genetic variation in tree populations. Proc. 18th IUFRO World Congress Ljubljana Div. 2 Vol. II; 589-599.

Namkoong. G. 1969. Nonoptimality of local races. In: Proc. 10th South. Conf. For. Tree Imp. Houston, Texas; pp. 149-153.

Namkoong, G. 1989a. Population genetics and the dynamics of conservation. In: Biotic Diversity and Germplasm Preservation, Global Imperatives (Knutson, L. and A. K. Stoner, Eds.). Kluwer Academic Publishers, pp. 160-181.

Namkoong, G. 1989b. Systems of gene management. In: Breeding tropical trees: population structure and genetic improvement strategies in clonal and seedling forestry (Gibson, G. I., A. R. Griffin, and A. C. Matheson Eds.); Oxford Forestry Institute, Oxford, U. K. and Winrock International, Arlington, Virginia, USA. Proc. IUFRO Conference, Pattaya, Thailand, November 1988.

Namkoong, G., R. D. Barnes, and J. Burley. 1980. Screening for yield in forest tree breeding. Commonw. For. Rev. 59(1): 61-68.

Namkoong, G. and J. Bishir. 1989. The interaction of genetics and ecology in forest ecosystems. Proc. 31st Northeast. For. Tree Imp. Conf. and 6th North Cent.Tree Imp. Conf., Univ. Park, PA, 1988; pp. 73-79.

Neale, D. B. and W. T. Adams. 1985. The mating system in natural and shelterwood stands of Douglas-fir. Theor. Appl. Genet. 71: 201-207.

Roberds, J. H. and M. T. Conkle. 1984. Genetic structure in loblolly pine stands: allozyme variation in parents and progeny. Forest Sci. 30(2): 319-329.

Shugart, H. H., Jr. and D. C. West. 1981. Long-term dynamics of forest ecosystems. Amer. Sci. 69: 647-652.

Smith, D. M. 1986. The Practice of Silviculture, 8th Ed. John Wiley & Sons, Inc. 527 pp.

Squillace, A. E. and J. F. Kraus. 1963. The degree of natural selfing in slash pine as estimated from albino frequencies. Silvae Genet. 12(2):41-72.

Stettler, R. F. 1986. Der Wald als Experiment. Schweiz. Z. Forstwes. 137(3):205-220.

Swindel, B. F., L. F. Conde, and J. E. Smith. 1984. Species diversity: concept, measurement, and response to clearcutting and site preparation. For. Ecol. and Mgt., 8: 11-22.

Theisen, P. A. 1980. Maintenance of genetic diversity and gene pool conservation of commercial or potentially commercial tree species in the Pacific Northwest Region United States Forest Service. Proc. Serv. Work. Gene Res. Mgt., pp. 61-186.

Wells, O. O. and P. C. Wakeley. 1966. Geographical variation in survival, growth, and fusiform-rust infection of planted loblolly pine. Forest Sci. Monograph 11. 40 pp.

Whittaker, R. H. 1970. Communities and Ecosystems. The Macmillan Company, Toronto, Ontario, xi+162 pp.

Wilusz, W. and M. Giertych. 1974. Effects of classical silviculture on the genetic quality of the progeny. Silvae Genet. 23(4): 127-130.

Author

Timothy La Farge
Zone Geneticist
Southern Region
1720 Peachtree Road, N.W.
Atlanta, Georgia 30367

RESEARCH STUDIES OF THE CLEARCUTTING REGENERATION HARVEST METHOD

Raymond C. Shearer
Intermountain Research Station
Missoula, MT

SUMMARY

Clearcutting or one of its variations has been used to successfully regenerate 44 of the 47 major forest cover types in the United States. A wide range of studies have been superimposed on some clearcuts and results from this research are used to formulate and justify management decisions. Biological and physical factors, or combinations of these factors, can limit the probability of success; sometimes within the most easily regenerated forest types. Often, regeneration success is not the issue that prevents the use of clearcutting, but the visual impacts, concerns for biodiversity, or other perceived problems. Managers expect research to fill gaps in knowledge and provide a defensible and scientific basis for decisions. Information is needed in each of the forest cover types to define: the minimum size opening and treatments required to maintain seral species in stands, the long-term implications of repeated clearcutting or the absence of a form of clearcutting on sites, and factors that inhibit the regeneration potential. Also, we need to understand the consequences of limiting or eliminating clearcutting in terms of changes in plant and animal composition, long-term impacts from disease and insects, wildlife habitat, water yield and quality, timber growth and yield, recreation, and fire management.

THE CLEARCUTTING REGENERATION HARVEST METHOD

Agriculture Handbook No. 445 (Burns 1983) provides a reasonably current synopsis of silvicultural systems used to regenerate the major forest types of the United States and is based on research and experience of managers. It documents that clearcutting or one of its variations, usually in combination with site preparation, can be used to regenerate most of these forest types. At least one of the clearcutting variations have successfully regenerated each of the western forest types:

Recommended (best system)	11
Can be used successfully	12
Not successful	0
	23

Table 1 expands this tabulation to show, for each of the western forest cover types, the expectation of successful regeneration following clearcutting, provide some specific comments, and give key references.

Most (88%) of the eastern forest types also regenerate using a form of the clearcutting method:

Recommended (best system)	10 [1]
Can be used successfully	13
Not successful	3 [1]
	25

[1]Sand pine: CC recommended for Ocala var. CC not successful for Choctawhatchee var.

Table 2 also expands this tabulation to show, for each of the eastern forest types, the expectation of successful regeneration following clearcutting, provide some specific comments, and give key references.

Clearcutting is the recommended silvicultural system for regenerating 48% of the western forest types and 38% of the eastern forest types. With such success regenerating most of the forest types, why is there such an outcry against the use of clearcutting? In some locations it simply doesn't look good; it offends our perception of how the cutover stand should appear. If esthetics were the only consideration, planning regeneration harvest cuts could be simple. But, usually there is a range of stand and site conditions that also must be considered. When these conditions are compounded with social concerns (such as maintaining biodiversity and enhancing the habitat for any endangered species, human attitudes, special-use areas, etc.), a complex of factors must be balanced to determine the strategy for proper harvest cutting. Planners need patience and often the "wisdom of Solomon" to choose the best of a wide range of potential decisions.

INFLUENCE OF UNIT SIZE

From the regeneration standpoint, if a uniform stand is clearcut and planted, size usually has little to do with the decision unless some limiting factor may adversely impact plantation survival. But, if natural regeneration is specified, then size, location, and perhaps shape must be considered to enhance the probability of prompt regeneration. Although some light-seeded, winged species disperse long distances, and occasionally heavier seeds travel farther than expected, most clearcuts are limited in size to assure that enough seed will be dispersed throughout the opening, especially in years of low seed production, to meet minimal stocking standards.

Reliance on natural regeneration is a gamble! Some forest types have much higher probabilities of success than others. Within each forest type, the manager must recognize indicators where the chances for natural regeneration are best, and least. When we opt for natural regeneration we also accept the probabilities that sufficient seed will (1) mature, (2) disperse throughout the opening, and (3) germinate to restock the area. Some species regularly produce copious amounts of seed while others infrequently produce seed crops; some disperse winged seed long distances (mostly by wind), while wingless seed drop to the ground near the parent trees or are carried by animals. The seed potential is often reduced dramatically from flower bud formation through dispersal. In fact, an entire seed crop can be killed by one frost or by insects. Managers must identify conditions promoting seed fall and identify the direction of dispersal. Prevailing and upslope winds probably disperse most tree seed but direction of these winds can be vary markedly. Dry storm fronts can also disseminate seed; often much farther than prevailing or upslope winds. All dispersed seed can be consumed by animals or die from disease before germination. Unfavorable biological or physical factors can severely limit seedling survival after germination. Dispersed seed to seedling ratios are sometimes calculated and found to range from <2:1 within the most favorable openings to >1,000,000:1 on unusually hostile sites.

Smaller clearcut blocks, patches, or strips enhance the degree of stocking and density of seedlings especially following years of low seed production or on severe sites. Larger clearcuts usually have a lower probability of restocking than smaller units.

DEVELOPMENT OF STANDS OVER THREE ROTATIONS

Clearcutting and site preparation that reduces the duff layer but maintains the productive potential and physical properties of forest soils usually also favor the reestablishment of both seral and climax species present in the virgin stand. But, organic matter levels in the forest floor decrease as a result of these activities (Jurgensen *et al.* 1990). These authors indicate these processes may be detrimental, particularly in dry or shallow soils. A continuous supply of organic matter, especially the woody component, should be kept following harvest to maintain the productivity of the site (Harvey *et al.* 1987). The organic material not only stores nutrients and moisture but is the media where microorganisms live that enhance the ability of conifers to extract nutrients and moisture from the soil. This is particularly critical on droughty sites. Physical soil properties usually are maintained by harvesting when equipment will minimally impact the site. When a mitigating treatment must be applied to improve soil properties, only certain site preparation techniques are effective (Morris and Lowery 1988).

Development of most forest stands should continue for at least three rotations or more if harvesting and site preparation are carefully planned, laid out, and executed with no more disturbance than necessary to establish seral tree species. But, if these methods are modified without some compensating action, distinct changes can occur by the end of the third rotation. With little or no disturbance, seral species will decline and climax or shade tolerant species will predominate. Conversely, greater tree utilization and excessive site treatment can decrease site productivity.

LONG TERM STUDIES

In the early 1970's national attention focused on the effects of clearcut logging on the nutrient status of these treated sites. Many long-term studies of the effects of clearcutting were initiated before or during this period and provide considerable information about the short- and long-term effects of clearcutting on the site and a wide range of other factors. Some of these studies include:

State	Location	Explanation	Citation
MN	Marcell Experimental Forest	Clearcut aspen and follow streamflow and nutrients	Verry 1972
MT	Coram Experimental Forest	Wide range of environmental consequences monitored after timber harvest	USDA For. Serv. 1980
MT	Flathead and Lolo National Forests	Clearcutting and fire (prescribed and wild) in western larch forests	DeByle 1981
NH	Hubbard Brook Experimental Forest	Clearcut northern hard-woods, vegetation killed by herbicides for 3 years after harvest--atypical treatment	Pierce *et al*. 1972
NH	White Mountain National Forest	Clearcut northern hard-woods, vegetation allowed to regrow after a typical harvest	Pierce *et al*. 1972
NC	Coweeta Hydrologic Laboratory	Effect of clearcutting Appalachian hardwoods on nutrient losses	Johnson and Swank 1971
OR	Alseas River watersheds	Nutrient outflow after road building and clearcut logging virgin Douglas-fir	Marston 1967
OR	H.J. Andrews Experimental Forest	Nutrient and sediment loss following clearcut and burning virgin Douglas-fir	Fredriksen 1971, 1972
WA	Cedar River Watershed	Nutrient loss from a clearcut 30-year-old Douglas-fir plantation	Gessel and Cole 1971
WV	Fernow Experimental Forest	Effects of clearcutting Appalachian hardwoods on water quantity and quality	Aubertin & Patric 1972

Most of these studies showed the resilience of stands to quickly recover from the effects of clearcutting and site preparation treatments. But, some treatments were unacceptable and provided documentation of these extremes.

Results of these studies neither conclusively show that clearcutting is bad nor good from the standpoint of the nutrient status of the site. Nutrients were continually being released from undisturbed ecosystems, the amount being a function of climate and of soil properties. Disturbance almost always caused an increase in nutrient outflow. The magnitude of loss was related to the severity of harvest and site treatment and to the length of time for reestablishing vegetation. These losses were relatively small in relation to the nutrient reserves. After one or two years the rate of loss declines and within three to five years nutrient loss returned to normal. However, any loss where nutrients are scarce is serious. This is particularly true on steep slopes where, once the slope equilibrium is upset, soil loss may continue until new equilibrium conditions are established. The continued erosion of soil organic matter and fine mineral fractions reduce site productivity.

These and other studies provide landmarks from which we can predict the consequences of the clearcut regeneration harvest method on factors affecting the site. The varied results show that clearcutting should not be applied as a standard procedure of harvest. Clearcutting should be used where it is the best silvicultural practice for regenerating a stand and maintaining the other values of the land. The soil stability and water quality of a watershed should be safeguarded. Once degraded, the rate of recovery is slow and a change in successional vegetation may occur. Usually the highly productive sites recover rapidly because they have a sufficient nutrient capital and water sources. These studies suggest the following for clearcuts:

1. Restrict their size and scatter them within the watershed.
2. During harvest and site preparation treatments, leave as much residue and other organic matter on the site as possible to maintain or enhance site productivity.
3. Obtain prompt and vigorous regrowth of vegetation.
4. Leave vegetated strips along water courses.
5. Use an alternative method on unstable soils, where exposure of the site establishes a harsh microenvironment, and when there may be a reduction in water or nutrient holding capacity.

Long-term studies are needed in most forest types of the United States to provide a scientific basis (justification) for the use of clearcutting. New perspectives forestry, to be effective, requires a thorough understanding of how each forest type responds not only to clearcutting but to all regeneration harvest cuttings and site-modifying treatments.

BIBLIOGRAPHY

Alexander, Robert R. 1987a. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and southern Rocky Mountains. Agric. Handb. No. 659. Washington DC: U.S. Department of Agriculture Forest Service; 144 p.

Alexander, Robert R. 1987b. Silvicultural systems, cutting methods, and cultural practices for Black Hills ponderosa pine. Gen. Tech. Rep. RM-139. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 32 p.

Aubertin, G.M. and J.H. Patric. 1972. Quality water from clearcut forest land? The Northern Logger and Timber Processer 20 (8): 14-15, 22-23.

Baker, James B. and W.E. Balmer. 1983. E. Loblolly pine. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington DC: U.S. Department of Agriculture, Forest Service; 148-152.

Barrett, James W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: the state of our knowledge, Gen. Tech. Rep. PNW-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 106 p.

Bassett, Richard L. 1987. Silvicultural systems for pinyon-juniper. In: Proceedings–pinyon-juniper conference; 1986 January 13-16; Reno, NV. General Technical Report INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 273-278.

Beck, Donald E. and L. Della-Bianca. 1981. Yellow poplar: characteristics and management. Agric. Handb. 583. Washington, DC: U.S. Department of Agriculture, Forest Service; 246 p.

Benzie, John W. 1977a. Manager's handbook for jack pine in the North Central States. Gen. Tech. Rep. NC-32. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 18 p.

Benzie, John W. 1977b. Manager's handbook for red pine in the North Central States. Gen. Tech. Rep. NC-33. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 22 p.

Boe, Kenneth N. 1975. Natural seedlings and sprouts after regeneration cuttings in old-growth redwood. Res. Pap. PSW-111. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 17p.

Britt, Robert W. 1973. Management of natural stands of Choctawhatchee sand pine. In: Proceedings, Sand Pine Symposium; 1972 December 5-7; Panama City Beach, FL. Gen. Tech. Rep. SE-2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 135-143.

Burns, Russell M., tech. comp. 1983. Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington DC: U.S. Department of Agriculture, Forest Service; 191 p.

Croker, T. C., Jr. and W.D. Boyer. 1975. Regenerating longleaf pine naturally. Res. Pap. SO-105. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 21 p.

DeBell, D. S., R.F. Strand and D.L. Reudema. 1978. Short-rotation production of red alder: Some options for future forest management. In: Briggs, D. G.; DeBell, D. S.; Atkinson, W. A. comps. Utilization and management of alder. Gen. Tech. Rep. PNW-70. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 231-245.

DeByle, Norbert V. 1981. Clearcutting and fire in the larch/Douglas-fir forests of western Montana—a multifaceted research summary. U.S. Department of Agriculture, Forest Service Gen. Tech. Rep. INT-99, Intermountain Forest and Range Experiment Station; 73 p.

DeByle, Norbert V. and R.P. Winokur Eds. 1985. Aspen: ecology and management in the western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 283 p.

Ferguson, E. R., E.R. Lawson and W.R. Maple. 1968. Mesavage, C. Managing eastern redcedar. Res. Pap. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 14 p.

Fowells, H. A., comp. 1965. Silvics of forest trees of the United States. Agric. Handb. 271. Washington DC: U.S. Department of Agriculture; 762 p.

Fowells, H. A. and N.B. Stark. 1965. Natural regeneration in relation to environment in the mixed conifer forest type of California. Res. Pap. PSW-24. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 14 p.

Frank, Robert M. and J.C. Bjorkbom. 1973. A silvicultural guide for spruce-fir in the Northeast. Gen. Tech. Rep. NE-6. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 29 p.

Franklin, Jerry F. 1963. Natural regeneration of Douglas-fir and associated species using modified clearcutting systems in the Oregon Cascades. Res. Pap. PNW-3. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 14 p.

Fredriksen, R.L. 1971. Comparative chemical water quality—natural and disturbed streams following logging and slash burning. In: Proceedings of a Symposium: Forest land uses and stream environment. Oregon State Univ.; 125-137.

Fredriksen, R.L. 1972. Nutrient budget of a Douglas-fir forest on an experimental watershed in western Oregon. In: Proceedings of a Symposium: Research on coniferous forest ecosystems. Bellingham, WA; 115-131.

Garrett, Peter W. and H. Fleming. 1983. Pitch pine. In: Silvicultural systems for the major forest types of the United States; Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture, Forest Service; 135-136.

Gessel, S.P. and D.W. Cole. 1971. Clearcutting of forests in relationship to forest soil problems in the Pacific Northwest. Prepared for Hearings of Subcommittee on Public Lands, Committee on Interior and Insular Affairs, United States Senate on the Management of Public Lands; 56-59.

Gordon, Donald T. 1973. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings. Res. Pap. PSW-90. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 22 p.

Graney, David L. and R.N. Kitchens. 1983. Oak-pine. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture, Forest Service; 172-174.

Haig, Irvine T., K.P. Davis and R.H. Weidman. 1941. Natural Regeneration in the western white pine type. Tech. Bull. 767. Washington, DC: U.S. Department of Agriculture; 99 p.

Harvey, Alan E., M.F. Jurgensen, M.J. Larsen and R.T. Graham. 1987. Decaying organic materials and soil quality in the inland Northwest: a management opportunity. Gen. Tech. Rep. INT-225. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 15 p.

Johnson, Philip L. and W.T. Swank. 1971. Nutrient budget studies in the southern Appalachians on four experimental watersheds with contrasting vegetation. Paper presented at IUFRO Congress; Gainesville, FL; 14-20.

Johnston, William F. 1975. Reproducing lowland conifer forests. J. For. 73(1): 17-20.

Johnston, William F. 1977a. Manager's handbook for black spruce in the north central States. Gen. Tech. Rep. NC-34. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 18 p.

Johnston, William F. 1977b. Manager's handbook for northern white cedar in the north central states. Gen. Tech. Rep. NC-35. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 18 p.

Jones, John R. 1974. Silviculture of southwestern mixed conifers and aspen: the status of our knowledge. Res. Pap. RM-122. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 44 p.

Jurgensen, J.F., A.E. Harvey, R.T. Graham, M.R. Gale, D. Page-Dumroese and G.D. Mroz. 1990. Harvesting and site preparation impacts on soil organic reserves. In: Forestry on the frontier, proceedings of the 1989 Society of American Foresters National Convention; 1989 September 24-27; Spokane, WA. Bethesda, MD: Society of American Foresters; 212-216.

Lancaster, Kenneth, F. and W.B. Leak. 1978. A silvicultural guide for white pine in the northeast. Gen. Tech. Rep. NE-41. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 13 p.

Langdon, O. Gordon and F.A. Bennett. 1976. Management of natural stands of slash pine. Res. Pap. SE-147. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 12 p.

Leak, William B. and R.W. Wilson, Jr. 1958. Regeneration after cutting of old-growth northern hardwoods in New Hampshire. Sta. Pap. 103. Broomall, PA; U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 8 p.

McDonald, Philip M. 1976. Forest regeneration and seedling growth from five major methods in north-central California. Res. Pap. PSW-115. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 10 p.

McDonald, Philip M. 1978. Silviculture-ecology of three native California hardwoods on high sites in north central California. Corvallis: Oregon State Univ.; 309 p. Dissertation.

McKnight, J. S. and R.L. Johnson. 1980. Hardwood management in southern bottomlands. For. Farmer 39 (5): 31-39.

Mann, William F., Jr. 1973. Loblolly-shortleaf pine. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture, Forest Service; 95-98.

Marquis, David A., T.J. Grisez, J.C. Bjorkbom, and B.A. Roach. 1975. Interim guide to regeneration of Allegheny hardwoods. Gen. Tech. Rep. NE-19. Broomall, PA; U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 14 p.

Marquis, David A., D.S. Solomon and J.C. Bjorkbom. 1969. A silvicultural guide for paper birch in the northeast. Res. Pap. NE-130. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 47 p.

Marston, Richard B. 1967. Pollutional concentrations and loads of some natural constituents and their relation to streamflow, before and after roadbuilding and tree harvesting in some small Alsea River watersheds in western Oregon. USDI, FWPCA, Pacific N.W. Water Lab. Prog. Rep.

Metzger, Frederick T. 1980. Strip clearcutting to regenerate northern hardwoods. Res. Pap. NC-186. St Paul, MN: U.S. Department of Agriculture, Forest Service, Northcentral Forest Experiment Station; 14 p.

Metzger, Frederick T. and C.H. Tubbs. 1971. The influence of cutting method on regeneration of second-growth northern hardwoods. J. For. 69(9): 559-564.

Minore, Don and M.E. Dubrasich. 1981. Regeneration after clearcutting in subalpine stands near Windigo Pass, Oregon. J. For. 79 (9): 619-621.

Minore, Don and D. Kingsley. 1983. Mixed conifers of southwestern Oregon. In: Silvicultural systems for the major forest types of the United States; Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture, Forest Service; 23-25.

Morris, Lawrence A. and R.F. Lowery. 1988. Influence of site preparation on soil conditions affecting stand establishment and tree growth. SJAF 12(3): 170-178.

Moyers, George B. 1979. Management of eastern white pine in the south. In: Proceedings, Symposium for the Management of Pines in the Interior South. Tech. Pub. SA-TP2. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry; 18-47.

Perala, Donald A. 1977. Manager's handbook for aspen in the North-Central States. Gen. Tech. Rep. NC-36. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 30 p.

Pierce, Robert S., C.W. Martin, C.C. Reeves, G.E. Likens and F.H. Bormann. 1972. Nutrient loss from clearcutting in New Hampshire. In: National Symposium on watersheds in transition. Proc. Series No. 14. American Water Resource Assoc.

Price, Murphy B. 1973. Management of natural stands of Ocala sand pine. In: Proceedings, Sand Pine Symposium; 1972 December 5-7; Panama City Beach, FL. Gen. Tech. Rep. SE-2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 144-152.

Roach, Benjamin A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. Re. Pap. NE-373. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 30 p.

Ruth, Robert H. and A.S. Harris. 1979. Management of western hemlock-Sitka spruce forests for timber production. Gen. Tech. Rep. PNW-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 197 p.

Sander, I. L. 1979. Silvicultural systems for the oak-hickory forest type. In: North America's forests: Gateway to opportunity: 1978 Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry. 1978 October 23-26; St. Louis, MO. Washington DC: Society of American Foresters; 344-348.

