AN ECONOMIC ASSESSMENT OF UNEVEN-AGED FORESTRY, BASED ON THE MODELLING OF FOREST OPERATIONS

BY

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DECLARATION

I declare that the work presented in this thesis is my own, unless otherwise stated, and that this thesis has been composed by me.