Schmidt, Wyman C. and R.R. Alexander. 1985. Strategies for managing lodgepole pine. In: Baumgartner, David M.; Krebill, Richard G.; Arnott, James T.; Weetman, Gordon F., comps.and eds. Proceedings, Lodgepole Pine the Species and Its Management Symposium; 1984 May 8-10; Spokane, WA. Pullman, WA; Cooperative Extension, Washington State University; 201-210.

Schmidt, Wyman C., R.C. Shearer and A.L. Roe. 1976. Ecology and silviculture of Western larch forests. Tech. Bull. 1520. Washington, DC: U.S. Department of Agriculture; 96 p.

Schubert, Gilbert H. 1974 Silviculture of southwestern ponderosa pine: the status of our knowledge. Res. Pap. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 71 p.

Seidel, K. W. and P.H. Cochran. 1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. Gen. Tech. Rep. PNW-121. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 70 p.

Smith, H. Clay. 1981. Managing central Appalachian hardwood stands. In: Proceedings, National Silviculture Workshop: 1981 June 1-5; Roanoke, VA. Washington DC: U.S. Department of Agriculture, Forest Service; 185-195.

Sowers, David W., Jr. 1956. Some factors affecting management of conifers in the Allegheny region. J. For. 54 (9): 563-567.

U.S. Department of Agriculture. Forest Service. 1965. Silvics of forest trees of the United States. Agric. Handb. 271. Washington DC: U.S. Department of Agriculture; 762 p.

U.S. Department of Agriculture. Forest Service. 1980. Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. U.S. Department of Agriculture, Forest Service Gen. Tech. Rep. INT-90. Intermountain Forest and Range Experiment Station, Ogden, UT; 526 p.

Verry, Elon S. 1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. In: National Symposium on watersheds in transition. Proc. Series No. 14. American Water Resource Association.

Zasada, John C. and D. Argyle. 1983. Interior Alaska white spruce—Hardwoods. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington D.C.: U.S. Department of Agriculture, Forest Service; 33-36.

Author

Raymond C. Shearer
Research Silviculturist
Intermountain Forest Experiment Station
P.O. Box 8089
Missoula, Montana 59807-8089

Table 1.–Recommendations for use of clearcutting by **western** forest cover types (Burns 1983).

Forest Cover Type	Rank[1]	Comments	Citation
Western Hemlock-Sitka Spruce	1		Ruth and Harris 1979
Pacific Douglas-fir	1		Franklin 1963
True fir-Hemlock	1	<20 acres	Minore 1981
Northwestern Ponderosa Pine and Associated Species	2		Barrett 1979
Grand fir, Douglas-fir, and Associated Species (Eastern OR and WA)	1		Seidel and Cochran 1981
Mixed Conifers of Southwestern Oregon	2	Do not use on some droughty and exposed sites	Minore and Kingsley 1983
Red Alder	1		DeBell *et al.* 1978
Southwest Oregon-Northern California Hardwoods	1	Tanoak regeneration uncertain	McDonald 1978
Interior Alaska White Spruce-Hardwoods	1		Zasada and Argyle 1983
Redwood	2		Boe 1975
Red Fir and White Fir	2	Openings <1.5 times tree height	Gordon 1973
Sierra Nevada Mixed Conifers	2		Fowells and Stark 1965
Pacific Ponderosa Pine	1		McDonald 1976
Ponderosa Pine and Rocky Mountain Douglas-fir	2		Fowells 1965
Western Larch	2		Schmidt *et al.* 1976
Engelmann Spruce--Subalpine fir	2		Alexander 1987a
Lodgepole pine	1		Schmidt and Alexander 1985
Mixed Conifers, Western White Pine and Western Redcedar	1		Haig *et al.* 1941
Southwestern Ponderosa Pine	2	Patch cutting for pest control	Schubert 1974
Southwestern Mixed Conifers	2	Clearcuts improve water yields	Jones 1974
Rocky Mountain Aspen	1		DeByle and Winokur 1985
Interior Ponderosa Pine in the Black Hills	2	260-ft wide opening in timber; 150-ft when timber only on one side	Alexander 1987b
Pinyon-Juniper	2	Needs more testing; alligator juniper sprouts easily	Bassett 1987

[1]Rank: 1=Recommended (best system); 2=Can be used successfully; 3=Limited success, not recommended.

Table 2.-Recommendations for use of clearcutting by **eastern** forest cover types (Burns 1983).

Forest Cover Type	Rank[1]	Comments	Citation
Red Pine	1		Benzie 1977b
Jack Pine	1		Benzie 1977a
Black Spruce	2	Strips and patches	Johnston 1977a
Tamarack	1		Johnston 1975
Balsam Fir	2		Frank and Bjorkbom 1973
Northern White-Cedar	1	Strips and patches	Johnston 1977b
Eastern Redcedar	2		Ferguson *et al.* 1968
Aspen	1		Perala 1977
Oak-Hickory	2		Sander 1979
Northern Hardwoods	3	Requires advance reproduction; promotes light-demanding species	Leak and Wilson 1958, Metzger 1980, Metzger and Tubbs 1971
Eastern Spruce-Fir	1	For older and pest-damaged stands	Frank and Bjorkbom 1973
Eastern White Pine incl. Eastern Hemlock	2	Clearcut during or just after a heavy pine seed crop	Lancaster and Leak 1978, Moyers 1979
Pitch Pine	2		Garrett and Fleming 1983
Cherry-Maple	2		Marquis *et al.* 1975, Roach 1977
Appalachian Mixed Hardwoods	2		Smith 1981
Paper Birch	2	Clearcut strips or patches best	Marquis *et al.* 1969
Loblolly Pine	2	Width <400 ft perpendicular prevailing wind	Baker and Balmer 1983
Longleaf Pine	3	Openings <100 feet of seed source	Crocker and Boyer 1975
Shortleaf Pine	2	Openings <200 feet of seed source	Mann 1973
Slash Pine	2		Langdon and Bennett 1976
Virginia Pine	1	About 100 ft openings	Sowers 1956
Sand Pine (Ocala variety)	1		Price 1973
(Choctawhatchee variety)	3		Britt 1973
Oak-Pine	1	Favors pine species	Graney and Kitchens 1983
Bottomland Hardwoods	1	Favors advance regeneration and sprouting	McKnight and Johnson 1980
Yellow-Poplar	2	Openings >0.5-acre for best growth	Beck and Della-Bianca 1981

[1]Rank: 1=Recommended (best system); 2=Can be used successfully; 3=Limited success, not recommended.

SEED-TREE REGENERATION METHOD

Richard L. Bassett
Southwestern Region
Albuquerque, NM

The second regeneration method that will be discussed under the even-aged silvicultural system is the seed-tree cutting method.

Briefly, the seed-tree regeneration method removes most of the trees from a stand in one entry, leaving only a few (5 to 10) good quality seed trees evenly scattered over the site to produce seed for a new stand. Variations are to leave the seed trees in groups or strips, depending upon the site conditions, tree species, and stand objectives.

The heavier logging from the seed-tree seed cut may result in similar ground disturbance as the clearcut, which may or may not help in preparing the site for natural regeneration. Additional site preparation is usually needed, timed with the presence of an adequate crop of seed from the existing seed trees.

Several years later, when a young stand of seedlings has been established, the seed trees may be removed as sawtimber or left for wildlife snags, or eventually down wood.

This method is most commonly restricted to deeper soils and firmly rooted tree species that will not blow over when the stand is suddenly opened up and exposed to strong winds. Species intolerant to shade do best with this method since the seedlings establish and grow in nearly full sunlight. This regeneration method has been used successfully on soils with a coarse texture. Frost heave can become a problem on the finer clay textured soils. The sparse seed tree overstory provides little protection or shelter for the new seedlings; more shelter than a clearcut, but less than a shelterwood seed cut.

The panel will continue to discuss the seed-tree regeneration method in the following order:

Silviculture, **Susan Gray**, Silviculturist, Rocky Mountain Region
Genetics, **Ray Steinhoff**, Geneticist, Ochoco National Forest
Research, **Phil Aune**, Pacific Southwest Forest Experiment Station
Questions after each speaker
Discussion after panel presentations

Author

Richard L. Bassett
Regional Silviculturist
Southwestern Region
517 Gold Avenue
Albuquerque, New Mexico 87102

SEED-TREE REGENERATION METHOD SILVICULTURAL CONSIDERATIONS

Susan E. Gray
Rocky Mountain Region
Lakewood, CO

INTRODUCTION

The seed-tree method has the notoriety of being the first reproduction method prescribed by law. The law was the Morris Act of 1902 and it's failure was mostly due to delayed seed crops which gave brush control of the site. This was a perfect example of what can be expected when legislation of silvicultural methods are out of sync with environmental conditions.

The seed-tree method is most appropriate to species which are intolerant, good seed producers, resistant to windthrow and breakage, and have comparatively light seed which can be easily carried by the wind.

Late successional species are not well adapted to the seed tree method. Blowdown, breakage, and sunscald of the seed trees is common. Also, exposed site conditions often cause heat or frost damage to the newly germinated seedlings of shade-tolerant trees such as grand fir, white fir, and subalpine fir.

Since most hardwood species sprout from roots or regenerate from dormant seeds in duff and litter, a seed-tree harvest would have the same effect that a clearcut would. An exception to this would be the birches which are fairly light seeded and whose seeds disseminate well in the wind.

The number of seed trees you would want to leave in an area would depend on:

1. the number of seeds per tree that you would expect a tree of the species in question to produce;
2. the distance that the seed could reasonably be carried by the wind;
3. how long you could expect the seed trees to survive given the threat from windthrow or other losses;
4. frequency of seed crops;
5. seeds per seedling ratio;
6. the desired number of seedlings per acre;
7. how much you would lose by leaving the seed trees out in the woods if it should prove infeasible to harvest them in the future; and
8. the length of time the seedbed is receptive and growing conditions favorable.

SELECTION OF SEED TREES

The seed trees should exhibit the following characteristics:

1. Dominant or Codominant;
2. Evidence of the ability to bear seed, like evidence of past cone crops;
3. No visible evidence of insects or disease; and

4. Indication of windfirmness, such as trees positioned near openings or where deep soils are evident.

SPECIES SELECTION

EASTERN HARDWOODS occur throughout the northern portions of the East and include the Lake States, New England, the Appalachian Mountains, and the Alleghany and Cumberland Plateaus (Marquis and Johnson 1989).

SPECIES	CONSIDER SEED-TREE?
Fagus spp. (beeches)	no
Acer spp. (maples)	no
Populus spp. (cottonwoods)	no
Prunus spp. (fruit trees)	no
Juglans spp. (hickories, etc...)	no
Fraxinus spp. (ashes)	no
Quercus spp. (oaks)	no
Betula spp. (birches) Fairly light-seeded, so it can work on sites with adequate site prep.	yes

NORTHEASTERN CONIFER forests are concentrated in New England and the Lake States (Benzie and Blum 1989).

SPECIES	CONSIDER SEED-TREE?
Pinus banksiana (jack pine) Site prep with fire is recommended to open the serotinous cones, this probably kills the seed trees, but will help to eliminate slash and control shrubs. Dead seed trees can be left on site for wildlife use.	yes
Pinus resinosa (red pine) Many attempts have been made with seed-tree, but most have been unsuccessful. No longer recommended.	no
Pinus strobus (Eastern white pine) It has been successful in some attempts, but shelterwood is still the recommended method.	yes
Tsuga canadensis type (Eastern hemlock type)	no
Picea rubens/Abies balsamea (red pine/balsam fir)	no
Larix laricina (Tamarack) Regenerates very well since the seedlings survive best with abundant sunlight. 10/tpa is recommended.	yes
Picea mariana (black spruce)	no
Thuga occidentalis (northern white-cedar)	no

SOUTHERN PINES occur in the Coastal Plain and Piedmont from Delaware and central Maryland south to central Florida and west to eastern Texas (Burns and Barber 1989).

SPECIES	CONSIDER SEED-TREE?
Pinus taeda, *P. echinata*, *P. palustris* (loblolly, shortleaf, longleaf)	yes
Abundant stocking occurs if adequate seedfall results within a year after site prep. Competition from hardwood understory species must be controlled and the openings must be large enough to allow the seedlings/saplings room to develop.	
Quercus spp./Pinus spp. (Oak/pine type) (*Q. coccinea*, *rubra*, *falcata*, *prinus/P. taeda*, *echinata*)	no
Usually high percentage of hardwoods in understory making regen. of pine difficult without planting.	
P. palustris/P. elliottii (longleaf/slash pine)	yes

WESTERN INLAND CONIFERS includes two general areas, the first being the lower slope and foothill forests which includes northwest, southwest, and interior (Black Hills) ponderosa pine, Rocky Mountain Douglas-fir, and pinyon-juniper. The second area is the montane forests which in the West includes areas between the mountain foothills and the subalpine zones, usually referred to as the mixed conifer (Schmidt and Larson 1989).

The lower slope and foothill forests major tree species are:

SPECIES	CONSIDER SEED-TREE?
Juniperus californica (Californica juniper)	no
J. deppeana (Alligator juniper)	no
J. monosperma (one seed juniper)	no
J. occidentalis (western juniper)	no
J. osteosperma (Utah juniper)	no
J. scopulorum (Rocky Mountain juniper)	no
Pinus cembroides (Mexican pinyon)	no
P. contorta (lodgepole pine)	yes
P. edulis (Rocky Mountain pinyon)	no
P. flexilis (Limber pine)	yes
P. monophylla (single leaf pinyon)	no
P. ponderosa (ponderosa pine)	yes
Pseudotsuga menziesii var. *glauca* (Douglas-fir)	yes

There has been limited success with seed-tree harvesting in this zone due to the generally harsh site conditions. The exception to this would be the Black Hills which has sites which are more conducive to natural regeneration of ponderosa pine.

Major species that grow in the MONTANE ZONE follow and can be categorized into early and late successional associations.

SPECIES	CONSIDER SEED-TREE?
EARLY SUCCESSIONAL	
Betula papyrifera (paper birch) *Larix occidentalis* (western larch) *Pinus contorta* (lodgepole pine) *Pinus lambertiana* (sugar pine) *Pinus monticola* (w. white pine) *Pinus ponderosa* (ponderosa pine) *Pinus strobiformis* (sw white pine) *Populus balsamifera* (balsam poplar) *Populus tremuloides* (aspen) *Pseudotsuga menziesii* (Douglas-fir)	when considered overall, yes
LATE SUCCESSIONAL	
Abies concolor (white fir) *Abies grandis* (grand fir) *Abies lasiocarpa* (subalpine fir) *Libocedrus decurrens* (incense cedar) *Picea engelmannii* (Engelmann spruce) *Picea glauca* (white spruce) *Picea pungens* (blue spruce) *Pseudotsuga menziesii* (Douglas-fir) *Thuja plicata* (western redcedar) *Tsuga heterophylla* (western hemlock)	when considered overall, no

SUBALPINE FORESTS abut the subalpine zone and occupy the coldest and generally wettest zone of the inland mountain West. Characterized by short growing seasons and deep snow, these areas are usually dominated by the Englemann spruce and subalpine fir (Schmidt and Larson 1989).

This zone includes all or portions of the following species:

SPECIES	CONSIDER SEED-TREE?
Abies lasiocarpa (subalpine fir) *Abies lasiocarpa* var *arizonica* (corkbark fir) *Larix lyallii* (subalpine larch) *Pinus albicaulis* (whitebark pine) *P. aristata* (bristlecone pine) *P. contorta* (lodgepole pine) *P. engelmannii* (Engelmann spruce) *Populus tremuloides* (aspen) *Tsuga mertensiana* (mountain hemlock)	no

Because of the shallow-rooted nature of trees in this zone, the risk of blowdown of seed trees all but precludes use of the seed-tree method.

PACIFIC COAST FORESTS

The seed-tree method has been successful in some Pacific coast forests, such as the true fir and mixed conifer forests, but it has seldom been used for regenerating even-aged stands in Pacific coast forests. Seed-tree can be used where the objective is to naturally regenerate extensive areas of timber in units too large to be seeded naturally from adjacent stands. Such applications, however, may be limited on some sites by the common occurrence of severe windstorms and presence of dwarf mistletoe (Fiske and DeBell 1989).

HARDWOOD FORESTS occur at low to middle elevations from Alaska to southern California.

SPECIES	CONSIDER SEED-TREE?
Populus trichocarpa (black cottonwood) *Lithocarpus densiflorus* (tanoak) *Arbutus menziesii* (Pacific madronne) *Umbellularia californica* (California laural) *Quercus agrifolia* (coastal live oak) *Q. chrysolepis* (canyon live oak) *Q. lobata* (valley oak) *Q. douglasii* (blue oak)	no

WESTERN HEMLOCK AND SPRUCE FORESTS are northern coastal forests occuring in areas with a maritime climate from south-central Alaska to southern Oregon.

SPECIES	CONSIDER SEED-TREE?
Tsuga heterophylla (western hemlock) *Picea sitchensis* (Sitka spruce) *Pseudotsuga menziesii* (Douglas-fir) *Thuja plicata* (western red cedar) *Chamaecyparis nootkatensis* (Alaska-cedar) *Alnus rubra* (red alder) *Acer circinatum* (vine maple) *A. macrophyllum* (bigleaf maple)	overall not recommended

DOUGLAS-FIR FORESTS are inland at low elevations west of the Cascade Range in Washington and Oregon, and on the west side of the Coast Range in northwestern California.

SPECIES	CONSIDER SEED-TREE?
Pseudotsuga menziesii (Douglas-fir) *Tsuga heterophylla* (western hemlock) *Thuja plicata* (western red cedar) *Alnus rubra* (red alder) *Populus trichocarpa* (black cottonwood) *Acer circinatum* (vine maple) *A. macrophyllum* (bigleaf maple) *Lithocarpus densiflorus* (tanoak) *Arbutus menziesii* (Pacific madronne)	overall not recommended

TRUE FIR-HEMLOCK FORESTS occur on the middle and upper shores of the cascade Range in Washington, Oregon, and California; in the Olympic Mountains of Washington; and on the upper slopes of the Sierra Nevada and northern California. The climate is cool and wet with long-lived snowpacks.

SPECIES	CONSIDER SEED-TREE?
Tsuga mertensiana (mountain hemlock) *Abies amabilis* (Pacific silver fir) *A. procera* (noble fir) *A. magnifica* (California red fir) *A. grandis* (grand fir) *A. concolor* (white fir) *Thuja plicata* (western red cedar) *Chamaecyparis nootkatensis* (Alaska-cedar) *Pinus monticola* (western white pine)	overall not recommended except for the pine

REDWOOD FORESTS typically occur on moist river flats and cool slopes near the coast up to about 3,000" elevation in northwest an central California, and the extreme southwestern corner of Oregon.

SPECIES	CONSIDER SEED-TREE?
Sequoia sempervirens (redwood) *Pseudotsuga menziesii* (Douglas-fir) *Chamaecyparis lawsoniana* (Port-Orford-cedar) *Lithocarpus densiflorus* (tanoak) *Arbutus menziesii* (Pacific madronne) *Umbellularia californica* (California laural)	overall not recommended

MIXED CONIFER FORESTS occur on drier sites inland from the Douglas-fir forests and at lower elevations than the true fir-hemlock forests in southwestern Oregon and northern California.

SPECIES	CONSIDER SEED-TREE?
Pseudotsuga menziesii (Douglas-fir) *Pinus ponderosa* (ponderosa pine) *P. lambertiana* (sugar-pine) *Abies concolor* (white fir) *Libocedrus decurrens* (incense-cedar) *Quercus garryana* (white oak) *Q. kelloggii* (Calif. black oak) *Q. chrysolepis* (canyon live oak)	overall can be considered

FOREST HEALTH

In general the seed-tree method is quite conducive to improving and maintaining forest health. It can be used to regenerate stands when creating an even-aged stand condition is fundamental to the control of certain insects and diseases. Stands which are infected with dwarf-mistletoes or stands which are infested with defoliating insects such as spruce budworms are prime candidates. It can also be used to regenerate old growth stands which are candidates for bark beetle outbreaks due to size, low vigor, and heavy stocking, by starting the stand over and managing the new stand to enhance vigor.

In mixed species stands, the selected seed trees can be those which are nonhost species; for example in stands where both ponderosa pine and Douglas-fir are present and the Douglas-fir is infected with a dwarf-mistletoe, leaving ponderosa pine seed trees would be an effective means of controlling the spread of Douglas-fir dwarf-mistletoe within a particular landscape. As a rule of thumb, blocks of nonhost species of trees interspersed among blocks of host species will insure that less acreage of host type would be affected if an infestation should occur.

AESTHETICS

Aesthetics is more important now than it has ever been. Although some consider a seed-tree harvest to have less of a visual impact than clearcutting, even a seed-tree cut is now coming under considerable scrutiny. Although some of our publics do consider this type of harvest as offensive as a clearcut, it is still a viable alternative in areas where special considerations must be given to areas with sensitive viewsheds.

In the foreground, some landscape architects recommend complete slash removal and covering stumps with dirt especially along trails. In the landscape, a manager may chose to leave a higher number of trees/acre than she would actually need to assure adequate regeneration in order to soften the edge between cut and non-cut areas as well as leaving whatever advanced regeneration is on site to soften the foreground visual impact. Since the advanced regeneration has probably been surpressed, it should be thinned out during the first precommercial thinning in the newly established stand.

LANDSCAPE POSITION

Since most of the seed trees left in a stand were grown with the protection of surrounding trees, the threat of windthrow is a serious problem. The position of a stand in the landscape is also an indicator of whether or not a seed-tree harvest will be an appropriate regeneration method.

In addition to soil depth, drainage, and the condition of your leave trees, topography has a major influence on wind risk to your leave trees (Alexander 1964).

Wind risk is always high on ridge tops. Slopes facing the direction from which the prevalent winds in a region come are a high wind risk. For example, if the prevalent winds are from the southwest, stands that are on south or west facing upper or mid-slopes that are moderate to steep are high risk; the back sides of those moderate to steep slopes are at moderate risk.

Wind risk would be moderate on moderate to steep slopes facing the prevailing winds if those faces are protected by higher ground, such as smaller ridges. In these cases, it would still be moderate on the steep mid and upper slopes facing away from the prevailing wind.

Wind risk can also be high in valley bottoms which parallel the prevailing winds and in saddles where the wind is funneled through.

There are 3 situations where the wind risk is low, or below average: 1. flat areas or valley bottoms which lie perpendicular to the wind; 2. lower slopes and gentle slopes that don't face the prevailing wind; and 3. lower slopes and gentle middle slopes facing the prevailing wind which are protected by higher ground. Stands on these sites are good candidates for seed-tree harvests.

HARVEST METHODS

Layout

Next to clearcutting, the seed tree method is the most inexpensive and easiest regeneration method to implement and it doesn't require a high degree of technical expertise to layout the sale units either. In almost all cases, a seed-tree harvest is a Leave Tree Mark (LTM). The harvest unit boundary is delineated and then the marking crew will select and mark the leave trees based on marking guides developed by a silviculturist or someone with comparable skills. The marking guide would describe the desired future condition of the unit being laid out and the attributes and density of the residual seed trees.

The marking guides will describe the species and desirable qualities that a seed tree should exhibit as well as the distribution of those selected. The distribution can be set based on a specific residual basal area, or on a spacing guide.

Costs incurred would include NEPA costs, stand inventory costs, and sale unit layout. The layout costs would usually consist of marking a sale unit boundary and then marking of the reserve seed trees.

To give you an idea of the cost of putting together a seed-tree harvest, I have these values from past sales in Region 2.

MARKING

PAINT	$ .46/AC
SALARY(4/GS-4'S)	$4.01/AC
TRANSPORTATION	$ .17/AC
MISC.	$ .03/AC
TOTAL	$4.67/AC

NEPA

EA, DIAGNOSIS and PRESCRIPTION, MARKING and CRUISING PLANS (AVE.)	$1.85/MBF (RANGE $1.14-2.60/MBF)

PREPARING PACKAGE, AWARDING, AND SELLING	$0.80/MBF

HARVEST METHODS[1]

Tractor

Conventional tractor logging is the most widely used method to harvest seed-tree prescriptions. It requires a comparatively low initial investment in equipment and can give good results with good sale administration.

Conventional tractor logging systems consist of the following parts:

| *Handfelling* | — | *Processing at felling site* | — | *Skidding log length pieces to landing* |

Tractors cannot conveniently skid on the contour on slopes over about 30 percent. From both a falling standpoint and a skidding standpoint, the ideal on uniformly steepslopes and a skidding standpoint is to fall timber up the hill and skid individual logs down the hill to a main skid road. On ground slopes under 30 percent, there will usually be more falling lead and skid road location options available. Tractors can do more contour skidding and fallers have much more flexibility in selecting leads. The direction of falling leads can be turned relatively easily. The number of skid roads entering landings are held to a minimum by converging as many skid roads as possible a suitable distance away from landings.

Skidding operations in residuals stands such as a with the seed-tree method, should use the following considerations:

1. Do not allow tractors to "wear out" a skid road. Before a tractor road becomes channeled to the point where it can't be properly cross-drained, retire it.

[1] from Forest engineering Institute Notes compiled & edited by Donald D. Studier, Corvallis, OR, 1985

2. Normally, you shouldn't allow tractors to operate on ground slopes averaging over 35%. If some trees must be removed from slopes over 35%, this can be accomplished by winching those trees to tractors stopped at the 35% slope limit and then tractor skidding those logs downhill to the skid road.

3. Tractors should be backed as close to logs as stocking conditions will tolerate. Hook onto logs and endline one or two logs at a time out of the residual stand. Operators should be required to bunch logs to make up a turn of logs where the residual stand will not be damaged.

4. Do not allow choke setters to set chokers in "the breaks"

5. Do not allow tractors to "roll out" logs to break limbs and accommodate choker setting without digging under logs.

6. Require bumper or shear logs to be used when necessary to keep log turns from damaging residual trees.

7. Cut all exposed limbs from logs which might damage residual trees.

8. Do not allow tree length skidding when tractor roads will not accommodate this without excessive damage.

9. Limit the number of tractors skidding to a landing to a number practical for the skid road layout. Too many tractors may get into one another's way and damage the residuals.

10. Do not allow arches or illegal dozer blades to operate in a residual stand off of constructed tractor roads.

11. Limit the number of chokers used to the number that meet stand protection needs. Consider this in view of protecting needed stocking as well as preventing scarring and culling of the residual seed trees. The width of the turn being skidded should not exceed the width of the skidding tractor.

12. Rubber-tired skidders and crawler tractors equipped with grapples should be restricted to approved skid roads unless equipped with a winch.

13. Rubber-tired skidders are faster and often cheaper to operate than crawler tractors. However, they cannot operate side hill on steep ground as well as crawler tractors.

Some Region 2 costs associated with a seed-tree harvest for conventional tractor logging are:

FELLING AND BUCKING	$ 27.00/MBF
SKIDDING, DECKING, AND LOADING	$ 33.00/MBF
HAULING (35 MI)	$ 50.00/MBF
ROAD MAINTENANCE	$ .75/MBF
SLASH (18")	$ 1.70/MBF
EROSION CONTROL	$ 1.03/MBF
MANUFACTURING	$130.11/MBF
BYPRODUCTS	$ 8.50/MBF
PROFIT & RISK	$ 30.34/MBF
TEMPORARY DEVELOPMENT	$ .12/MBF
LOGGING OVERHEAD	$ 17.01/MBF

NO SPEC. ROADS INCLUDED IN ABOVE COSTS

MECHANIZED—Ground Based

Whole tree and tree-length systems can both be used for seed-tree harvests provided that the residual seed trees are spaced at distances apart that are greater than the heights of the tallest trees being removed.

Whole tree systems consist of the following parts:

| *Fell & Bunch* |—| *Skid Whole Trees* |—| *Process at Landing* |

Normally, for harvesting small timber on mountainous terrain less than 40 percent slope, this method consists of a feller-buncher, two skidders, landing processor, and a log loader.

There are several resource implications that are pertinent to using a whole tree system in a seed-tree harvest. Chief among them are that most of the limbs and tops are brought to the landings resulting in large slash piles; no slash mat is left on main skid trails to reduce soil impacts; in areas where one is dealing with short rotation ages, soil nutrient cycling can be negatively affected; and most importantly, it is difficult to control damage to residual trees.

In order to minimize damage to residual trees, the following procedures should be followed in addition to those mentioned for the skidding:

1. The feller travel paths should be spaced at least 50' apart.

2. Old skid trails should be used whenever possible.

3. Agree with the operator on the locations before starting because the skid trails will coincide with feller travel paths.

4. Bunches should be placed in skid trails to protect the residuals.

5. Drive-to-tree feller bunchers aren't recommended for partial cuts, but can be used if the seed trees are widely spaced. If the spacing of the seed trees is a concern, swing boom feller bunchers can do a better job especially on sensitive soils because they have a longer reach and don't need to be repositioned as often as the drive-to-tree feller bunchers do.

6. Cross slope skidding in which the trailing end of logs or bunches slide downslope against residual trees should always be avoided.

Tree length systems consist of the following parts:

| *Fell, limb & Top at stump* |—| *Skid Tree-length* |

Precautions for this method would be similar to those for conventional logging and whole-tree logging. Since tree-length pieces are being skidded, it is much easier to damage the residual seed trees, so care must be taken during felling to position the fallen tree so that it will be skidded away from the residual trees rather than against them.

Cut-to Length or LOG-forwarder

This system consists of the following parts:

| *Fell, Merchandise at stump, & Prebunch* |—| *Forward to landing* |

In this system, a harvester fells, limbs, measures, bucks, and presorts logs as it moves through the woods. A forwarder comes in after the harvester and delivers the prebunched logs to the landing or to truck trailers.

This system is extremely effective where one is concerned about damage to residual trees and so I consider it the best ground based system for harvesting a seed-tree prescription. For any given volume per acre that is being removed, a LOG-forwarder can remove it with fewer turns and lighter loaded ground pressures. Also, because the LOG-forwarder carries the turn of short logs ahead of the rear load bearing axle and free from the ground, skid trails are not gouged out of the soil from dragging logs, nor are the residual trees damaged by the drag of the logs (Gorsh 1989).

Cable Based Systems

All cable logging systems can be used for implementing a seed-tree harvest. It is more difficult than for clearcutting because lines must be pulled out and restrung every time the cable roads are changed. The skyline is preferred over the hi-lead because extensive damage to the residual trees is not uncommon. When soil damage is a concern, skyline is recommended because at least one end of the log is elevated.

Hi-lead

Logs are pulled or dragged along the ground by a cable attached to a remote winch. The pulling line is elevated by passing it through a lead block on a boom or spar.

1. Jammer: cable is returned to logs by manpower operates on 30-55% slopes with a maximum yarding distance of 450'.

2. Standard hi-lead: cable returned by haul-back line operates on slopes 30-70% with a maximum yarding distance of 1000'.

Skyline

Part or all of the weight of the logs is supported by suspended cable. Logs are pulled along the cable by attaching them to a carriage or pulley which is transported along the suspended cable by a remote winch and cable system. It can be operated on slopes 30-90% with yarding distances of 500' to 4000'.

1. Standing skyline: length of the skyline is fixed because its is anchored at both ends. The load-carrying capacity is fixed also.

2. Live skyline: length of the skyline can be easily changed because one end is anchored and the other is attached to a winch drum. The length may or may not be changed during yarding, depending on the need to change the shape of the catenary curve to obtain more load capacity.

3. Running skyline: a special case of the live skyline in which the skyline is also the haul-back line and its length changes any time the carriage moves.

SITE PREPARATION

In order for seed-tree regeneration to be successful, there must be adequate ground disturbance, exposing bare mineral soil, which coincides with a decent cone crop. Site prep usually isn't effective if it is done more than a year before the seed is released. Often, the mechanized harvesting methods and even the conventional tractor harvesting doesn't create enough ground disturbance to produce an adequate seedbed. In these cases, we must do our own site preparation.

Generally, our site preparation falls into one of three categories:

1. Burning
2. Mechanical
3. Chemical

Burning can be used to do site preparation after a seed-tree harvest, but care must be taken to write a burning prescription which will not significantly affect the longevity of the seed trees. Usually, this means that the burning costs will be high because fuels will need to be moved away from the seed trees and the fire will need to be hot enough and slow enough to burn to the mineral soil over about 40-50% of the harvest area and also knock back the shrubby/hardwood undergrowth. The exception to this might be trees with serotinous cones in which you would burn beneath the seed trees to open the cones.

Burning is probably the least effective method of site prep if it is used alone or in only one application. Often, it only serves to increase the competition for conifer seedlings by encouraging sprouting of some understory hardwoods.

Mechanical site preparation is fairly common and effective in seed-tree harvest areas. The type of equipment used would depend on degree of clearing and the type of ground cover one has to work with. The types of equipment typically used are:

1. A Root Plow which undercuts shrub root systems at depths down to 24". This method usually can eliminate or significantly reduce sprouting. Generally it is limited to slopes under 25%.

2. The Brush or Root Rake is used for piling logging slash and brush. The piles can then be disposed of by burning or just left in the woods. This method can be used on whatever steepness of slope the tractor pulling it can handle.

3. The drum-type roller choppers, which are usually large hollow drums equipped with dull spikes and filled with water to increase their weight, are attached to a tractor and pulled over slash in the harvested area. The rolling action of the drum breaks up the slash into smaller pieces and creates some soil disturbance. This method isn't very effective as site prep for seed-tree regeneration because it usually leaves a continuous mat of slash over the harvest area. It can be effective if it is used in conjunction with brush rake or prescribed burning. It's use is limited to large areas, slopes less than 25% and light to medium slash with diameters less than 6 inches.

4. Discs can be used for site prep when there is a need to prepare a grassy site. Discs with heavy 30 to 36 inch blades are usually required to thoroughly displace the the grass roots. This method disturbs but does not remove the topsoil. Its use is limited to unrocky soils and slopes less than 20-25%.

5. Rippers can be used when compaction is a problem or when hardpans exist within 16" of the soil surface. Vegetation between the ripping teeth recovers rapidly after disturbance, so in order for ripping to be effective for the seed-tree method, it should be done in conjunction with chemical site prep or prescribed burning. It's use on slopes is limited by the tractor pulling it.

6. A piece of equipment which is fairly new on the scene is a patch scarifier. This operates similarly to a rolling chopper, but instead of the evenly spaced dull teeth, it has scraping blades placed at adjustable intervals on the drum. This shows great promise as a method of site prep for natural regeneration because by varying the scraping interval on the drum, you are giving yourself some control over the amount of regeneration you can expect and there is less disturbance to the overall site. The slope limitations would be similar to the rolling chopper.

Although **Chemical** herbicides have been used extensively in the past, their current use is debatable for site preparation for seed-tree regeneration for three main reasons:

1. The use of chemical herbicides being applied by the broadcast method has fallen into great disfavor with certain publics, since seed-tree regeneration units are usually large, any other method of chemical application such as injection or basal application could be cost prohibitive.

2. Ripping or burning would usually need to accompany chemical site prep in order to remove the dead competing vegetation to expose bare mineral soil. This would be an additional expense.

3. Since most conifer trees are quite sensitive to herbicides, one would run the risk of poisoning the seed trees if the wrong herbicide is selected or if the timing of the "right" herbicide is wrong.

But, there is a new class of herbicides becoming available called imidazolinones which attack the enzymes found in plants and not in mammals. This new technology could change public acceptance of the use of herbicides and again allow it to be used in common practice.

EFFECTS ON ECOLOGY, WILDLIFE, SOILS AND WATER

"Forest land managers deal primarily with unsubsidized forest ecosystems which have evolved over time under the constraints of specific climatic, edaphic and biotic environments and consist of mixtures of species each filling a different niche. The result is a community reacting within itself and adjusted to , as well as adjusting the abiotic environment. Any such system is exceedingly complex and involves many species at various trophic levels, as primary producers, consumers, predators or decomposers. In natural systems, all biomass eventually becomes residue and is processed biologically, supplying energy and releasing nutrients. The rates of biomass production, storage and utilization depend upon the species and resources available.

Any form of human manipulation may change the rules under which the original system operated" (Stearns 1975).

A simulated catastrophic event such as a seed tree harvest combined with site preparation which removes most of the standing trees and redistributes or removes slash will return a stand to an early developmental stage. This return is caused by some changes to the energy budget of the stand in question. Although the stand receives the same available net energy from solar radiation and thermal radiation, before it is cut as after it is cut, the distribution of the energy has changed (Figure 1; Smith 1962).

An average uncut stand would have an energy budget that would have about <3% of the energy in photosynthesis-respiration, about 22% of the energy would be in heating, and about 75% would be in evapo-transpiration. After a seed-tree harvest, where most of the trees are removed, there is almost an even reversal in the amount of energy used for heating and evapo-transpiration; photosynthesis-respiration would remain about the same. This change has a significant effect on all the balances in the ecosystems (Blomquist 1979).

The energy used for heating has increased and it is available now at or near the ground level. This causes an increase in soil temperature which effects germination and survival by rapidly drying the soil or by increasing the rate of humus decomposition through increases in numbers and activity of soil flora and fauna. The increase in direct solar radiation at ground level might also increase the response of shrubs and forbs which had remained semi-dormant in the shade of the uncut stand.

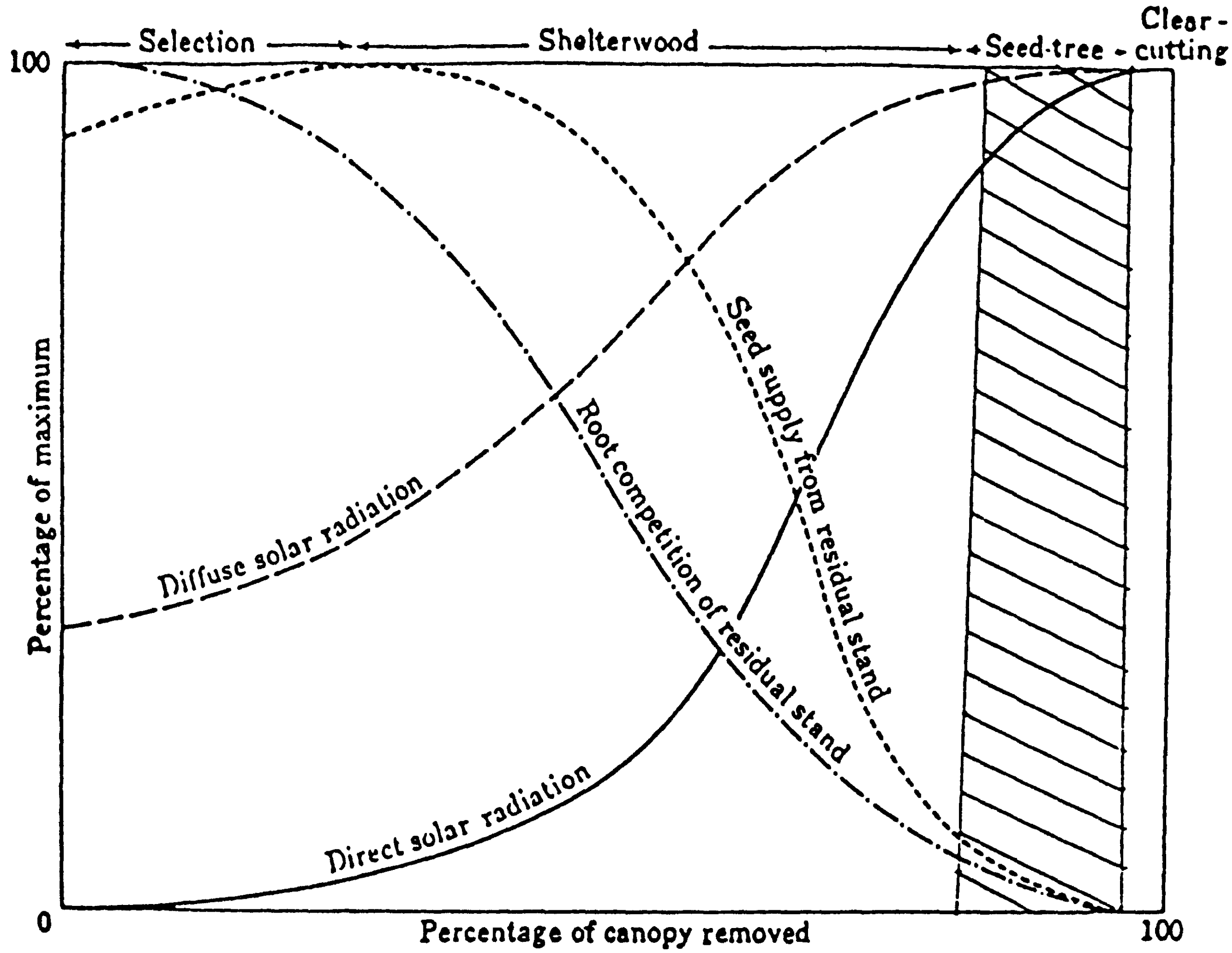


Figure 1. Distribution of solar energy based on the percentage of canopy removed.

The Water budget changes too. What isn't lost through transpiration would now probably show up as increased streamflow or increased runoff.

This change in vegetation predicates a change in animal and bird populations.

WILDLIFE[2]

The effects of seed-tree harvest on wildlife was evaluated for three forested cover types, lodgepole pine, ponderosa pine and Douglas-fir. Habitat capability values for initial conditions and as a result

[2] Contributed by Melanie Woolever, Wildlife Biologist, USDA-FS, Rocky Mountain Region.

of seed-tree harvest were estimated using the Rocky Mountain Region habitat capability model (HABCAP) (Tables 1-6).

All 45 species available in the HABCAP model were evaluated. Results discussed are for those species which had significant changes in habitat capability as a result of treatment. Most species evaluated reflected a decrease in habitat value for either feeding or cover in conjunction with seed-tree harvest. A few species, specifically those associated with early successional stages for both feeding and cover such as Nuttall's cottontail, Versper sparrow and deer mouse, were positively affected by opening the area through harvest.

Species negatively affected by the treatment are those strongly associated with at least a moderate density of mature trees. Red-naped sapsucker, southern red-backed vole, ruby-crowned kinglet, hairy woodpecker and northern three-toed woodpecker experienced a decrease in habitat capability in both feeding and cover categories. Changes in overall habitat capability for these species is in the range of 30-50% decrease in response to the reduction in the number of mature trees.

Mountain bluebird and Rocky Mountain elk benefit from an increase in forage through seed tree harvest although cover for these species was reduced by 50%. If treatment areas are fairly small or of narrow, linear design surrounded by trees providing cover, elk will be positively affected by the treatment providing that the overall area does not already have an over abundance of foraging sites. Large open areas providing no cover will not be used for feeding unless the area is extremely remote with little human activity. Bluebirds prefer open terrain with scattered trees, but must have trees which provide holes for nesting. Again, as long as the treated area is bordered by an area providing nesting cover, bluebirds will respond positively to the treatment.

As stand conditions return to a state comparable to the preharvest condition, the wildlife component will also return to a composition comparable to the preharvest composition.

SOIL-WATER EFFECTS[3]

Effects of seed-tree silviculture on soil and water are about the same as those of clearcutting. Soil quality may be impaired through compaction, erosion, or nutrient export. Water quality may be impaired through increased sediment or temperature, or reduced supply of large woody material.

SOIL COMPACTION is caused by the weight of machinery on the ground. Compaction can be reduced by laying out roads and skid trails to minimize their area, and by operating on frozen ground, deep snow, or when soils are dry.
Also, use of mechanized harvesting equipment which can operate on the slash it creates can also minimize compaction.

SOIL EROSION is caused by exposing and tilling soil which happens more in conjunction with road building and site preparation than during actual harvesting. Erosion can be reduced by minimizing the extent of roads and skid trails, by locating them on gentle slopes and grades, by providing good drainage onto hardened surfaces, and by revegetating promptly when use ends.

[3] Contributed by James Maxwell, Hydrologist, USDA-FS, Rocky Mountain Region.

NUTRIENT EXPORT is caused mostly by complete removal of vegetation, soil heating, and soil displacement. Whole tree harvest can remove nutrients from the site. A severe slash burn can vaporize most organic matter and nitrogen from the topsoil. A burn will also make nitrogen and other nutrients available at one time right after the burn, not let it release slowly over time. Soil displacement occurs when topsoil is physically moved to piles or windrows. A net loss of 10-25% of site nitrogen over one rotation may result is a significant amount of topsoil is removes from the site.

Soil heating can be reduced by burning slash when soil, duff, and large fuels are moist. Soil displacement can be reduced by closely spacing piles and windrows and by operating brush rakes to not move duff or soil.

SEDIMENT can be reduced by protecting bank vegetation and by limiting the areal extent of harvest and roads in a watershed.

WATER TEMPERATURES are increased and supplies of large **WOODY MATERIAL** are reduced by cutting trees and shrubs near streams. Increased temperatures stress fish and aquatic insects; reduced supplies of large woody material impair the diversity of fish habitat. These effects can be reduced by retaining most woody vegetation in a streamside zone whose width is equal to the height of its dominant plants.

CONCLUSION

The seed-tree method is an effective and appropriate tool for creating and maintaining even-aged stands throughout many timber types across the United States and is a viable alternative to clearcutting.

The advantages of the seed-tree method are:

1. There is a more even distribution of seed than with clearcutting.
2. There is better control of the species composition in the new crop due to the manager being able to select species for the seed source.
3. There is no limitation on area cut except for political reasons.
4. Logging costs are the lowest next to clearcutting.
5. You can achieve a better aesthetic appearance than with clearcutting.

The disadvantages are:

1. There is little control of spacing of the regeneration and timing of the new crop.
2. It is limited to species in which windfirmness in individual trees is a common characteristic.
3. It is commonly limited to lightseeded species.
4. Soil protection can be difficult when extensive slash removal is part of the site preparation procedure.
5. Rodents, seedbed conditions, and growing conditions are difficult to control.
6. If seed trees are not harvested there is a monetary loss; if they are harvested, seedlings are damaged.

LITERATURE CITED

Alexander, R. R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. Forest Science 10:130-142.

Benzie, J. W. and B. M. Blum. 1989. Silviculture of Northeastern Conifers, The Scientific Basis for Silvicultural and Management Decisions in the National Forest System, USDA-FS, Gen. Tech. Report WO-55.

Blomquist, R. 1979. Shelterwoods-Ecological Considerations, Proceedings of the National Silviculture Workshop, Charleston, South Carolina, September 17-21, 1979.

Burns, R. M. and J. C. Barber. 1989. Silviculture of Southern Pines, The Scientific Basis for Silvicultural and Management Decisions in the National Forest System, USDA-FS, Gen. Tech. Report WO-55.

Fiske, J. N. and D. S. DeBell. 1989. Silviculture of Pacific Coast Forests, The Scientific Basis for Silvicultural and Management Decisions in the National Forest System, USDA-FS, Gen. Tech. Report WO-55.

Gorsh, J. W. 1989. Future Trends in Mechanized Harvesting Systems in the Intermountain Area; Presented at Council of Forest Engineering Meeting; Coeur d'Alene Idaho; August 27-30, 1989.

Marquis, D. R. and R. L. Johnson. 1989. Silviculture of Eastern Hardwoods, The Scientific Basis for Silvicultural and Management Decisions in the National Forest System, USDA-FS, Gen. Tech. Report WO-55.

Schmidt, W. C. and M. Larson. 1989. Silviculture of Western Inland Conifers, The Scientific Basis for Silvicultural and Management Decisions in the National Forest System, USDA-FS, Gen. Tech. Report WO-55.

Smith, D. M. 1962. The Practice of Silviculture, Seventh Edition. John Wiley & Sons, Inc., New York. Pg 363.

Stearns, F. 1975. Dept. of Botany, University of Wisconsin-Milwaukee, Logging Residue Removal-Ecological and Wildlife Effects, presented at Logging Residue Conference, June 4-6, 1975, West Virginia University, Morgantown, WV.

Author

Susan E. Gray
Regional Silviculturist
Rocky Mountain Region
11177 W. 8th Avenue
Lakewood, Colorado 80225

Table 1.

HABCAP (Rev. 03.00)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: LODGEPOLE PINE
ALTERNATIVE: INITIAL

03-AUG-90 05:12:04 PM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Lodgepole Pine	0.	0.	0.	0.	500.	0.	0.	1000.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads =	.00
Secondary roads =	1.50
Primitive roads =	.00
Road density =	1.05
Effect on elk =	.59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	<------ INDICES ------> FEEDING VALUE	COVER VALUE	HABITAT CAPABILITY	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	<-- SUITABLE ACRES --> USED FOR FEEDING	USED FOR COVER
1. Bear, black	SUMMER	.20	1.00	.45	.00075	1.	1500.	1500.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.00	.33	.00	.25000	0.	0.	1000.
4. Bighorn sheep	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
5. Bobcat	YEAR	.20	.80	.40	.00016	0.	1500.	1500.
6. Cottontail, Nuttall's	YEAR	.20	.30	.24	.33333	122.	1500.	1500.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.07	1.00	.26	.06667	26.	500.	1500.
	WINTER	.07	1.00	.26	.10000	39.	500.	1500.
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
10. Eagle, bald	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
11. Elk, Rocky Mountain	SUMMER	.20	1.00	.12	.02500	4.	1500.	1500.
	WINTER	.20	1.00	.12	.02500	4.	1500.	1500.
12. Falcon, Am. peregrine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						

13	Flicker, common	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
14.	Goshawk	SUMMER	.20	1.00	.45	.00029	0.	1500.	1500.
		WINTER	.20	1.00	.45	.00029	0.	1500.	1500.
15.	Grouse, blue	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
16.	Grouse, ruffed	YEAR	.07	.07	.07	<b>	<b>	500.	500.
17.	Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18.	Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	.67	1.00	.82	1.00000	1225.	1000.	1000.
19.	Hare, snowshoe	YEAR	.13	.71	.31	.10000	46.	1000.	1500.
20.	Kinglet, ruby-crowned	SUMMER	1.00	1.00	1.00	<b>	<b>	1500.	1500.
21.	Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22.	Mallard	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23.	Marten, pine	YEAR	.73	1.00	.86	.00250	3.	1500.	1500.
24.	Moose	YEAR	.50	1.00	.71	.00100	1.	1500.	1500.
25.	Mouse, deer	YEAR	.20	.20	.20	3.84600	1154.	1500.	1500.
26.	Nuthatch, pygmy	SUMMER	.13	.27	.19	.66667	189.	1000.	1000.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
27.	Osprey	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
28.	Pipit, water		This species does not utilize the Cover Types presently included in this model.						
29.	Pronghorn	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
31.	Sapsucker, red-naped	SUMMER	.50	1.00	.71	.20000	212.	1500.	1500.
32.	Sparrow, vesper	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
33.	Sparrow, white-crowned	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
34.	Squirrel, Abert's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
35.	Squirrel, red	YEAR	.83	.83	.83	<b>	<b>	1500.	1500.
36.	Towhee, green-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
37.	Turkey, Merriam's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
38.	Vireo, warbling	SUMMER	.20	.00	.00	1.11111	0.	1500.	0.

39	Vole, southern red-backed	YEAR	.73	1.00	.86	50.00000	64226.	1500.	1500.
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
42.	Warbler, Wilson's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
43.	Woodpecker, hairy	YEAR	1.00	.83	.91	<b>	<b>	1500.	1500.
44.	Woodpecker, Lewis'	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
45.	Woodpecker, n. 3-toed	YEAR	.33	.51	.41	.02000	12.	1000.	1000.

<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species.
Consequently "Habitat Capability Expressed as Number of Animals" cannot be computed.

Table 2.

HABCAP (Rev. 03.00)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: LODGEPOLE PINE
ALTERNATIVE: SEED TREE

06-AUG-90 10:14:27 AM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Lodgepole Pine	500.	0.	0.	0.	500.	0.	0.	500.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads =	.00
Secondary roads =	1.50
Primitive roads =	.00
Road density =	1.05
Effect on elk =	.59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	FEEDING VALUE (INDICES)	COVER VALUE (INDICES)	HABITAT CAPABILITY (INDICES)	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	SUITABLE ACRES USED FOR FEEDING	SUITABLE ACRES USED FOR COVER
1. Bear, black	SUMMER	.30	1.00	.55	.00075	1.	1500.	1000.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.33	.17	.24	.25000	88.	500.	500.
4. Bighorn sheep	SUMMER	.33	1.00	.58	.00800	7.	500.	500.
	WINTER	.33	1.00	.58	.00800	7.	500.	500.
5. Bobcat	YEAR	.47	.53	.50	.00016	0.	1500.	1000.
6. Cottontail, Nuttall's	YEAR	.47	.45	.46	.33333	229.	1500.	1500.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.40	1.00	.63	.06667	63.	1000.	1000.
	WINTER	.40	.83	.58	.10000	87.	1000.	1000.
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
10. Eagle, bald	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
11. Elk, Rocky Mountain	SUMMER	.47	1.00	.27	.02500	10.	1500.	1000.
	WINTER	.47	1.00	.27	.02500	10.	1500.	1000.
12. Falcon, Am. peregrine	SUMMER	.33	(a)	.33	(b)	(b)	500.	0.

13	Flicker, common	SUMMER	.33	.00	.00	<b>	<b>	500.	0.
14.	Goshawk	SUMMER	.47	1.00	.68	.00029	0.	1500.	1000.
		WINTER	.47	1.00	.68	.00029	0.	1500.	1000.
15.	Grouse, blue	SUMMER	.33	.25	.29	.07812	34.	500.	500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
16.	Grouse, ruffed	YEAR	.07	.07	.07	<b>	<b>	500.	500.
17.	Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18.	Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	.33	.67	.47	1.00000	707.	500.	500.
19.	Hare, snowshoe	YEAR	.40	.48	.44	.10000	65.	1000.	1000.
20.	Kinglet, ruby-crowned	SUMMER	.67	.67	.67	<b>	<b>	1000.	1000.
21.	Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22.	Mallard	SUMMER	.33	.33	.33	<b>	<b>	500.	500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23.	Marten, pine	YEAR	.73	1.00	.86	.00250	3.	1500.	1000.
24.	Moose	YEAR	.67	1.00	.82	.00100	1.	1500.	1000.
25.	Mouse, deer	YEAR	.30	.30	.30	3.84600	1731.	1500.	1500.
26.	Nuthatch, pygmy	SUMMER	.07	.13	.09	.66667	94.	500.	500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
27.	Osprey	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
28.	Pipit, water		This species does not utilize the Cover Types presently included in this model.						
29.	Pronghorn	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
31.	Sapsucker, red-naped	SUMMER	.33	.67	.47	.20000	141.	1000.	1000.
32.	Sparrow, vesper	SUMMER	.33	.17	.24	<b>	<b>	500.	500.
33.	Sparrow, white-crowned	SUMMER	.17	.07	.11	<b>	<b>	500.	500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
34.	Squirrel, Abert's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
35.	Squirrel, red	YEAR	.67	.67	.67	<b>	<b>	1500.	1500.
36.	Towhee, green-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
37.	Turkey, Merriam's	SUMMER	.17	.67	.33	.00585	3.	500.	500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
38.	Vireo, warbling	SUMMER	.13	.00	.00	1.11111	0.	1000.	0.

39	Vole, southern red-backed	YEAR	.40	.80	.57	50.00000	42426.	1000.	1000.
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
42.	Warbler, Wilson's	SUMMER	.17	.00	.00	.83333	0.	500.	0.
43.	Woodpecker, hairy	YEAR	.73	.50	.61	<b>	<b>	1500.	1000.
44.	Woodpecker, Lewis'	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
45.	Woodpecker, n. 3-toed	YEAR	.17	.25	.21	.02000	6.	500.	500.

<a> This species does not utilize the cover types selected for either feeding or cover.
<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species.
Consequently "Habitat Capability Expressed as Number of Animals" cannot be computed.

Table 3.

HABCAP (Rev. 03.00)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: PONDEROSA PINE
ALTERNATIVE: INITIAL

10-AUG-90 02:40:52 PM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Ponderosa Pine	200.	0.	0.	500.	0.	0.	800.	0.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads = .00
Secondary roads = 1.50
Primitive roads = .00
Road density = 1.05
Effect on elk = .59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	<------ INDICES FEEDING VALUE	COVER VALUE	------> HABITAT CAPABILITY	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	<-- SUITABLE ACRES USED FOR FEEDING	--> USED FOR COVER
1. Bear, black	SUMMER	1.00	1.00	1.00	.00075	1.	1500.	1300.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.57	.27	.39	.25000	146.	1500.	800.
4. Bighorn sheep	SUMMER	.13	1.00	.37	.00800	4.	200.	1500.
	WINTER	.13	1.00	.37	.00800	4.	200.	1500.
5. Bobcat	YEAR	.57	1.00	.75	.00016	0.	1500.	1300.
6. Cottontail, Nuttall's	YEAR	.41	.36	.38	.33333	191.	1500.	1500.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.57	1.00	.75	.06667	75.	1500.	1300.
	WINTER	.57	1.00	.75	.10000	113.	1500.	1300.
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						

10. Eagle, bald	WINTER	<a>	.60	.60	<b>	<b>	0.	1300.
11. Elk, Rocky Mountain	SUMMER	.57	1.00	.33	.02500	13.	1500.	1300.
	WINTER	.57	1.00	.33	.02500	13.	1500.	1300.
12. Falcon, Am. peregrine	SUMMER	.57	<a>	.57	<b>	<b>	1500.	0.
13. Flicker, common	SUMMER	.57	.53	.55	<b>	<b>	1500.	800.
14. Goshawk	SUMMER	1.00	1.00	1.00	.00029	0.	1500.	1300.
	WINTER	1.00	1.00	1.00	.00029	0.	1500.	1300.
15. Grouse, blue	SUMMER	.83	.75	.79	.07812	93.	1500.	1500.
	WINTER	.11	.21	.15	.07812	18.	800.	800.
16. Grouse, ruffed	YEAR	.33	.33	.33	<b>	<b>	1300.	1300.
17. Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18. Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
	WINTER	.27	.53	.38	1.00000	566.	800.	800.
19. Hare, snowshoe	YEAR	.41	.39	.40	.10000	60.	1500.	1300.
20. Kinglet, ruby-crowned	SUMMER	.87	.87	.87	<b>	<b>	1300.	1300.
21. Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22. Mallard	SUMMER	.13	.13	.13	<b>	<b>	200.	200.
	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23. Marten, pine	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
24. Moose	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
25. Mouse, deer	YEAR	.73	.73	.73	3.84600	4231.	1500.	1500.
26. Nuthatch, pygmy	SUMMER	.53	1.00	.73	.66667	730.	800.	800.
	WINTER	.53	1.00	.73	.66667	730.	800.	800.
27. Osprey	SUMMER	<a>	.11	.11	<b>	<b>	0.	800.

28.	Pipit water		This species does not utilize the Cover Types presently included in this model.							
29.	Pronghorn	SUMMER	.13	.13	.13	.00000	0.	700.	700.	
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!							
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!							
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!							
31.	Sapsucker, red-naped	SUMMER	.43	.87	.61	.20000	184.	1300.	1300.	
32.	Sparrow, vesper	SUMMER	.13	.07	.09	<b>	<b>	200.	200.	
33.	Sparrow, white-crowned	SUMMER	.13	.03	.06	<b>	<b>	200.	200.	
		WINTER	.13	.03	.06	<b>	<b>	200.	200.	
34.	Squirrel, Abert's	SUMMER	.60	.54	.57	.06993	60.	1300.	800.	
		WINTER	.60	.54	.57	.06993	60.	1300.	800.	
35.	Squirrel, red	YEAR	.43	.17	.27	<b>	<b>	1300.	1300.	
36.	Towhee, green-tailed	SUMMER	.20	.20	.20	<b>	<b>	1500.	1500.	
37.	Turkey, Merriam's	SUMMER	.57	1.00	.75	.00585	7.	1500.	1500.	
		WINTER	.50	1.00	.71	.00585	6.	1500.	1300.	
38.	Vireo, warbling	SUMMER	.43	.15	.26	1.11111	427.	1300.	500.	
39.	Vole, southern red-backed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!							
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!							
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!							
42.	Warbler, Wilson's	SUMMER	.23	.10	.15	.83333	191.	700.	500.	
43.	Woodpecker, hairy	YEAR	.93	.87	.90	<b>	<b>	1500.	1300.	
44.	Woodpecker, Lewis'	YEAR	.53	.80	.65	.13333	131.	800.	800.	
45.	Woodpecker, n. 3-toed	YEAR	.27	.40	.33	.02000	10.	800.	800.	

<a> This species does not utilize the cover types selected for either feeding or cover.
<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species. Consequently "Habitat Capability Expressed as Number of Animals" cannot be computed.

Table 4.

HABCAP (Rev. 03.0_)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: PONDEROSA PINE
ALTERNATIVE: SEED TREE

10-AUG-90 02:42:28 PM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Ponderosa Pine	600.	0.	0.	500.	0.	0.	400.	0.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads	=	.00
Secondary roads	=	1.50
Primitive roads	=	.00
Road density	=	1.05
Effect on elk	=	.59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	<------ INDICES ------> FEEDING VALUE	COVER VALUE	HABITAT CAPABILITY	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	<-- SUITABLE ACRES --> USED FOR FEEDING	USED FOR COVER
1. Bear, black	SUMMER	1.00	.87	.93	.00075	1.	1500.	900.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.70	.13	.31	.25000	115.	1500.	400.
4. Bighorn sheep	SUMMER	.40	1.00	.63	.00800	8.	600.	1500.
	WINTER	.40	1.00	.63	.00800	8.	600.	1500.
5. Bobcat	YEAR	.70	1.00	.84	.00016	0.	1500.	900.
6. Cottontail, Nuttall's	YEAR	.62	.48	.54	.33333	272.	1500.	1500.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.70	1.00	.84	.06667	84.	1500.	900.
	WINTER	.70	.75	.72	.10000	109.	1500.	900.
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						

10.	Eagle, bald	WINTER	<a>	.33	.33	<b>	<b>	0.	900.
11.	Elk, Rocky Mountain	SUMMER	.70	1.00	.41	.02500	15.	1500.	900.
		WINTER	.70	.75	.41	.02500	15.	1500.	900.
12.	Falcon, Am. peregrine	SUMMER	.70	<a>	.70	<b>	<b>	1500.	0.
13.	Flicker, common	SUMMER	.70	.27	.43	<b>	<b>	1500.	400.
14.	Goshawk	SUMMER	1.00	1.00	1.00	.00029	0.	1500.	900.
		WINTER	1.00	1.00	1.00	.00029	0.	1500.	900.
15.	Grouse, blue	SUMMER	.83	.75	.79	.07812	93.	1500.	1500.
		WINTER	.05	.11	.08	.07812	9.	400.	400.
16.	Grouse, ruffed	YEAR	.20	.20	.20	<b>	<b>	900.	900.
17.	Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18.	Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	.13	.27	.19	1.00000	283.	400.	400.
19.	Hare, snowshoe	YEAR	.62	.31	.44	.10000	66.	1500.	900.
20.	Kinglet, ruby-crowned	SUMMER	.60	.60	.60	<b>	<b>	900.	900.
21.	Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22.	Mallard	SUMMER	.40	.40	.40	<b>	<b>	600.	600.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23.	Marten, pine	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
24.	Moose	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
25.	Mouse, deer	YEAR	.87	.87	.87	3.84600	5000.	1500.	1500.
26.	Nuthatch, pygmy	SUMMER	.27	.53	.38	.66667	377.	400.	400.
		WINTER	.27	.53	.38	.66667	377.	400.	400.
27.	Osprey	SUMMER	<a>	.05	.05	<b>	<b>	0.	400.

28.	Pipit, water		This species does not utilize the Cover Types presently included in this model.						
29.	Pronghorn	SUMMER	.27	.27	.27	.00000	0.	1100.	1100.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
31.	Sapsucker, red-naped	SUMMER	.30	.60	.42	.20000	127.	900.	900.
32.	Sparrow, vesper	SUMMER	.40	.20	.28	<b>	<b>	600.	600.
33.	Sparrow, white-crowned	SUMMER	.40	.08	.18	<b>	<b>	600.	600.
		WINTER	.40	.08	.18	<b>	<b>	600.	600.
34.	Squirrel, Abert's	SUMMER	.33	.27	.30	.06993	32.	900.	400.
		WINTER	.33	.27	.30	.06993	32.	900.	400.
35.	Squirrel, red	YEAR	.30	.12	.19	<b>	<b>	900.	900.
36.	Towhee, green-tailed	SUMMER	.20	.20	.20	<b>	<b>	1500.	1500.
37.	Turkey, Merriam's	SUMMER	.70	1.00	.84	.00585	7.	1500.	1500.
		WINTER	.50	.87	.66	.00585	6.	1500.	900.
38.	Vireo, warbling	SUMMER	.30	.15	.21	1.11111	355.	900.	500.
39.	Vole, southern red-backed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
42.	Warbler, Wilson's	SUMMER	.37	.10	.19	.83333	239.	1100.	500.
43.	Woodpecker, hairy	YEAR	.80	.60	.69	<b>	<b>	1500.	900.
44.	Woodpecker, Lewis'	YEAR	.27	.40	.33	.13333	65.	400.	400.
45.	Woodpecker, n. 3-toed	YEAR	.13	.20	.16	.02000	5.	400.	400.

<a> This species does not utilize the cover types selected for either feeding or cover.
<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species.

Table 5.

HABCAP (Rev. 03.00)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: DOUGLAS FIR
ALTERNATIVE: INITIAL

06-AUG-90 10:02:11 AM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Douglas-fir	200.	0.	0.	500.	0.	0.	800.	0.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads =	.00
Secondary roads =	1.50
Primitive roads =	.00
Road density =	1.05
Effect on elk =	.59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	<------ INDICES ------> FEEDING VALUE	COVER VALUE	HABITAT CAPABILITY	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	<-- SUITABLE ACRES --> USED FOR FEEDING	USED FOR COVER
1. Bear, black	SUMMER	1.00	1.00	1.00	.00075	1.	1500.	1300.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.57	.27	.39	.25000	146.	1500.	800.
4. Bighorn sheep	SUMMER	.13	1.00	.37	.00800	4.	200.	1500.
	WINTER	.13	1.00	.37	.00800	4.	200.	1500.
5. Bobcat	YEAR	.57	1.00	.75	.00016	0.	1500.	1300.
6. Cottontail, Nuttall's	YEAR	.13	.10	.12	.33333	58.	200.	200.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.57	1.00	.75	.06667	75.	1500.	1300.
	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
10. Eagle, bald	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
11. Elk, Rocky Mountain	SUMMER	.41	1.00	.24	.02500	9.	1500.	1300.
	WINTER	.20	1.00	.12	.02500	4.	1500.	1300.
12. Falcon, Am. peregrine	SUMMER	.31	<a>	.31	<b>	<b>	1500.	0.

13	Flicker, common	SUMMER	.20	.53	.33	<b>	<b>	700.	800.
14.	Goshawk	SUMMER	1.00	1.00	1.00	.00029	0.	1500.	1300.
		WINTER	1.00	1.00	1.00	.00029	0.	1500.	1300.
15.	Grouse, blue	SUMMER	.83	.75	.79	.07812	93.	1500.	1500.
		WINTER	.53	1.00	.73	.07812	86.	800.	800.
16.	Grouse, ruffed	YEAR	.17	.17	.17	<b>	<b>	1300.	1300.
17.	Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18.	Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	.11	.53	.24	1.00000	358.	800.	800.
19.	Hare, snowshoe	YEAR	.41	.39	.40	.10000	60.	1500.	1300.
20.	Kinglet, ruby-crowned	SUMMER	.43	.43	.43	<b>	<b>	1300.	1300.
21.	Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22.	Mallard	SUMMER	.13	.13	.13	<b>	<b>	200.	200.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23.	Marten, pine	YEAR	.36	1.00	.60	.00250	2.	1500.	1300.
24.	Moose	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
25.	Mouse, deer	YEAR	.50	.50	.50	3.84600	2885.	1500.	1500.
26.	Nuthatch, pygmy	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
27.	Osprey	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
28.	Pipit, water		This species does not utilize the Cover Types presently included in this model.						
29.	Pronghorn	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
31.	Sapsucker, red-naped	SUMMER	.43	.87	.61	.20000	184.	1300.	1300.
32.	Sparrow, vesper	SUMMER	.13	.07	.09	<b>	<b>	200.	200.
33.	Sparrow, white-crowned	SUMMER	.13	.03	.06	<b>	<b>	200.	200.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
34.	Squirrel, Abert's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
35.	Squirrel, red	YEAR	.87	.43	.61	<b>	<b>	1300.	1300.
36.	Towhee, green-tailed	SUMMER	.20	.20	.20	<b>	<b>	1500.	1500.
37.	Turkey, Merriam's	SUMMER	.24	.61	.38	.00585	3.	1500.	1500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
38.	Vireo, warbling	SUMMER	.43	.39	.41	1.11111	689.	1300.	1300.

39	Vole, southern red-backed	YEAR	.17	.35	.25	50.00000	18385.	1300.	1300.
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
42.	Warbler, Wilson's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
43.	Woodpecker, hairy	YEAR	.93	.70	.81	<b>	<b>	1500.	1300.
44.	Woodpecker, Lewis'	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
45.	Woodpecker, n. 3-toed	YEAR	.27	.40	.33	.02000	10.	800.	800.

<a> This species does not utilize the cover types selected for either feeding or cover.
<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species.
Consequently "Habitat Capability Expressed as Number of Animals" cannot be computed.

Table 6.

HABCAP (Rev. 3.00)
Rocky Mountain Region -- Wildlife Habitat Capability

ANALYSIS: DOUGLAS FIR
ALTERNATIVE: SEED TREE

06-AUG-90 11:10:28 AM

ACRES BY COVER TYPE

	GRASS -FORB	SHRUB -SEED	POLE (A)	POLE (B)	POLE (C)	MATURE (A)	MATURE (B)	MATURE (C)	OLD GROWTH	NO STAGE	TOTAL
Douglas-fir	600.	0.	0.	500.	0.	0.	400.	0.	0.	0.	1500.

TOTAL ACRES ANALYZED = 1500.

MILES OF OPEN ROAD PER SQUARE MILE FOR:

Primary roads =	.00
Secondary roads =	1.50
Primitive roads =	.00
Road density =	1.05
Effect on elk =	.59

HABITAT CAPABILITY RESULTS

SPECIES	SEASON	FEEDING VALUE	COVER VALUE	HABITAT CAPABILITY	MAX DENSITY AT OPTIMUM HABITAT	HAB. CAP. EXPRESSED AS # ANIM.	SUITABLE ACRES USED FOR FEEDING	SUITABLE ACRES USED FOR COVER
1. Bear, black	SUMMER	1.00	.87	.93	.00075	1.	1500.	900.
2. Beaver	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
3. Bluebird, mountain	SUMMER	.70	.13	.31	.25000	115.	1500.	400.
4. Bighorn sheep	SUMMER	.40	1.00	.63	.00800	8.	600.	1500.
	WINTER	.40	1.00	.63	.00800	8.	600.	1500.
5. Bobcat	YEAR	.70	1.00	.84	.00016	0.	1500.	900.
6. Cottontail, Nuttall's	YEAR	.40	.30	.35	.33333	173.	600.	600.
7. Crane, sandhill	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
8. Deer, mule	SUMMER	.70	1.00	.84	.06667	84.	1500.	900.
	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
9. Deer, white-tailed	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
10. Eagle, bald	WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
11. Elk, Rocky Mountain	SUMMER	.62	1.00	.37	.02500	14.	1500.	900.
	WINTER	.20	.75	.12	.02500	4.	1500.	900.
12. Falcon, Am. peregrine	SUMMER	.52	<a>	.52	<b>	<b>	1500.	0.

13	Flicker, common	SUMMER	.47	.27	.35	<b>	<b>	1100.	400.
14.	Goshawk	SUMMER	1.00	1.00	1.00	.00029	0.	1500.	900.
		WINTER	1.00	1.00	1.00	.00029	0.	1500.	900.
15.	Grouse, blue	SUMMER	.83	.75	.79	.07812	93.	1500.	1500.
		WINTER	.27	.53	.38	.07812	44.	400.	400.
16.	Grouse, ruffed	YEAR	.12	.12	.12	<b>	<b>	900.	900.
17.	Grouse, sharp-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
18.	Grosbeak, pine	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	.05	.27	.12	1.00000	179.	400.	400.
19.	Hare, snowshoe	YEAR	.62	.31	.44	.10000	66.	1500.	900.
20.	Kinglet, ruby-crowned	SUMMER	.30	.30	.30	<b>	<b>	900.	900.
21.	Lynx, Canada	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
22.	Mallard	SUMMER	.40	.40	.40	<b>	<b>	600.	600.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
23.	Marten, pine	YEAR	.28	1.00	.53	.00250	2.	1500.	900.
24.	Moose	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
25.	Mouse, deer	YEAR	.50	.50	.50	3.84600	2885.	1500.	1500.
26.	Nuthatch, pygmy	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
27.	Osprey	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
28.	Pipit, water		This species does not utilize the Cover Types presently included in this model.						
29.	Pronghorn	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
30.	Ptarmigan, white-tailed	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
31.	Sapsucker, red-naped	SUMMER	.30	.60	.42	.20000	127.	900.	900.
32.	Sparrow, vesper	SUMMER	.40	.20	.28	<b>	<b>	600.	600.
33.	Sparrow, white-crowned	SUMMER	.40	.08	.18	<b>	<b>	600.	600.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
34.	Squirrel, Abert's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
35.	Squirrel, red	YEAR	.60	.30	.42	<b>	<b>	900.	900.
36.	Towhee, green-tailed	SUMMER	.20	.20	.20	<b>	<b>	1500.	1500.
37.	Turkey, Merriam's	SUMMER	.32	1.00	.57	.00585	5.	1500.	1500.
		WINTER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
38.	Vireo, warbling	SUMMER	.30	.27	.29	1.11111	477.	900.	900.

39	Vole, southern red-backed	YEAR	.12	.24	.17	50.00000	12728.	900.	900.
40.	Warbler, MacGillivray's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
41.	Warbler, Virginia's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
42.	Warbler, Wilson's	SUMMER	This species does not occur in this Season/Cover Types/Structural Stages combination!						
43.	Woodpecker, hairy	YEAR	.80	.43	.59	<b>	<b>	1500.	900.
44.	Woodpecker, Lewis'	YEAR	This species does not occur in this Season/Cover Types/Structural Stages combination!						
45.	Woodpecker, n. 3-toed	YEAR	.13	.20	.16	.02000	5.	400.	400.

<a> This species does not utilize the cover types selected for either feeding or cover.
<b> The value for "Maximum Density at Optimum Habitat" is not presently available for this species.
Consequently "Habitat Capability Expressed as Number of Animals" cannot be computed.

GENETIC CONSIDERATIONS AND CONSEQUENCES IN USING THE SEED-TREE REGENERATION METHOD.

Raphael J. Steinhoff
Ochoco National Forest
Prineville, OR

INTRODUCTION

The seed-tree, or any other natural regeneration method, depends on trees currently on the site, or near the edge of the stand around the perimeter of the harvested area to produce the next generation. Consequently, these trees must produce enough seed within a few years to provide enough seedlings to fully stock the site. The seedlings must also: 1. be adapted to the overall site conditions, 2. contain sufficient diversity to tolerate microsite and moderate climatic variation and pest problems, and 3. be capable of producing good quality trees with at least normal growth potential.

Items to be considered before embarking on a seed-tree regeneration harvest.

1. Are there sufficient numbers of good quality trees available within the site or around its perimeter with a history of cone and pollen production available to regenerate the site? A minimum of 5 seed trees should be available for each acre of the harvest area. Although pollen can travel for miles, there should be numerous good pollen producers within a few hundred yards of the area to insure additional diversity. If low quality trees, such as wildlife trees, are left on the site, one might pick their cones before they shed seed.

2. What is the cone crop frequency for the site and can harvesting and/or site preparation be timed to coincide with a bumper cone crop to facilitate prompt regeneration? If more than one tree species is involved, will they produce cones in the same year or do they need different site conditions for their seedlings to become established?

3. Will harvest and site preparation methods promote or hinder reestablishment of the normal associated vegetation so overall vegetative diversity will be maintained or enhanced?

4. Will timing of the harvest be compatible with the desired age-diversity for the larger area of which the unit is a part.

What then are the genetic consequences of using the seed-tree method on: 1. Adaptation, 2. Diversity, and 3. Productivity and Quality?

1. Adaptation.
   A. Short term.
   Since the reproduction comes from trees growing on the site it should be well adapted to the present conditions unless the site is drastically altered during the harvesting operation.

B. Long term.

Over the long term—several centuries to several millenia—local adaptability will depend on the diversity of the trees contributing seed for reproduction and the magnitude and rapidity of climatic or other change. If changes of the magnitude of the ice-age cycles occur, local populations are not likely to contain sufficient diversity to adapt and will be displaced (Mehringer 1985). If the changes occur slowly, populations may "migrate" to adjacent areas with more favorable conditions. However, should a worst-case senario of the greenhouse-effect, or something similar occur, populations probably would not have enough diversity to adapt and survive, nor could they "migrate" fast enough to survive in new areas where conditions will have become similar to those in their former habitats. Should such changes occur rapidly, natural regeneration would not be an appropriate regeneration method unless a species change is possible and acceptable. Indeed, if the site is near the limit of the species' distribution there may not be any populations or individuals of the species that would be adapted to the new conditions.

2. Diversity.

A. At the landscape level.

A single seed-tree regeneration unit within a large area probably would have little deleterious effect on diversity if it is surrounded by numerous native trees of seed and pollen bearing age. However, if most of the surrounding area has been planted at one time or another and there has been little natural regeneration, leaving only a limited number of seed trees could substantially reduce the desired diversity. similarly, a seed-tree cut in a small isolated population could be very deleterious. Visually, a seed-tree cut might degrade, enhance, or have little effect on diversity depending on the situation. If rare plants or animals inhabit the area, and any cutting is allowed, the regeneration method could have drastic effects on the populations and their diversity. In other situations, creating openings could provide additional desirable habitat.

B. At the regeneration site level.

Obviously, a seed-tree cut will immediately reduce the diversity among trees on a site but this should be regenerated in the new seedlings. Age, size, and quality diversity will be reduced and number of tree species present may also change. Diversity in understory vegetation may be reduced by the site preparation process but then may be enhanced by the open conditions until the tree canopy again closes. There will be a shift from shade tolerant to sun-loving species soon after cutting but the mix will return toward pre-harvest conditions as the trees develope.

C. At the preferred species level.

The new stand regenerated from a seed-tree cut may be more or less diverse than the original. If a diverse collection of seed trees are left and a diverse pollen supply contributes to the seed crop adequate or even enhanced diversity should result. However, if closely related trees are left to supply seed and outside pollen and seed production is limited, diversity may be substantially reduced. If abundant seedlings are produced so the selection process has many to choose from, the final crop trees available to produce the next generation may still be adequately diverse.

Because of the widely scattered distribution of seed trees, the seedlings around each tree will be more likely to be closely related than under a shelterwood or clearcut and plant program. Such clusters of related individuals could result in reduced diversity in subsequent generations if outside pollen is limited.

3. Productivity and Quality.

In order to maintain or improve volume production and tree quality there must be good trees available and well distributed over the harvest unit which can be retained as the seed trees. The quality of trees should also be at least average in the surrounding stand because they will probably be supplying much of the pollen to the seed trees in the unit. Quality of the seed trees can be an important concern in areas that have repeatedly been subjected to selective harvesting of the high-grading variety (Howe 1989). If quality seed trees are not available, supplemental planting or supplemental mass pollination could be used to improve the overall quality of the reproduction but it might be more economical to clearcut and plant if that is an option.

SUMMARY—RECOMMENDATIONS

Maintaining adaptation, diversity, and productivity in the National Forests and having a variety of harvest and regeneration methods to accomplish those goals is very important. What should be done when it would be desirable to use a harvest method that retains some tree cover but the expected diversity and quality of the natural regeneration may be less than desired? The obvious answer is to do supplemental planting with seedlings of known adaptability, diversity, and quality. Most Forests now have seed available from selected trees of the major local species. Some have seed from seed orchards and others will have soon. Because of the selection process the trees should be diverse, of at least average or or better quality, and adapted within the appropriate planting zone. Seedlings from seed orchard seed should be even better.

Because of questions about diversity and quality of leave trees in a seed-tree, or other natural regeneration harvest method, it may be prudent to consider doing some supplemental planting with improved seedlings on a routine basis as a kind of insurance program. However, the goal should not be to convert every acre to the improved stock because, although it is diverse, there is much additional, and very valuable, diversity available in trees in the natural stands. It is desirable to maintain stands or populations with different assortments of genes rather than having the same mix spread uniformly over the entire landscape (Namkoong 1990).

LITERATURE CITED

Howe, George E. 1989. Genetic effects of even-aged and uneven-aged silviculture. Proceedings, National Silviculture Workshop, Petersburg, AK, July, 1989.

Mehringer, Peter J., Jr. 1985. Late-quaternary pollen records from the Interior Pacific Northwest and Northern Great Basin of the United States. p. 167-189. In: American association of stratigraphic palynologists.

Namkoong, G. 1990. Forest genetics: 2050—the quick and the dead. Proc. Joint meeting Western Forest Genetics Association and IUFRO working parties S2.02-05, 06, 12, and 14. Olympia, WA. Aug. 1990.

Author

Raphael J. Steinhoff
Area Geneticist
Ochoco National Forest
P.O. Box 490
Prineville, Oregon 97754

SEED-TREE METHOD

Philip S. Aune
Pacific Southwest Research Station
Redding, CA

INTRODUCTION

The seed-tree method is one of the classic cutting methods used to establish even-age stands. The method is appropriate to a wide variety of forest types and stand conditions given the objective of establishment of even-age stands. This cutting method has not been widely used as a method for regenerating even-age stands during the past two decades. Interest in the seed-tree cutting method has increased recently and is frequently mentioned today as one of the methods applicable to the development of "New Forestry" or "New Perspectives." This is based on the premise that these "new" practices generally have objectives of retaining residual green trees throughout the life of the new stand and that leaving the seed trees will fulfill the green tree retention objective. To help determine if the seed-tree method is appropriate for the "New forestry/New Perspectives" objectives or any other forest stand management objective is first dependent upon a clear understanding of the seed-tree cutting method definition. The Society of American Foresters' *Terminology of Forest Science, Technology, Practice and Products* defines the Seed-Tree Cutting Method as follows (Ford-Robertson 1971):

> Removal in one cut of the mature timber from an area, save for a small number of seed bearers left singly or small groups. Note: (1) If these are retained for increment as well as seed, termed a reserve cutting. (2) Not a true silvicultural system.

Others describe silvicultural systems and discuss the seed-tree cutting method as the seed-tree system to specifically point out that the cutting methods are part of a system of silviculture rather than only a method of harvest cutting. The seed-tree system involves harvesting nearly all of the timber on selected area in one cut. A few of the better trees of the desired species are left well distributed over the area to reseed naturally. This system applies mainly to conifers (Burns 1983).

In their overview of the ecological basis for silvicultural systems, Loftus and Fitzgerald describe the seed-tree cutting method as follows (Burns 1989):

> In the seed tree method, the area is clearcut except for a few seed-producing trees selected to naturally regenerate the harvested area. When feasible, the seed trees are harvested after regeneration is established. In contrast to the shelterwood method, not enough seed trees are left per unit area to significantly shelter or compete with the newly established seedlings. Successful regeneration by this method requires careful selection of the seed trees, preparation of the seed bed, and control of competing vegetation. In choosing seed trees particular attention should be given to the selection of appropriate species for the site. Also, selected trees must be mature enough to produce abundant fertile seed. This method is not commonly used because of the unreliability of seed crops when they are needed; rapid invasion of completing vegetation; seed tree mortality from insects, diseases, and windthrow; and the inefficiency of harvesting relatively few trees after the area is regenerated.

Clearly, the problem of determining if the seed-tree method is appropriate for "new" or "old" forestry is not simply a definitional problem. The real problems are to completely describe the desired stand structures and stand management objectives. Schmidt pointed out in his expansion of the classic definitions of the silvicultural systems that, "Silviculture is the science and art of managing forests to meet resource needs. No matter the resource or management objective—be it aesthetics, water, timber, wildlife, or recreation—silvicultural practices are the driving force, the means used to achieve the desired end" (As quoted in Prouty 1987). The purpose of this paper is to further aid in determining whether if the seed-tree method can be "the means used to achieve the desired end."

The key feature of the seed-tree method is the establishment of a new stand. This has been the focus of most of the published work on this method to date. As Loftus and Fitzgerald pointed out, the key to successful regeneration is careful selection of seed trees, preparation of the seedbed, and control of competing vegetation. Each of these keys will be discussed separately.

CAREFUL SELECTION OF SEED TREES

Because the main purpose of the seed trees is to provide for natural regeneration of the area, knowledge of basic genetic principles is fundamental to successful selection of seed trees. Genetic considerations such as heritability, inbreeding, insect and disease resistance, dysgenic selection and others will guide in the selection of desirable phenotypes. In addition, essential understanding of seed and cone biology for each tree species selected as a seed tree will assist in the application of a successful seed-tree prescription.

Knowledge of cone flower location and development, pollination, seed maturation dates, normal seedfall period, seed size and weight plus method of dissemination, germination requirements, role of cone and seed insects and animals, cone crop frequency, and characteristics of trees bearing frequent cones are all necessary for selecting effective seed trees. General information about cone crop frequency can be found in descriptions of silvical characteristics, seed manuals, and individual research articles. Table 1 is an example of the cone crop frequency information for a few selected western species (Schopmeyer 1974).

Table 1. Cone crop frequency for selected conifers

	NUMBER OF YEARS FOR A CONE CROP CLASSED AS:		
Species	Medium-Heavy	Heavy	Bumper
Ponderosa	2*	3	8
	*1-7***	*1-8*	*3-6*
Sugar pine	2	4	-
	1-4	*2-7*	-
White fir	3	5	7
	1-6	*3-9*	*5-9*

*Average **Range

Data from: Schopmeyer 1974.

An example of available information on tree characteristics and percent of trees bearing cones for 16 years of observation is displayed in Table 2 (Fowells and Schubert 1956).

Table 2. Percent of trees bearing 1 or more cones for 16 years for selected species by Dunning Class

Tree Class	Age Class	Crown Shape	Crown Ratio	Ponderosa Pine	Sugar Pine	White Fir
			---------Percent---------			
1	Young	Pointed	>65	57	46	63
2	Young	Pointed	<65	14	1	4
3	Mature	Rounded	>65	100	100	100
4	Mature	Rounded	<65	100	83	88
5	Old Growth	Flat	Any	100	100	96

Data from: Fowells and Schubert 1956.

General information describing general tree characteristics for candidate seed trees based on years of observations is ordinarily available for local areas and individual species. To illustrate, key features that are easily recognized by tree markers have been developed for white fir (*Abies concolor*) and red fir (*Abies magnifica*) as indicated below (Laacke 1990).

—About the same proportions as a .30 caliber rifle round. No broken tops.

—A clean, straight bole, free of conks, dwarfmistletoe cankers or bulges.

—A healthy, symmetrical root system (i.e., no twins, triplets or closely spaced trees. There should be little growing around the base to about 15 feet).

—Spacing adequate to cover ground (about 1 to 1-1/2 tree heights).

Application of the seed-tree method also requires consideration of effects on biological diversity during the seed-tree selection process. Paying attention to such details as the number of seed-tree species, effects of edge species, genetic potential, past success of natural regeneration, length of time estimated for seed-tree survival, and effects of plant competition and plant interactions will influence future within stand diversity.

PREPARATION OF THE SEEDBED

The need for adequate seedbed preparation is common knowledge for successful natural regeneration prescription, including the seed-tree method. One of the basic considerations for the "new forestry" and current National Forest Standards and Guidelines is maintenance of organic matter and coarse woody debris for soil protection and maintaining long-term soil productivity. The goals of maintaining organic matter and woody debris could be in conflict with the need to provide an adequate seedbed for natural regeneration. Prescriptions requiring either extreme (complete removal or no removal or preparation are probably in error on the basis of the results of past research and decades of experience. A brief review of some of the published literature found an interesting retrospective study in Pakistan on several factors relating to successful natural regeneration of the fir forest, *Abies pindrow* (Khattak 1970). One of the factors evaluated was the depth of undecomposed litter (Table 3).

Table 3. Number and percent of stocked and unstocked plots by depth of humus (inches).

	Humus Depth Zero Inches	Up to 3 Inches	Over 3 Inches
Number *(%)* of *Stocked Plots*	92 *(22)*	614 *(48)*	35 *(19)*
Number *(%)* of Unstocked Plots	320 *(78)*	673 *(52)*	147 *(81)*

Data from: Khattak 1970.

On the basis of these data, Khattak (1970) concluded, a thin layer of humus seems to favour natural regeneration due probably to its effect as mulch in maintaining favourable moisture conditions in the top layer of the soil to which the roots of slow growing fir seedlings are confined for several years of early life. But when the humus layer is too thick, the seedlings may die during dry spells due to their inability to tap the mineral soil where water is more easily available to the plants than the humus layer.

The general conclusions for all of the factors evaluated in this study indicated (Khattak 1970),

> It would appear that in Kaghan Province at least, there is no overall problem of natural regeneration in fir forests. Though regeneration is scanty on southern exposures and on gentle slopes, over the greater part of the rest of the area adequate natural regeneration can probably be established by attention to obvious details such as proper density of overwood, shrub control and control of grazing intensity. Where the humus is over about 3 inches in depth, it must be disturbed by allowing grazing in the area before regeneration can be established.

Khattak's conclusion to use grazing as a method to disturb the humus can be viewed as similar to a scarification practice. Table 4 indicates the effect of brush rake scarification by aspect and slope position for Ponderosa pine (*Pinus ponderosa*) natural regeneration in Idaho in small group selection cuts (Foiles and Curtis, 1965).

Table 4. Seedlings per acre and percent stocked quadrats for scarified and unscarified treatments.

Position	*Seedbed Treatment*	*Seedlings Per Acre*	*% Quadrats Stocked*
Northeast	Scarified	9,046	75
	Unscarified	*24*	*2*
Southwest	Scarified	4,080	32
	Unscarified	*57*	*3*
Ridge	Scarified	1,408	26
	Unscarified	*25*	*2*
All	Scarified	4,696	40
	Unscarified	*42*	*3*

Data from: Foiles and Curtis 1965.

These results clearly indicate the value of at least scarifying the site to improve the chances for successful natural regeneration in small group selection clearcuts. So far the effects of the depth of undecomposed litter and simple seedbed scarification on natural regeneration success have been displayed. Other types of site preparation are used to prepare seedbeds for natural regeneration including hand-pile and burn, dozer-pile and burn, and spot burning. Table 5 displays the results of one study on natural regeneration comparing the seed-tree and shelterwood cutting methods, followed by three site preparation methods for western larch (*Larix occidentalis*) and other species in the Blue Mountains in the Kootenai National Forest and the Coram Experimental Forest in Western Montana (Roe 1955).

Table 5. First-year number of seedlings per acre for seed-tree and shelterwood cutting methods.

	SLASH DISPOSAL METHOD					
	Hand-pile and burn		Dozer-pile and burn		Spot Burn	
Cutting Method	Larch	Other	Larch	Other	Larch	Other
Blue Mountain, Kootenai National Forest						
Seed-Tree	259	247	4598	2725	1799	464
Shelterwood	1144	1468	9509	2204	10592	1941
Coram Experimental Forest, Western Montana						
Seed-Tree	*575*	*100*	*2211*	*421*	*1528*	*806*
Shelterwood	*3045*	*136*	*12205*	*882*	*7352*	*343*

Data from: Roe 1955.

Roe (1955) stated, "To single out any one cutting method as the best for all conditions is exceedingly difficult. It is apparent, for instance, that regardless of whether the seed source is in a shelterwood, scattered seed trees, or the uncut timber surrounding clearcuttings, a favorable seedbed is requisite to successful regeneration. When such a seedbed does not occur naturally or is not provided by the logging operation (and it rarely is, in sufficient quantity), other means must be employed to improve the seedbed, irrespective of the cutting method" (Roe 1955). The literature includes numerous publications on seedbed preparation for specific forest types and conditions. This review was not intended to be complete but to demonstrate some of the basic effects of seedbed preparation and natural regeneration. The most effective seedbed for natural regeneration for specific areas should be well known and established on the basis of results of research studies and local experience.

CONTROL OF COMPETING VEGETATION

The effects of competing vegetation on the reestablishment of conifers are well known and documented. The adverse effects are most immediate and frequently limit initial seedling survival and are further exacerbated by reducing growth of the surviving seedlings. The effects can be especially acute or chronic or both in the dry or seasonally dry climates where available soil moisture is limiting. The effect of competing vegetation on young seedlings for available light is also important, especially where soil moisture is not limiting. Competition for light generally affects subsequent growth rather than initial survival. The effects of reduced nutrient availability from direct competition with seedlings are generally not apparent, especially for seedling survival. The direct effects of competing vegetation limiting either moisture or light are generally more limiting. In the long-run, early competing vegetation, especially nitrogen fixers, can aid in the subsequent growth and development of the re-established stand.

One example from the early literature illustrates the effects of grass competition on the establishment and growth of Ponderosa pine in Arizona. From the observations more than 100 seedling plots from 1919 to 1930, the findings summarized for natural Ponderosa pine regeneration include (Pearson 1942):

> —Under tall grass or weeds, germination was generally good but survival and growth poor.
>
> —On moderately or closely grazed areas, survival was better unless browsing was too severe, but growth was slow.
>
> —On denuded spots, such as log landings and roads, germination was sometimes deficient because of high evaporation or because the seeds were swept away by water; but where seedlings occurred they grew more rapidly than where obliged to compete with herbaceous vegetation.

These effects of grass competition are displayed in a slightly different way as a function of increasing or decreasing ground cover density in more modern experiments. Different levels of grass and forb cover in two Montana sites affect seedling survival where grass competition is a major cause of seedling mortality (Table 6) (Peterson 1982).

Table 6. Effect of different levels of grass competition on seedling survival in Montana.

COW CREEK SITE		RIDGE ROAD SITE	
Grass and Forb Cover %	P. Pine Survival %	Grass and Forb Cover %	P. Pine Survival %
14	86	54	89
52	76	72	87
26	72	22	85
116	35	132	68

Data from: Peterson 1982.

Adding other low vegetation to the grass components further complicates the effects of competing vegetation. The results of a 1948 site preparation study in the Blacks Mountain Experimental Forest in Northeastern California on Ponderosa pine and Jeffrey pine (*Pinus jeffreii*) stocking for the first and fourth year in the presence of different levels of competition are displayed in Table 7 (Roy 1983). The ratings for ground cover density were based on the amount of ground cover present on each milacre quadrat in the transects established for the experiment. If the quadrat had one-tenth or less of its surface covered, it was classified as bare; if more than one-tenth but not greater than four-tenths, light; if more than four-tenths but not over seven-tenths, medium; and if more than seven-tenths, heavy. The ground cover consisted (in order of appearance) of bunchgrasses Idaho fescue (*Festuca idahoensis*), squirreltail (*Sitanion hystrix*), and western needlegrass (*Stipa occidentalis*); Squaw carpet (*Ceanothus prostratus*); Wooly mules-ears (*Wyethia mollis*); and other miscellaneous grasses and sedges.

Table 7. Effects of different levels of vegetation competition on survival and stocking in NE Calif.

	SURVIVAL		*STOCKED QUADRATS*			
			Percent Stocked		*Number*	
Ground Cover Density	First Year	Fourth Year	First Year	Fourth Year	First Year	Fourth Year
None	42	33	90	70	164	115
Light	26	11	66	33	119	101
Medium	19	4	37	14	38	36
Heavy	16	4	17	8	70	63

Data from: Roy 1982.

Roy (1983) concluded that the effect of ground cover upon pine seedlings was evident as early as the first growing season. The relatively low survival on areas with only light cover shows that even a small amount of competition is unfavorable to seedling establishment. Stocking based on stocked quadrat basis of one or more seedlings per milacre quadrat further demonstrates the effect of increasing the density of ground cover.

Another long-term study in the Mt. Shasta, California brush, fields documented the effects for 18 years on the growth and development of Ponderosa pine in the presence of different levels of woody plant competition, primarily greenleaf manzanita (*Arctostaphylos patula*), snowbrush (*Ceanothus velutinus*), and Sierra plum (*Prunus subcordata*) (McDonald and Oliver 1984). These data (Table 8) clearly indicate the effects on long-term growth and development of Ponderosa pine by reducing diameter growth by up to 75 percent and height growth by up to 65 percent (McDonald and Oliver 1984).

Table 8. Effects of woody brush competition on survival, height, and diameter of Ponderosa pine.

Effects after 18 Years of Growth and Development	*Percent Shrub Cover*			
	0	21	35	44
Survival (%)	98	98	98	80
Height (Feet)	16.5	12.0	9.3	5.8
Diameter (Inches)	5.1	3.9	2.9	1.3

Data from: McDonald and Oliver 1984.

Finally, the competitive effects of the seed trees (remaining overstory trees) and the edge effects of the uncut timber on the growth and development of the new seedlings have been demonstrated in a research investigation in the Challenge Experimental Forest in the northern Sierra Nevada-mixed conifer forest of California (McDonald 1976). The effects of overstory vegetation resulting from five different cutting methods on seedling density and height nine years after cutting are displayed in Tables 9 and 10. The cutting methods used included clearcutting (no overstory present), seed-tree (minor overstory density present), shelterwood seed step (moderate overstory density), group selection (equivalent of moderate overstory density from edge trees on the small groups), and single tree selection (heaviest overstory density present. The species present included PP—Ponderosa pine, SP—sugar pine (*Pinus lambertiana*), DF—Douglas-fir (*Pseudotsuga menziesii*), WF—white fir, and IC—incense cedar (*Libocedrus decurrens*) (McDonald 1976).

Table 9. Number of seedlings per acre by cutting method and species 9 years after harvest in Calif.

Cutting Method	TREE SPECIES PP	SP	DF	WF	IC	ALL
Single-tree	860	111	308	400	44	1723
Group Selection	1500	185	134	565	16	2400
Shelterwood	3620	240	80	192	470	4602
Seed-Tree	2100	75	174	66	67	2482
Clearcut	1115	51	157	166	-	1489

Data from: McDonald 1976.

Table 10. Height of natural regeneration 9 years after harvest by cutting method & species in Calif

Cutting Method	TREE SPECIES PP	SP	DF	WF	IC
Single-tree	0.5	1.0	0.7	1.4	0.9
Group Selection	1.0	1.5	1.5	1.5	0.9
Shelterwood	2.7	2.6	2.1	2.9	1.9
Seed-Tree	3.7	3.4	3.1	3.7	2.7
Clearcut	6.2	5.5	4.2	4.0	-

Data from: McDonald 1976.

The total number of trees per acre was greatest in the shelterwood cutting method followed by the seed-tree and group selection methods and last by the single-tree selection and clearcutting methods. All species were established in each cutting method except for incense-cedar in the clearcutting method. Seedling distribution and stocking followed a similar pattern as the number of trees per acre. Establishing well-stocked stands of multiple-species natural regeneration was achieved for all cutting methods, with the seed-tree method providing densities similar to those from a group selection cutting method but less than those from the shelterwood seed-step cutting method (McDonald 1976).

The effects on height provided some interesting trends after the first nine years of growth. For both the intolerant and tolerant species, height growth was greatest in the open conditions created by the clearcutting method followed in order by the seed-tree, shelterwood, group selection, and least for the single tree selection method. The descending order of height growth by cutting method was true for all species (McDonald 1976)). These data indicate the cumulative growth effects of overstory shade, edge shade, and competition for moisture and nutrients. Removal of the overstory trees in the seed-tree and shelterwood methods will probably reduce the early height growth effects in typical rotations established for even-age stands. Retaining the overstory trees will probably continue the expression of reduced growth rates.

The seed-tree method has been used to successfully regenerate even-age stands for many years. This brief review of selected literature has described some of the key features for a successful seed-tree system, including careful selection of the seed trees, adequate site preparation for natural regeneration, and control of competing vegetation. It is not clear if the seed-tree method will meet the larger postulation described in proposals for "new forestry" and "new perspectives." That applicability will depend on the development of clear stand-management objectives considering features such as composition, structure, and function of the resultant stand over time.

LITERATURE CITED

Burns, Russell M., tech. comp. 1983. Silvicultural Systems for the Major Forest Types of the United States. Agriculture Handbook 445. U.S. Department of Agriculture, Forest Service. Washington, D.C. 191 p.

Burns, Russell M., tech. comp. 1989. The Scientific Basis for Silvicultural and Management Decisions in the National Forest System. General Technical Report WO-55. U.S. Department of Agriculture, Forest Service. Washington, D.C. 189 p.

Foiles, Marvin W. and J. D. Curtis. 1965. Natural Regeneration of Ponderosa pine on Scarified Group Cuttings in Central Idaho. Journal of Forestry, 63:530-535.

Ford-Robertson, F.C., ed. 1971. Terminology of Forest Science, Technology, Practice and Products. Society of American Foresters. Washington, D.C. 349 p.

Fowells, H.A.; Schuber, G.H. 1956. Seed Crops of Forest Trees in the Pine Region of California. Technical Bulletin No. 1150. United States Department of Agriculture. Berkeley, CA. 47 p.

Khattak, G.M. 1970. The Occurrence of Natural Regeneration in the Fir *Abies pindrow*) Forests of Kaghan. The Pakistan Journal of Forestry. 20(2):157-162.

Laacke, R. James. 1990. Silvicultural Silvics. Unpublished paper presented to the Region 5, U.S. Forest Service Silviculture Refresher Course. Meadow Valley, CA. 15 p.

McDonald, Philip M. 1976. Forest Regeneration and Seedling Growth from Five Major Cutting Methods in North-central California. United States Department of Agriculture, Forest Service Research Paper PSW-115. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. 10 p.

McDonald, Philip M.; and Oliver, William W. 1984. Woody Shrubs Retard Growth of Ponderosa Pine Seedlings and Saplings. In: Proceedings 5th Annual Forest Vegetation Management Conference, November 2-3, 1983. Redding, CA. p. 65-89.

Pearson, G.A. 1942. Herbaceous Vegetation a Factor in Natural Regeneration of Ponderosa Pine in the Southwest. Ecological Monographs. 12:315-338.

Peterson, T.D. 1982. Guidelines for using Velpar for Site Preparation in Montana Based on Second Year Research Trials. Research Note RM 82-9. Champion International Corp., Milltown, MT. 8 p.

Prouty, Mike. 1987. Silviculture Research in Forests of the Inland West. Forestry Research West. U.S. Department of Agriculture. Fort Collins, CO. 5 p.

Roe, Arthur L. 1955. Cutting Practices in Montana Larch-Douglas Fir. Northwest Science. 29(1):23-34.

Roy, Douglass F. 1983. Natural Regeneration. In: Robson, Thomas F. and Richard B. Standiford, eds., Management of the Eastside Pine Type in Northeastern California, Proceedings of a Symposium. Northern California Society of American Foresters. Arcata, CA. p. 87-102.

Schopmeyer, C.S., tech. comp. 1974. Seeds of the Woody Plants in the United States. Agriculture Handbook No. 450. U.S. Department of Agriculture, Forest Service. Washington, D.C. 883 p.

Author

Philip S. Aune
Project Manager
Pacific Southwest Forest Research Station
2400 Washington Avenue
Redding, California 96001

SHELTERWOOD METHOD

Kenneth E. Denton
Pacific Southwest Region
San Francisco, CA

The shelterwood method represents a wide range of opportunities. "Shelterwood cutting", from SAF, is: "...regeneration cutting in a more or less regular and mature crop, designed to establish a new crop under the protection of the old." Department of Agriculture Handbook #445, says: "In the shelterwood system the mature stand is removed in a series of cuts. Regeneration of the new stand occurs under the cover of a partial forest canopy, or shelterwood. A final harvest cut removes the shelterwood and permits the new stand to develop in the open as an even-age stand." And Daniel, Helms, and Baker report: "The capability of manipulating stand density to provide the environment required for the regeneration of one or several species on a variety of sites makes the shelterwood method the most flexible way of producing even-aged stands."

The theme here is cover and protection. Site amelioration if you will. Shelterwoods may or may not get intensive site preparation, and may or may not be planted. The overstory may contain all or only some of the ultimate desired species mix. They may mean a mix of natural and planted regeneration. And basal areas may be very low, to well over 100 square feet.

This system may also represent our 'lowest risk' option, as Sharon Freidman suggested we find, since the decision on the final step can be tailored to the needs at a future time. But of course there are pros and cons, which is part of what this presentation is about. I will stop here, as our first speaker will describe the system in more detail.

Our first speaker is **Gary Petersen**, District Silviculturist on the Sisters RD, Deschutes NF in R-6.

Our second speaker is **Vicky Erickson**, Zone Geneticist for the Umatilla, Malhuer, and Walawa-Whitman NFs in R-6.

Our third speaker is **Don Beck**, research silviculturist at the Southeastern Station in Ashville, North Carolina.

Author

Kenneth E. Denton
Regional Silviculturist
Pacific Southwest Region
630 Sansome Street
San Francisco, California 94111

THE SHELTERWOOD METHOD—WHAT, WHEN, AND WHERE

Gary Petersen
Deschutes National Forest
Bend, OR

INTRODUCTION

The shelterwood method can be used to meet a wide variety of land management objectives. Several good textbook descriptions of the shelterwood method are in print and available for use, since the technique has been used as a regeneration and harvest method for many years. This paper will address primarily vegetative aspects, although opportunities exist to utilize shelterwoods to meet visual, range, watershed and wildlife resource objectives as well.

Definitions include Smith (1962), who defines two objectives for a shelterwood as "space is made available for reproduction by cutting trees that are no longer capable of much further increase in value; Those that are left may be chosen not only as a source of seed or protection for the new stand but also for their capacity to increase in value at an attractive rate."

Daniels (and others, 1970), defines the shelterwood method as a "reproductive method" with the essential purpose "to accomplish the regeneration of the site under the shade and protection of the final crop trees."

DESCRIPTION OF THE METHOD

Regardless of which scholastic definition is chosen, the shelterwood method follows a defined sequence. Selected trees are gradually removed in a shelterwood method through a series of partial cuttings that extend over a portion of the rotation. The exercise of the shelterwood method may involve up to three cuttings:

1) preparatory cuttings, which prepare the overstory and forest floor for reproduction.
2) seed cuttings, which provide for establishing reproduction.
3) removal cuttings, which free the established seedlings.

Preparatory cut—This is a light partial cut to correct unfavorable stand conditions such as poor crown development or wind firmness, to improve seedbed conditions, or to stimulate seed production. Several preparatory cuts may be made on the same stand.

Seed cut—Seed cuttings open the canopy sufficiently to allow for regeneration of the desired species. When a stand has achieved acceptable established advanced growth, the function of the seed cut has been performed.

Removal cuts or final cuts—One or more removal cuts occur after the seed cut has provided adequate regeneration which has grown sufficiently in height. The number of removal cuts is dependant upon how sensitive the seedling stand is to sudden exposure, and must be done in a manner that ensures the survival of the established regeneration.

Shelterwood method as applied in the Pacific Northwest is typically a two-step method of regeneration. Step one involves the first harvest entry in which designated trees are left to provide seed and improve site conditions for establishment of planted or natural regeneration. Step two involves removal of the shelter trees after establishment of the understory stand. Normally step two occurs in one entry, but a removal cut in several stages can be used.

The pattern of shelterwood cutting may be uniform, in groups, or in strips. Uniform cutting refers to evenly spaced shelter trees. Group cutting removes small patches of trees and strip shelterwood involves narrow opening which receive shelter from the adjacent uncut portion of the stand.

SHELTERWOOD CONSIDERATIONS

Method Advantages

1. Reproduction is more extensive and certain on some sites.
2. A guaranteed local seed source is provided.
3. Both even-aged or uneven-aged stand structure can be developed.
4. Site is protected from environmental extremes.
5. Provides for retaining best trees on site for seed source—higher quality regeneration.
6. Allows for stand species manipulation or deliberate species change.
7. Flexibility in overstory tree removal.
8. Higher aesthetic rating than clearcut alternative.
9. Reproduction of tolerant species easily obtained.
10. Planting costs reduced or eliminated.
11. Captured growth on shelter trees.

Method Disadvantages

1. Greater skill levels required at all levels—prescribing, lay-out, logging, and administration.
2. Not viable for all species or areas (wind firmness and coastal areas).
3. Not viable in some stand conditions; root disease, brush, heavy fuel loading, mistletoe in shelter trees.
4. Part of reproduction is destroyed in removal cutting.

5. Conditions may be unfavorable for establishment and growth of intolerant species.

6. Need to remove shelter trees in a timely manner if objective is to minimize seedling damage, or maintain maximum growth rate.

7. Increased costs in logging and sales administration.

HIGHLIGHTED SHELTERWOOD ISSUE EXAMPLES

Forest managers are faced with making decisions on when and if to conduct a final removal harvest on shelterwood units. These units usually have a young, manageable understory which is being suppressed by varying amounts of shelterwood trees left after regeneration cuts. Potential conflicts exist between the desire to remove these trees to prevent suppression of the understory, and the desire to retain these trees to create a more visual pleasing landscape or grow a high value product or meet perceived wildlife tree needs. Managing two age class stands is seen as a technique to minimize visual impacts while still providing acceptable levels of stand growth and yield.

A second consideration is that retention of large-diameter trees in a shelterwood regeneration cut stand is often thought to provide acceptable levels of economic return because of increased growth rates of the larger trees. This view holds that the retained trees produce larger-size material which equates to higher value when compared to the clearcut alternative.

As a matter of highlighting some of the difficulties in reaching a decision, this paper attempts to compare and evaluate two stand treatment alternatives and identify some of the costs and benefits associated with selection of either alternative.

The Prognosis Model (Stage 1973) was selected for use in developing yields for selected stands. Five stands representing medium and highly productive sites on the Sisters Ranger District were selected to evaluate under both alternatives. All output data were grouped and averaged to account for variation in site productivity.

The Prognosis model uses actual stand inventory data run against formatted instructions, called "Keywords", which indicate silvicultural options selected and control the program execution and output.

A word of caution in regard to models: models are only a representation of actuality. Consequently, output figures are only approximate and are not absolute figures in any sense. However, they are accurate relative to each other and are a good basis for doing comparisons between alternatives.

STRATEGIES COMPARED

Strategy One—Shelterwood with planted understory.

Shelterwood trees removed by harvest 10 years after stand initiation and resulting stand left to grow for an additional 110 years. At the end of that period, resulting stand production is available for harvest.

Strategy Two—Shelterwood with planted understory.

Shelterwood trees are retained for the entire rotation period of 120 years. At the end of 120 years, resulting stand production (consisting of both large residual trees and new second-growth) is available for harvest.

Production costs do not vary greatly between the alternatives examined.

RESULTS

Total volume production was appreciably greater on the units where the large trees were removed 10 years after stand initiation, when compared to the units where the large trees were retained for the length of the rotation. Production on the large-tree-retained units was only 73.3 percent of that of the units with the large trees removed. The prognosis model estimates total volume (in board feet) on the large-tree-removed units as averaging 28,724 board feet per acre as compared to 21,060 board feet per acre on the large-tree-retained units.

This loss of production is thought to be due primarily to a large residual tree suppression effect on the developing stand. In recent field surveys conducted on the Sisters District, sites occupied with an average of seven large trees per acre reduced height growth of planted seedlings to 0.76 of that of seedlings growing on similar sites not supporting large residual trees. While the larger trees do exhibit increased diameter growth rates, this increased growth rate does not offset the loss in height growth the smaller trees are experiencing. Based upon a sample of 160 increment borings of trees growing on shelterwood units on the District, large residual trees grew at a rate of 1.78 inches diameter in the first decade following removal of surrounding trees. This compares to a growth rate of 0.84 inches diameter in the decade immediately preceding removal of the surrounding trees.

When looking at model output at the end of the projection period, not surprisingly, average stem size was also reduced on the large-tree-retained units. Even though these units still supported seven large overstory residuals per acre, the average-size tree was only 20.2 inches diameter on these units. This compares to 21.9 inches diameter on the large-tree-removed units at the end of the projection period.

At the end of the projection period, the large-tree-retained unit contained 39.2 percent of its volume in large-sized residual trees, while the smaller second-growth component contained 60.8 percent of the board foot volume.

ECONOMIC EFFICIENCY OF ALTERNATIVE

The economic efficiency of any selected silvicultural alternative depends upon a combination of factors that include tree grade, tree size, total unit production, point in time of benefit or monetary availability, and future product value. Each of these factors will be discussed separately.

1. Tree Grade and Size

Tree grade influences economic returns in that higher graded material commands a higher selling value in the marketplace. Grade 1 material has more than double the value of Grade

5 material. However, this relationship does not hold true in regard to size. First, increasing larger sized material does not necessarily equate with proportionately increased value. Utilizing the selling value table and stand valuation summary (FSH 2409.22), a simple comparison can be made.

For example: A 9-inch diameter Grade 5 log has a basic value of $502/M, whereas a 45-inch diameter Grade 5 log has a basic value of $583/M. In this example, a five-fold increase in log diameter has only increased the value of that grade material 16 percent.

For all economic evaluations of volume production of silvicultural alternatives in this paper, the following log grade percentages were used:

Grade 1, 2.2 percent; Grade 2, 5.9 percent; Grade 3, 13.2 percent; Grade 5, 78.7 percent.

These percentages were derived from actual cruise data on a similar type sale on the District.

2. Total Unit Production

Total productivity is a function of both the biological capability of a site and the silvicultural manipulations to which it is subjected. While biological capability is primarily fixed, silvicultural manipulations can influence stand production dramatically. In addition, the periods of availability of production are also determined by when activities take place and the type of activities that take place.

In this case, the choice to retain large residual trees throughout the rotation dramatically influences the total production of the units.

As per model estimates, total production on the large-tree-removed sites averaged 28,724 board feet per acre as compared to 21,060 board feet per acre on the large-tree-retained units. These figures are for the entire 120-year rotation period.

3. Period of Return of Benefits

The time period benefits and/or money becomes available can influence economic value of a silvicultural alternative. Money returned early in a rotation period has a much higher present value (PV) than money returned late in a rotation period.

In this comparison of two silvicultural alternatives, certainly working against the large-tree-retention alternative is the long waiting period of 120 years before any economic return is realized for the large trees. The other alternative is able to generate economic return at year 10 removal cut, thereby dramatically increasing present value.

4. Future Product Value

Questions have been raised about the value of products in the future as those products become increasingly scarce. For purposes of this comparison, a 1 percent per year real price trend for stumpage was used. This figure was applied for the next 40 years, then a 0 percent price trend was assumed for the remaining 70 years of the harvest scheduling planning horizon. This implies that nominal stumpage prices will increase during the next 40 years at a rate of 1 percent greater than the rate of inflation and equal to the rate of inflation thereafter (Deschutes National Forest Draft Plan, p. 181).

December 1989 selling values and stand valuation figures were used in the calculations of current economic returns.

PRESENT VALUE OF ALTERNATIVES

1. Retain large residual trees, 7 per acre

   a. Residual trees

      (1) 120-year production = 8,253 bd.ft./ac.
      (includes original volume plus growth for 120 years.)

      (2) Value adjustment for grade, size = $493.61
      (30.8 inch diameter grows to 42.7 inch diameter tree)

      8,253 bd.ft. x $493.61 = $4,073.76

      (3) Real price trend increase
      1 percent for 40 yrs. (1.4889)

      $4,073.76 x 1.4889 = $6,065.43

   b. Second Growth

      (1) 120-year production = 12,807 bd.ft./ac.

      (2) Value adjustment for grade, size = $396.45
      (19.2 inch diameter tree)

      12,807 bd.ft. x $396.45 = $5,077.34

      (3) Real price trend increase
      1 percent for 40 years (1.4889)

      $5,077.34 x 1.4889 = $7,559.65

c. Present Value (PV)

(1) Residual tree

Value at 120 years = $6,065.43
Present value of future dollars = 0.0090
(120 years factor)

$6,065.43 x 0.0090 = $54.59

(2) Second growth
Value at 120 years = $7,559.65
Present value of future dollars = 0.0090

$7,559.65 x 0.0090 = $68.04

Present value of residual + present value of second growth
$54.59 + $68.04 = $122.63

2. Remove large residual trees, 7 per acre, at 10 years

a. Residual Trees

(1) 10-year production = 5,998 bd.ft./ac.
(Includes original volume plus growth for 10 years.)

(2) Value adjustment for grade, size = $469.27
(30.8 inch diameter)

5,998 bd.ft. x $469.27 = $2,814.68

(3) No real price trend increase because December 1989 values (current) were used.

b. Second Growth

(1) 120-year production = 22,726 bd.ft./ac.

(2) Value adjustment for grade, size = $410.32
(21.9 inch diameter tree)

22,726 bd.ft. x $410.32 = $9,324.93

(3) Real price trend increase = 1.4889
(1 percent for 40 years)

$ 9324.93 x 1.4889 = $13,883.89

c. Present value (PV)

(1) Residual trees
Value at 10 years (today) = $2,814.68

(2) Second growth

Value at 120-years = $13,883.89
Present value of future dollars = 0.0090

$13,883.89 x 0.0090 = $124.96

Present value of residual + present value of second growth

$2,814.68 + $124.96 = $ 2,939.64

SHELTERWOOD ISSUE EXAMPLES SUMMARY

The end result of comparing the two alternatives suggests that leaving large residual trees on shelterwood units through the entire growing period is not a desirable alternative from the standpoint of timber production and timber revenues. Looking at total per acre production of both alternatives suggests that removing the larger residual trees results in higher levels of production (28,724 bd.ft./ac. vs. 21,060 bd.ft./ac.), and larger diameter second-growth due to a reduction in suppression effect upon the understory. Even though the residual trees exhibit increased growth rates, the increased rates do not compensate for decreased growth in the understory.

Second, the end result of the Present Value study suggests that leaving large residual trees on the units through the entire growing period is not desirable economically. The Present Value of the retain residual alternative is $122.63. This compares to a Present Value of $2,939.64 for the removal alternative. Removing the trees at this time returns almost 24 times the economic value that the other alternative provides. This can be viewed as the opportunity cost of leaving the large diameter trees, and needs to be considered carefully when considering leaving large diameter trees for benefits resulting from enhanced visual quality, wildlife benefits, or other resource objectives.

CONCLUSIONS

The shelterwood method has been available to forest manager for many years. The sequential cutting of Forest Stands with a preparatory cut, a seed cut, and finally a removal cut has numerous advantages and disadvantages which must be considered by the manager. Clearly defined objectives, complete prescriptions which define all aspects of the operation, timely and skillful application, and commitment and coordination of all affected resource groups will insure success in implementing shelterwoods. Two examples of growth impacts and economic considerations are evaluated as issues managers must resolve in utilizing the shelterwood method.

LITERATURE CITED

Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. Principles of silviculture. 2 ed. New York: McGraw - Hill. 500p.

Smith, David M. 1962. The Practice of silviculture. 7th Ed. New York: John Wiley and Sons, Inc. 578p.

Stage, Albert R. 1973. Prognosis model for stand development. USDA, Forest Service Res. Pap. INT-137. Intermountain For. and Range Exp. Station, Ogden, UT. 32p.

USDA Forest Service. 1989. Timber appraisal handbook. USDA Forest Service FSH 2409.22, R-6 Appendix 414.22A. Region Six. Portland, OR.

USDA Forest Service. 1987. Working draft-forest plan. USDA Forest Service. Deschutes National Forest. Region Six. Bend, OR. 349p.

Author

Gary Petersen
District Silviculturist
Sisters Ranger District
Deschutes National Forest
P.O. Box 249
Sisters, Oregon 97759

SHELTERWOOD REGENERATION METHOD:
A Genetic Perspective

Vicky J. Erickson
Umatilla National Forest
Pendleton, OR

INTRODUCTION

Natural regeneration methods play a major role in the management of National Forest System lands. Despite the predominance of these methods, limited information is available regarding their effect on the genetic structure and composition of regenerated stands. This paper examines the shelterwood method of regeneration and the potential impacts of its use on the genetic resources of commercially important forest tree species, particularly those occurring in the Pacific Northwest.

SHELTERWOOD METHOD

The shelterwood method is an important silvicultural tool for managing many forest tree species. The method mimics large-scale disturbances where small numbers of residual trees (generally 10-15/ac) provide seed and shelter the natural regeneration from extreme heat and cold. Shelterwood methods provide extreme flexibility, as tree densities can be varied to suit stand conditions and the ecological requirements of favored species (Daniel et al. 1979). Shelterwoods are especially useful and appropriate for regenerating sites where selection pressures are expected to be strong, such as hot, dry sites or high elevation, frost-prone areas.

GENETIC CONSIDERATIONS

Forest tree species have been found to be among the most variable of plant taxa, owing largely to long life spans, large geographic ranges, high fecundity rates, high outcrossing rates, and wind-pollination (Hamrick et al. 1981, Hamrick and Godt 1989). There are great differences among tree species, however, in terms of the total amount of genetic variation they harbor, as well as the manner in which this variation is partitioned within and among populations. The exact genetic consequences of forest management practices are thus very difficult to generalize, as they likely vary with species and with populations within species.

All natural regeneration methods, including shelterwood methods, have the inherent potential for altering the genetic composition of natural stands, although not necessarily in a detrimental or irreversible manner. In shelterwood management, there are several stages where the genetic characteristics of a stand may become differentiated from that of the original population. In transitioning from an uncut stand to a shelterwood overstory, for example, large reductions in the parent-tree population could lead to a genetic bottleneck, whereby stand regeneration occurs with a small or restricted set of genotypes. In the absence of other evolutionary forces (e.g., migration, natural selection, mutation), the theoretical consequences of this type of event include the loss of rare alleles or genes, random shifts in allele frequencies, and reduced variability compared with pre-harvest conditions (Hartl 1980). These effects could be compounded if the source-tree population itself was regenerated by a few number of parents, such as following a wildfire or other large-scale disturbance.

The mating system—how gametes are combined to form zygotes—plays a central role in population genetics (Levin and Kerster 1974, Hamrick and Schnabel 1985), and can greatly influence the genetic quality and variability of regenerated stands of forest trees (Adams 1983; Adams and Birkes 1988). For example, shelterwoods with small numbers of widely spaced leave trees could have an increased potential for inbreeding due to selfing. When leave trees are left in clumps or strips in stands having genetic spatial structure (i.e, groups or clusters of families), then matings between near-neighbor relatives may also contribute to inbreeding. Conditions which reduce the size of the breeding population, such as limited pollen migration from surrounding stands, asynchronous flowering periods among leave tree parents, or large differences in seed or pollen production could further enhance the opportunity for inbreeding.

The deleterious effects of increased levels of inbreeding and losses in genetic variability are well documented for most forest tree species. Inbreeding, particularly selfing, leads to reduced seed set, poor germination and survival, and diminished growth performance (Franklin 1970, Sorensen 1971, Griffin and Lindgren 1985, Park and Fowler 1984, Sorensen and Miles 1974,1982). In long-lived tree species, genetic diversity is important for long-term productivity, as well as for adaptability to changing climates and environmental stresses (Adams 1981, Campbell 1979). The maintenance of genetic diversity may be especially important in shelterwood environments, where conditions are often stressful and less than optimal for seedling regeneration and growth.

Selection intensities in shelterwoods are low to moderate (approximately 1 tree out of every 4, Daniel et al. 1979), as are heritabilities and thus genetic gain estimates for most traits of economic importance. Moreover, selection opportunities for high quality leave trees may often be limited due to past management activities. For instance, if stands chosen for shelterwood regeneration have been repeatedly entered, particularly by selective harvests, it's likely that the larger and better quality trees have already been removed, leaving available for seed production the less desirable phenotypes. Under these types of stand conditions, forest managers should be especially concerned about losses in productivity, as well as inbreeding and drift effects.

RESEARCH RESULTS AND NEEDS

Despite an increased awareness of the relationship between proper management of forest gene pools and long term productivity (Adams 1981, Brown 1978, Brown and Moran 1981, Frankel and Bennet 1970, Millar and Westfall 1990), limited and often conflicting empirical data exist on this subject. In large part, this deficiency is due to the lack of adequate tools, which have only recently become available through the application of isozyme technology to forest tree species (see Adams 1983 for review). Innovations in this area, such as the newly established NFS electrophoresis laboratory (NFGEL) in Placerville, CA, finally give geneticists and land managers the opportunity to obtain baseline data and directly assess and monitor the impacts of management practices on genetic resources.

The most important contribution to our knowledge of the genetic effects of the shelterwood method comes from an isozyme study of old-growth Douglas-fir (*Pseudotsuga menziesii*) stands in southwest Oregon (Neale 1985, Neale and Adams 1985). The study investigated the influence of the shelterwood method by comparing outcrossing rates and levels of genic diversity in shelterwood leave trees with those of trees in uncut stands. Despite an 85 percent reduction in the number of parent trees in the two shelterwoods examined (6 and 14 TPA), no significant differences in allele frequencies or genic diversity measures were observed among four life cycle stages: (1) uncut stands adjacent to shelterwoods, (2) shelterwood leave trees, (3) seed crops, and (4) 3-5 year old natural regeneration.

Neale also found little evidence of inbreeding in the seed crops or seedling regeneration of the shelterwood stands. Interestingly, there was evidence for a higher proportion of related matings other than selfing in the uncut stands relative to the shelterwood leave trees. This finding was attributed to the possible presence of family substructuring in the uncut stands, but absent (i.e., eliminated by harvesting) in the shelterwood stands. Average seed and pollen dispersal distances within the shelterwoods were 207' and 230', respectively. A minimum of 22 percent of the seed and 24 percent of the pollen, however, were estimated to have come from outside the 6 acre shelterwood plots.

The major conclusion from this study was that shelterwood harvesting appeared to have little impact on the mating system or the genetic structure of natural regeneration. The results were attributed to several factors, including: (1) large within population variability (2) moderate seed and pollen dispersal distances and effective population size, and (3) high outcrossing (mean = 95%) and fecundity, and (4) close adaptation to environmental parameters.

The genetic consequences of harvesting a specific stand, geographic area, or species are likely to vary greatly depending on a number of factors, including stand history and life history traits, as well as the ecological and genetic characteristics of the species and populations involved. For example, the loss of genetic variation due to genetic drift and inbreeding is expected to be proceed more rapidly in small populations, especially those with reduced variability. Thus, shelterwoods with substantially reduced densities, or species or populations with a small proportion of within-stand variability, may not be as amenable to shelterwood harvesting and regeneration (Neale 1985).

Although not generally of economic importance, endemic or regionally distributed species are also likely to be more susceptible to drift and inbreeding effects due to human activities and management practices (Zobel and Talbert 1984). The same may be true for populations of tree species that have become differentiated due to historical or geologic factors such as isolation by glaciation or fire, or adaptation to particular climatic or ecologic conditions. Whatever the reason, populations or stands that are unique in some way, or show differentiation from the mainstream, should probably be managed as "light-handedly" as possible. Likewise for isolated stands or marginal populations, which are typically characterized as having small population sizes, reduced variability, and limited opportunities for pollen migration (Hamrick et al. 1979, 1981, Hamrick and Godt 1989). Species or stands stressed by natural or human-caused events such as past dysgenic selection practices, insect/disease outbreaks, or climatic extremes, may also be at risk. Research efforts need to be focused on these and other types of stand conditions so that we can more fully understand population genetic structure and the consequences of various management activities, including shelterwood (and other) natural regeneration systems.

MANAGING FOR DIVERSITY

In the absence of empirical data, we should be conservative and light-handed in our management of forest trees. Thus, from both a genetics and silvicultural standpoint, shelterwood management may often be the method of choice, particularly if supplemental plantings are used to enhance the diversity and genetic quality of regenerated stands. Applying sound genetic principles to stand management can also conserve genetic diversity and reduce the impact of human activities.

Stands and geographic areas differ greatly in their inherent ability to produce viable seed crops. Obviously, silviculturists and prescription writers shouldn't rely on natural regeneration on sites with poor seed crop history. In shelterwoods, selection intensities tend to be low because a certain number of trees always have to be left to provide seed and shelter. In order to enhance diversity, however, and ensure that a large number of individuals are involved in matings, as many seed trees per acre as possible should be retained, while still maintaining environments favorable for seedling establishment and growth. To the extent possible, the phenotypically "worst" trees should be selected for removal, and the higher quality trees (with evidence of past seed crops) left for seed production. One caveat is that selection for flowering, rather than growth or form, or insect/disease resistance, should be avoided due to possible negative correlations between growth and flowering characteristics (Linhart and Mitton 1985). It goes without saying that the success of leave tree selection (and shelterwood management) will be highly dependent on the quality and interest level of the marking crew.

From studies of both natural and seed orchard populations, we know that (1) forest trees differ markedly in their capacity to contribute their genes through seed and pollen (Eriksson et al. 1973; Jonsson et al. 1976; Griffin 1982, 1984; Yazdani et al. 1989), and (2) mating success is highly dependent on pollen output, as well as the degree of floral synchrony among potential parents (Shoen and Stewart 1986, Erickson and Adams 1989, 1990). As a consequence, silviculturists shouldn't rule out the use of intensive practices such as stem girdling, nitrogen fertilization, or insect control in seed crops, all of which enhance seed and pollen production, and improve the balance of parental contributions to the gene pool. Site preparation techniques that promote abundant seedling regeneration and establishment (e.g., burning, scarifying) are also desirable from a genetic standpoint, since they provide enhanced opportunities for natural selection to operate.

Silviculturists can exert a more direct influence on regeneration methods by performing supplemental plantings with growing stock selected for specific traits or for the diversity they introduce (species, as well as within-species diversity). Throughout the rotation of a stand, conscious efforts should be made to continually upgrade the genetic quality by culling poorer performing phenotypes in precommercial and commercial thinnings. During these intermediate entries selection should always favor the "best" of both natural and artificial regeneration.

LITERATURE CITED

Adams, W. T. 1981. Population genetics and gene conservation in Pacific Northwest conifers. In: G. G. E. Scudder and J. L. Reveal (Eds.), Evolution Today, Proceedings of the Second International Congress of Systematic and Evolutionary Biology. pp. 401-415.

Adams, W. T. 1983. Application of isozymes in tree breeding. In: S. D. Tanksley and T. J. Orton (Eds.), Isozymes in plant genetics and breeding, part A. Elsevier Science Publ. B. V., Amsterdam. pp. 381-400.

Adams, W. T. and D. S. Birkes. 1988. Estimating mating patterns in forest tree populations. In: Proceedings, International workshop on plant biology, biochemical markers in population genetics of forest trees. Institute for Agroforestry of the National Research Council of Italy (CNR). Porano-Orvieto, Italy.

Brown, A. H. D. 1978. Isozymes, plant population genetic structure and genetic conservation. Theor. Appl. Genet. 52:145-157.

Brown, A. H. D. and G. F. Moran. 1981. Isozymes and the genetic resources of forest trees. In: M. T. Conkle (Ed.), Isozymes of North American Forest Trees and Forest Insects. General Technical Report PSW-48. USDA Forest Service PSW Forest and Range Experiment Station, Berkeley, CA.

Campbell, R. K. 1979. Genecology of Douglas-fir in a watershed in the Oregon Cascades. Ecology 60:1036-1050.

Daniel, T. W., J. A. Helms, and F. S. Baker. 1979. Principles of Silviculture. 2nd Ed. McGraw-Hill, New York. 500 pp.

Eriksson, G., A. Jonsson, and D. Lindgren. 1973. Flowering in a clone trial of *Picea abies* Karst. Studia Forestalia Suecica Nr 110, Royal College of Forestry, Stockholm.

Erickson, V. J. and W. T. Adams. 1989. Mating success in a coastal Douglas-fir seed orchard as affected by distance and floral phenology. Can. J. For. Res. 19:1248-1255.

Erickson, V. J. and W. T. Adams. 1990. Mating system variation among individual ramets in a Douglas-fir seed orchard. Can. J. For. Res. 20:1672-1675.

Frankel, O. H. and E. Bennet (Eds.). 1970. Genetic resources in plants—their exploration and conservation. F. A. Davis Co. Philadelphia. 554 pp.

Franklin, E. C. 1970. Survey of mutant forms and inbreeding depression species of the family *Pinaceae*. USDA Forest Service Research Paper SE-61.

Griffin, A. R. 1982. Clonal variation in radiata pine seed orchards. I. Some flowering, cone and seed production traits. Aust. For. Res. 12:295-302.

Griffin, A. R. 1984. Clonal variation in radiata pine seed orchards. II. Flowering phenology. Aust. For. Res. 14:271-281.

Griffin, A. R. and D. Lindgren. 1985. Effect of inbreeding on production of filled seed in *Pinus radiata*—experimental results and a model of gene action. Theor. Appl. Genet. 71:334-343.

Hamrick, J. L. and Godt, M. J. 1989. Allozyme diversity in plant species. In: H. D. Brown, M. T. Clegg, A. L. Kahler, and B. S. Weir (Eds.). Plant Population Genetics, Breeding, and Genetic Resources. Sinauer Assoc., Sunderland, MA. pp. 43-63.

Hamrick, J. L., Y, B. Linhart, and J. B. Mitton. 1979. Relationship between life history characteristics and electrophoretically detectable genetic variation in plants. Ann. Rev. Ecol. Syst. 10:173-200.

Hamrick, J. L., J. B. Mitton, and Y. B. Linhart. 1981. Levels of genetic variation in trees: Influences of life history traits characteristics. In: M. T. Conkle (Ed.). Isozymes of North American Forest Trees and Forest Insects. General Technical Report PSW-48. USDA Forest Service, PSW Forest and Range Experiment Station, Berkeley, CA.

Hamrick, J. L. and A. Schnabel. 1985. Understanding the genetic structure of plant populations: Some old problems and a new approach. In: H. R. Gregorius (Ed.), Population genetics in forestry. Lecture notes in Biomathematics 60, Springer-Verlag, New York. pp. 50-70.

Hartle, D. L. 1980. Principles of Population Genetics. Sinauer Associates, Inc., Sunderland, MA. 488 pp.

Jonsson, A., I. Ekberg, and G. Eriksson. 1976. Flowering in a seed orchard of *Pinus sylvestris* L. Studia Forestalia Suecica Nr 135, Swedish College of Forestry, Stockholm.

Levin, D. A. and H. W. Kerster. 1974. Gene flow in seed plants. In: T. Dobzhansky, M. T. Hecht, and W. C. Steer (Eds.), Evol. Biol. 7. Plenum Press, New York. pp. 139-220.

Linhart, Y. B., and J. B. Mitton. 1985. Relationships among reproduction, growth rates, and protein heterozygosity in ponderosa pine. Am. J. Bot. 72(2):181-184.

Millar, C. I. and R. D. Westfall. 1990. Allozyme markers in forest genetic conservation. Proceedings, IUFRO international symposium on population genetics of forest trees, Corvallis, OR.

Neale, D. B. 1985. Genetic implications of shelterwood regeneration of Douglas-fir in southwest Oregon. Forest Sci. 31:995-1005.

Neale, D. B. and W. T. Adams. 1985. The mating system in natural and shelterwood stands of Douglas-fir. Theor. Appl. Genet. 71:201-207.

Park, Y. S. and D. P. Fowler. 1984. Inbreeding in black spruce: self-fertility, genetic load, and performance. Can. J. For. Res. 14:17-21.

Shoen, D. J. and S. C. Stewart. 1986. Variation in male reproductive investment and male reproductive success in white spruce. Evolution 40:1109-1120.

Sorensen, F. C. 1971. Estimates of self-fertility in coastal Douglas-fir from inbreeding studies. Silvae Genet. 20:115-120.

Sorensen, F. C. and R. S. Miles. 1974. Self-pollination effects on Douglas-fir and ponderosa pine seeds and seedlings. Silvae Genet. 23:135-138.

Sorensen, F. C. and R. S. Miles. 1982. Inbreeding depression in height, height growth, and survival of Douglas-fir, ponderosa pine, and noble fir to 10 years of age. Forest Sci. 28:283-292.

Yazdani, R., D. Lindgren, and S. Stewart. 1989. Gene dispersion within a population of *Pinus sylvestris*. Scand. J. For. Res. 4:295-306.

Zobel, B. J. and J. T. Talbert. 1984. Applied Forest Tree Improvement. John Wiley and Sons, New York. 505 pp.

Author

Vicky J. Erickson
Area Geneticist
Umatilla National Forest
2517 S.W. Hailey Avenue
Pendleton, Oregon 97801

THE SHELTERWOOD METHOD
A Research Perspective

Donald E. Beck
Southeastern Forest Experiment Station
Asheville, North Carolina

INTRODUCTION

As has already been pointed out in this session, the fundamental purpose of the shelterwood method is to get a new crop of trees established before the old one is completely removed. Stands created by shelterwood cutting are usually even-aged, but there are variants in which the stands have two age classes or have trees ranging over several decades in age. Probably the outstanding feature of the shelterwood method is its extreme flexibility. The number and intensity of cuts, interval between cuts, and treatment of the understory and forest floor can be varied to achieve a wide range of environmental effects in both space and time. As Smith (1986) has pointed out, adjustments can be made to meet the environmental needs of almost all species except those that are extremely intolerant of shade or root competition. It can also be used to create a wide range in visual effects.

SPECIES CHARACTERISTICS

Based on the characteristics of the commercially important species, I would say that the shelterwood has not been used to nearly the extent that it can and probably should be used. Relatively few of our major species can be considered to be the true pioneers that can be consistently regenerated by clearcutting. Only a few have consistent seed crops with wide dispersal, have the capacity for rapid establishment on exposed sites, and have rapid juvenile growth rates in very open conditions. Similarly, at the other end of the spectrum, not many species are tolerant enough to become established and grow to maturity in the shaded conditions typical of the selection system. The majority of species with which we deal depend on well-established advance reproduction but are intolerant or intermediate in tolerance to shaded conditions for extended periods of time (Kelty 1988, Smith 1986, Spurr and Barnes 1980). As a result, they need to become established under a canopy but later need relatively open conditions to develop; thus, they are prime candidates for regeneration by shelterwood. I would include in this category species that may be able to establish themselves in very open conditions, but because of sporadic and unreliable seed crops require seedlings in place before the seed source is removed, if natural reproduction is going to be successful.

USES OF SHELTERWOOD

Given that numerous species of trees are theoretically suited to regeneration by the shelterwood method, here are some things shelterwoods can be designed to do:

1. Enhance seed production.
2. Provide a favorable microclimate for germination and seedling establishment.
3. Promote seedling growth.

4. Retard development of competition.
5. Protect from harsh conditions (e.g., heat and cold).
6. Protect from insects and disease.
7. Manage the growing stock.

A shelterwood designed to accomplish all of these things would be difficult to envision, much less design. In practice, however, shelterwoods will seldom be required to accomplish more than a few objectives. The key is to make site-specific prescriptions based on a thorough understanding of the ecological characteristics and reproductive requirements of the desired and competing species. The shelterwood method has not been studied as extensively as it would seem to deserve. However, its application to a few species may serve to illustrate the types of regeneration problems it can help to solve and suggest how it might apply to other species and forest types with similar problems.

Application to longleaf pine

Longleaf pine has a long list of regeneration problems—very erratic seed production, poor seedling establishment, low seedling survival, and slow seedling growth—that a carefully designed shelterwood system can solve. One or more of these characteristics is shared by many other species, particularly conifers.

A highly effective shelterwood system for longleaf pine includes a preparatory cut, seed and removal cuts, and treatments with prescribed fire and/or herbicides to prepare the seedbed and control understory competition (Croker and Boyer 1975). Seed crops, seedling establishment, and growth must be closely monitored to properly time cultural treatments.

The objectives of the initial cut, the preparatory cut, are to take out trees that are unsuitable seed sources and to develop large crowns on the trees that are left. This cut should leave a residual basal area of 60 to 70 square feet per acre, depending on the site quality. In previously unthinned stands, 5 or more years may be required to develop the crowns. In previously thinned stands less time may be required, and in some cases the preparatory cut may not be needed.

The seed cut is designed to maximize seed production and develop a well-stocked stand of reproduction. Seed production is maximized at a density of about 30 square feet of basal area per acre. This amount of overstory also holds hardwood encroachment in partial check. Trees that have well formed crowns and are over 30 years old and at least 10 inches in diameter are the most prolific seed producers. Seed production increases with tree diameter up to about 15 inches. Some trees are inherently more fruitful than their neighbors, regardless of morphological characteristics (Allen 1953, Croker 1964). Trees therefore are often picked to leave because large numbers of cones on the ground indicate that they are good seed producers.

Several years may elapse between the seed cut and establishment of adequate regeneration. Seedbeds should be prepared shortly before a good seedfall. Because seedbed preparation is usually ineffective if done more than 1 year in advance, it is desirable to estimate seed crops in advance. The current-year's and the following year's seed crops can be estimated by counting, with the aid of binoculars, conelets and flowers present in the spring (Croker 1971). Spring counts of conelets give very good estimates of the current year's crop. Estimates of the following year's crop from flower counts may vary considerably from actual production because losses of flowers are variable and sometimes heavy. Prescribed fire and/or mechanical treatment may be used to prepare a receptive seedbed when good seed crops are anticipated.

The removal cut is delayed until stocked quadrat surveys show that the amount and distribution of reproduction are adequate. In addition to regenerating the stand, the shelterwood system allows the growth of 150 to 200 board feet per acre per year of high-quality wood during the process. I think this sketchy outline of a rather sophisticated and complicated system illustrates what can be done with a difficult species if there is a good, research-based understanding of its requirements.

Application to oak reproduction

A simple, but effective, shelterwood technique has been developed for northern red oak in the Southern Appalachians to accomplish one mission: promote the growth of advance seedlings to a competitive status. Northern red oak is probably the most valuable single species in coves and moist-slopes of the Appalachians. It is also one of the most difficult species to regenerate. It became evident in the early 1960's that northern red oak, even when it was present in large numbers as small advance seedlings, was not regenerating well (McGee and Hooper 1970, 1975; Beck 1970; Beck and Hooper 1986; Loftis 1983). Research showed that the small seedlings simply could not compete with yellow-poplar, red maple, sweet birch, and other aggressive and fast growing species. Only advance oak reproduction with stems at least 4-5 feet tall at the time of a heavy removal cut were able to compete.

The goal, then, was to stimulate the growth of advance oak seedlings without stimulating that of competitors. The method finally arrived at consists of reducing basal area of all stems 1.0" dbh and larger by 30-40 per cent starting from below (Loftis 1990a). In essence, the treatment consists of herbicide treatment of the understory and midstory stems of tolerant species such as dogwood and red maple, which are profuse in most cove stands. Removal of the prescribed basal area may require taking out a few trees from the main canopy. In essence, the treatment eliminates the understory and midstory trees, while maintaining high shade from an overstory without gaps. Residual basal areas may run as high as 110 square feet per acre. The treatment, therefore, is distinctly different from what we normally think of as a shelterwood cut.

The amount of light under the intact overstory canopy permits small, advance red oak seedlings, already in place, to develop without stimulating yellow-poplar and other intolerant species. Another study has shown that it takes 8 to 10 years for a significant number of the seedlings to reach a competitive size and be assured of a place in the dominant canopy of the developing stand after the removal cut (Loftis 1990b). Research in the central hardwoods region has shown that the oaks there respond to similar methods (Sander 1979, Graney 1988).

Success of the shelterwood method depends on having small reproduction in place before the first treatment. Where the small reproduction is absent or numbers are insufficient, underplanting may be one solution (Chambers and Henkel 1988, Johnson 1984). After seedlings are introduced into the stand, all other treatments are carried out just as when natural reproduction is present. Given the well-known difficulties of planting oaks successfully in cut-over areas (McGee and Loftis 1986), underplanting in the shelterwood system may also provide the best means for introducing genetically improved stock into our stands. When you consider the frequent and widespread failures of conifer plantings on hot, dry sites, underplanting a shelterwood to provide some protection might be worth trying.

The method described has been tested most thoroughly on the oaks. However, there are good indications that it may work equally well with other species of intermediate tolerance and slow height growth in the early stages of development, such as hickories, ash, and cucumber magnolia, to name a few eastern hardwoods. There are certainly others, conifers as well as hardwoods.

Application to mixed Appalachian hardwoods to manage the growing stock

In addition to regeneration, one of the most attractive features of the shelterwood method is the opportunity to manage a selected portion of the growing stock. The residual trees in the shelterwood can continue to grow and produce high-quality wood while providing seed and protection. And we saw in the case of longleaf pine that growth of the residual trees can be considerable. The usual procedure is to leave trees from the dominant and codominant crown classes. A somewhat different opportunity presents itself in the mixed hardwood stands of the Eastern United States and in particularly the Southern Appalachians. Because of differential growth rates among species, different modes of origin in natural stands, and past cutting practices, mixed hardwood stands are likely to contain a wide range of diameters that may be in several strata. I think subdominant trees often are in that position because of the dynamics of stand development and past treatment, rather than because they are genetically inferior. Thus, stands with mature sawtimber may contain a number of trees in subdominant crown classes that are below merchantable size for sawtimber but are capable of further growth (Beck 1981, 1988; Smith and Lamson 1977). Also, many trees that are just above the merchantability limits have only marginal value. Fisher et al. (1980) showed that by leaving these subdominant trees of good vigor and form—mostly in the 6- to 14-inch diameter classes—substantial increases in value may be realized relatively quickly while reproduction is being developed.

There is a good deal of flexibility in the timing of residual-tree removal. Residuals can be removed in a conventional way to create an even-aged stand. Or, all or part of the residuals could be maintained indefinitely to create a two-aged stand. This latter procedure would be called an irregular shelterwood under Smith's (1986) terminology. Given this flexibility of maintaining two age classes, I think the shelterwood method comes closest to offering "New Perspectives" of any of the feasible reproduction methods.

SUMMARY

The shelterwood is an extremely flexible method that can be used to solve a wide range of regeneration problems. Practically all the major species of this country are amenable to its use and many demand it. While it is usually thought of in connection with natural regeneration, it also can be used in conjunction with direct seeding or planting. In fact, it may be at least a partial answer for some of the failures now being experienced when planting following clearcutting. Given the option of maintaining two-aged stands, it has the potential to incorporate esthetic, wildlife, and other management needs into a regeneration method for species that are intolerant or intermediate in tolerance. It therefore is suitable for a majority of the commercially important timber species.

As should be very clear from the examples given in this paper, successful application depends on site-specific prescriptions based on a thorough understanding of the ecological characteristics and reproductive requirements of the desired and competing species.

LITERATURE CITED

Allen, R.M. 1953. Release and fertilization stimulate longleaf pine cone crop. Journal of Forestry 51:827.

Beck, Donald E. 1970. Effect of competition on survival and height growth of red oak seedlings. Res. Pap. SE-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, 7 pp.

Beck, Donald E. 1981. Evaluating a diameter-limit cut in Southern Appalachian hardwoods through stem analysis. In: Barnett, James P., ed. Proceedings of the first biennial southern silvicultural research conference; 1980 November 6-7; Atlanta, GA. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 164-168.

Beck, Donald E. 1989. Selection thinning in Southern Appalachian hardwoods. In: Miller, James H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 291-294.

Beck, Donald E.; Hooper, Ralph M. 1986. Development of a Southern Appalachian hardwood stand after clearcutting. Southern Journal of Applied Forestry 10:168-172.

Chambers, Jim L.; Henkel, Mary W. 1989. Survival and growth of natural and artificial regeneration in bottomland hardwood stands after partial overstory removal. In: Miller, James H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 277-283.

Croker, T.C., Jr. 1964. Fruitfulness of longleaf trees nore important than culture in cone yield. Journal of Forestry 62:822-823.

Croker, T.C., Jr. 1971. Binocular counts of longleaf pine strobili. Res. Note SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 3 pp.

Croker, T.C., Jr.; Boyer, William D. 1975. Regenerating longleaf pine naturally. Res. Pap. SO-105. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 pp.

Fisher, Burnell C.; Standiford, Richard B.; Callahan, John C. 1980. Value growth rates from overwood trees in the irregular shelterwood method in Southern Indiana upland hardwoods. In: Garrett, Harold E.; Cox, Gene S., eds. Proceedings of the third central hardwood conference; 1980 September 16-17; Columbia, MO. Columbia, MO: University of Missouri: 401-407.

Graney, David L. 1989. Growth of oak, ash and cherry reproduction following overstory thinning and understory control in upland hardwood stands of Northern Arkansas. In: Miller, James H., comp. Proceedings of the fifth biennial southern silvicultural research conference, 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 245-252.

Johnson, P. S. 1984. Responses of planted northern red oak to three overstory treatments. Canadian Journal of Forest Research 14:536-42.

Kelty, Matthew J. 1988. Sources of hardwood regeneration and factors that influence these sources. In: Smith, H. Clay; Kidd, Arlyn W.; Kidd, William E., Jr., eds. Workshop proceedings: Guidelines for regenerating Appalachian hardwood stands; 1988 May 24-26; Morgantown, WV. SAF Publ. 88-03. Morgantown, WV: West Virginia University Books: 17-30.

Loftis, David L. 1983. Regenerating Southern Appalachian mixed hardwood stands with the shelterwood method. Southern Journal of Applied Forestry 7:212-217.

Loftis, David L. 1990a. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science [In press].

Loftis, David L. 1990b. Predicting post-harvest performance of advance red oak reproduction in the Southern Appalachians. Forest Science [In press].

McGee, Charles E.; Hooper, Ralph M. 1970. Regeneration after clearcutting in the Southern Appalachians. Res. Pap. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 12 pp.

McGee, Charles E.; Hooper, Ralph M. 1975. Regeneration trends 10 years after clearcutting of an Appalachian hardwood stand. Res. Note SE-227. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 3 pp.

McGee, Charles E.; Loftis, David L. 1986. Planted oaks perform poorly in North Carolina and Tennessee. Northern Journal of Applied Forestry 3:114-16.

Sander, Ivan. 1979. Regenerating oaks with the shelterwood system. In: Harvey A. Holt; Fischer, Burnell C., eds. Regenerating oaks in upland hardwood forests—The 1979 John S. Wright Forestry Conference; 1979 February 22-23; West Lafayette, IN. Purdue, IN: Purdue Research Foundation: 54-60.

Smith, David M. 1986. The Practice of silviculture. 8th ed. New York: John Wiley & Sons, Inc. 527 pp.

Smith, H. Clay; Lamson, Neil I. 1977. Stand development 25 years after a 9.0-inch diameter-limit first cutting in Appalachian hardwoods. Res. Pap. NE-379. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 pp.

Spurr, S. H.; Barnes, B.V. 1980. Forest ecology. 3rd ed. New York: John Wiley & Sons. 687 pp.

Author

Donald E. Beck
Research Forester
Southeastern Forest Experiment Station
Bent Creek Experimental Forest
Route 3, Box 1249
Asheville, North Carolina 28806

SUMMARY COMMENTS: ROLE OF SILVICULTURE AND GENETICS IN NATIONAL FOREST MANAGEMENT

Dean S. DeBell
Pacific Northwest Research Station
Forestry Sciences Laboratory
Olympia, WA

INTRODUCTION

This paper contains some general thoughts about the silvicultural systems discussed at the Genetics/Silviculture Workshop and also includes suggestions on the role that geneticists and silviculturists may play in forest resource management and the controversies surrounding it. I hope these summary comments will serve to reinforce several points made by others in presentations and discussions.

SILVICULTURAL SYSTEMS AND MODIFIED FOREST PRACTICES

Our workshop consisted of excellent presentations and productive discussions on basic silvicultural systems; the papers contained in this volume include some thoughtful analyses that go beyond standard textbook descriptions. The five classical systems were considered, each with several variants; and today—under "New Perspectives"—many people are experimenting with an even wider range of modifications. Advantages, disadvantages, and some of the concerns associated with the systems and some variants thereof were discussed. It was emphasized time and time again that sites and stands may pose a variety of physical constraints and species have biological limitations; and that these constraints and limitations must be considered in applications of systems to meet any objective or objectives. We also discussed differences among systems in apparent costs, required skill levels, existing knowledge bases, and capabilities for dealing with insect, disease, and fire problems. But given the range of systems and the diversity of our landscapes, species, and management objectives, why have we relied mostly on evenaged systems (and primarily on one of these—clearcutting) in both research and practice, particularly in the Southeast and Pacific Northwest? It is probably because we have continued to focus on trees and wood production, rather than on the forest as a whole and the many other forest values that can be managed. Given that narrow focus, clearcutting is clearly the system of choice. Also, many of us believed that "as trees go—so goes the forest." This belief is now being questioned. And to some extent the continued attack on clearcutting is due to the fact that in many areas we are not using a wider range of silvicultural systems, even when alternatives to clearcutting may be suitable. The survival of clearcutting as a usable tool may therefore hinge on our willingness and ability to successfully apply other systems when circumstances permit.

I also want to comment on the matter of objectives. It is important that management objectives be decided upon and clearly stated. But, as recognized in our discussions, sometimes even stated "objectives" can be rather nebulous. We may say, for example, that the objective is improvement in wildlife habitat—but what wildlife species are to be favored and what stand conditions are desired? For some cases, we can answer such questions reasonably well; for other cases, we can not. We need to be specific about objectives and about approaches to attaining them; doing so will either clarify the situation for others or expose our own fuzzy thinking. One of the themes of "New Perspectives" is to manage with more emphasis on ecological values and processes. What does this really mean—what are we managing and how do we monitor our management of it? We are trying many different things on the National Forests today—some of the practices are based on speculation as to what is "ecologically good;" some are based on what is thought to be "publicly acceptable;" and, yes, some are based on sound scientific information. Yet, many of our ideas—particularly in the Pacific Northwest—are based primarily on studies that have characterized processes and properties in natural forests, predominantly old growth forests. We have not done research to characterize the same processes and properties (or their analogs) in managed stands. Thus, much of the current discussion regarding non-timber values provided or not provided therein as well as many of the ideas regarding the value of alternative silvicultural practices consist mostly of conjecture and a fair amount of ideology.

It is unfortunate that we do not have long-term, comprehensive comparisons of the basic silvicultural systems for most forest types. Except for data on regeneration and early growth, all we can do is speculate about other effects of different silvicultural systems—even on basic questions such as growth and yield. Factual answers to questions about wildlife habitat and other ecological values are even more difficult to come by. The exception to these generalities is the work at Crossett, Arkansas (and perhaps a few other places), but even there the data relates primarily to timber production. I hope that the creative energy and enthusiasm that is associated with "New Perspectives" can be channeled into some long-term tests and demonstrations in major forest types. We should establish a spectrum of silvicultural systems and stand conditions, and these should be monitored and evaluated with regard to a wide range of characteristics and objectives. Unless we do this, we are likely to not only make a mess of portions of our National Forest lands (some have referred to such situations as "the Green Lie")—but neither will we have learned anything about how to do things better.

Management decisions obviously can not wait until results from such long-term evaluations are available, but we can do some things to provide a more valid base for current management decisions. Someone suggested resurrecting the compartment studies that were established 40 to 50 years ago in many regions. Many of those studies were abolished in the 1960's, but where the plots still exist a re-assessment of stand conditions would have considerable value today. Such an assessment must include nontimber as well as timber values, and thus should be conducted by other specialists (wildlife biologists, plant ecologists, soil scientists, geneticists, and social scientists) along with silviculturists and economists. Retrospective assessments are another means we can use to provide some data for management in the near future. For example, we can locate stands and landscapes that appear to provide conditions that are desired and *not desired*. Such conditions may have developed naturally or be the result of past management or mismanagement. These stands and lands can be examined to determine if they do indeed provide values desired or conditions to be avoided; moreover, some stands can be "reconstructed" by stem analyses to understand how they arrived at their present state. In short, there are some things we can and should do to reduce the level of speculation in current discussions of forest management and changes proposed therein.

OPPORTUNITIES FOR GENETICISTS AND SILVICULTURISTS

In the past, many of us—geneticists and silviculturists—have focussed our efforts primarily on timber management or production forestry. We did what we were asked and paid to do, and did it reasonably well. Unfortunately, this focus has left many of us "out of the loop" as values and emphases in public forest management have changed. As a group, we have had relatively little influence on current thinking as to those lands allocated as reserves (which are unmanaged or merely protected) or on practices for multi-purpose, multi-value forest lands. Other resource specialists have been the major contributors to current proposals regarding these lands. However, I believe all will benefit if silviculturists and geneticists play a stronger role in decisions and practices on such lands. For example:

1. *Preserves*—these may be Research Natural Areas, Habitat Conservation Areas, Biodiversity Preserves, etcetera.

   I believe that geneticists (with their knowledge of genetic structure, variation, and population dynamics) and silviculturists (with their knowledge of stand dynamics) could be very helpful in the selection of areas to meet specific needs.

2. *Multi-purpose Forests*—current trends indicate that a larger portion (perhaps a major portion) of our National Forest lands will be managed in an integrated fashion to provide a diversity of values and products.

   Many practices—including proposals made under the banner of "New Perspectives"—are not optimum from standpoint of timber production; and they are not intended to be. Because they may not be optimal for timber production, many people have assumed that technology developed for intensive wood production is irrelevant in these forests. Some folks are advocating natural regeneration and minimal ("let nature take its course") management. I don't see it that way. Such an approach may be effective in very favorable environments, but the "hands off" approach is more likely to result in a mess that falls considerably short of intended goals. In many situations, intensive practices—including planting with genetically-improved stock—will be essential to the attainment of an optimal mix of management objectives. The reasons for this need range from avoidance of dysgenic selection and unnecessary reduction in wood yield to enhancement of biodiversity and forest or soil productivity.

   I'm sure we could all give specific examples of such needs and possibilities. The main point I want to make, however, is that we should not dismiss—*nor let anyone else dismiss*—the important contribution that geneticists and silviculturists can make in this era of "New Perspectives." Thus, I hope those of you who *may be inclined* toward reduced efforts in tree nurseries and tree improvement programs do not restrict future options for such contributions.

My concern about foreclosing some of our options for future management is also related to the fact that we are presently in a period of considerable confusion regarding public land management objectives; there is much polarization not only within general society, but also within the ranks of the resource management professions. Erroneous information and misleading statements have played a role in some current management conflicts and also in our thinking about proposed solutions. Some of this misinformation and related ideology is now being challenged by members of the scientific community (e.g. Aune et al. 1990; Botkin 1990). And I suspect that when calmer, more rational times return, intensive forest management will be judged more important than it is today, even on public lands or portions thereof.

Recently we learned some things about gains from management in the Douglas-fir region; or perhaps I should say we obtained documentation for some long-held beliefs:

1. Volume production of plantations is substantially higher than that of fully-stocked natural stands—a comparison of side-by-side stands, aged 35-38 years, showed this difference in live volume (ft^3/acre) to average *40 percent* (Miller et al., in preparation). The stands were all established on slash-burned clearcuts, located on National Forests in the Cascades; the planting stock had not been genetically selected and nursery procedures were those used 40 years ago. Because of improved technology of artificial regeneration and availability of genetically selected seed, gains from current planting are likely to be even greater.

2. "Cornfield" forests—the "cornfield" metaphor has been used to belittle plantation forests. The implication is that planted stands are extremely uniform and consist almost entirely of planted Douglas-fir. Presentations and discussions at this Workshop pointed up the misleading nature of this metaphor in planted stands throughout the country. In the Douglas-fir region, such stands are much rarer (by several orders of magnitude) than are spotted owls. The half-dozen such stands that we have been able to locate were all established on former farm land—there were no biological legacies from old growth. Growth and yield on these few areas are outstanding (Murray and Harrington 1990); they are "off-the-charts" of our current understanding of growth and yield and "off-the-charts" of our current stand models.

I have not mentioned the above findings because I think we should implement "cornfield forestry" throughout the National Forest System. I do, however, believe that the *magnitude* of gains and values produced with such technology should be recognized in current discussions of management objectives and tools for achieving them. Such information is an essential feature of assessing trade-offs and achieving better, more acceptable strategies and combinations of strategies for public land management. Intensive forest management practices are tools—just as are Wilderness and Habitat Enhancement Areas—in the general toolbox for meeting societal needs and desires on forest lands.

SOME FINAL THOUGHTS

As we begin to deal with serious environmental problems and the needs of expanding populations throughout the nation and the world, we will find that several regions of the United States (including the public forests in them) are much better endowed with soils, climates, and tree species than are most other countries. When this is recognized, wood production on National Forests (and other values associated with it) is likely to attain a higher importance than many people think it has today. Thus we must do what we can to see that scientific and management capabilities in the Forest Service do not diminish during this period of turmoil and confusion. Moreover, I think it is equally important that we play a much larger role than we have in the past on those forest lands that are not dedicated primarily to timber production. Let's work with others—in the true spirit of "New Perspectives"—to develop and evaluate some practices that provide desired mixes of values, uses, and products on our National Forest lands.

LITERATURE CITED

Aune, P.S., W.W. Oliver, R.F. Powers, J.R. Boyle, J.C. Tappeiner, D.S. DeBell, and C.D. Oliver. 1990. A Scientific Review. [A review of "The Redesigned forest."] Journal of Forestry 88(12):33-36.

Botkin, Daniel B. 1990. Discordant Harmonies – A New Ecology for the Twenty-first Century. Oxford University Press. 241 pp.

Miller, R.E., R.E. Bigley, and S. Webster. Volume and other characteristics of planted vs. naturally regenerated Douglas-fir stands in the Cascade Range. (submitted to Western Journal of Applied Forestry).

Murray, M.D. and C.A. Harrington. 1990. Yield comparison of three Douglas-fir plantations on former farmland in western Washington. W. J. Appl. Forestry 5(4):123-126.

Author

Dean S. DeBell
Project Leader, Principal Silviculturist
Forestry Sciences Laboratory
Pacific Northwest Forest Experiment Station
3625 93rd Avenue, S.W.
Olympia, Washington 98502

☆ U.S. Government Printing Office : 1991 - 282-960/40241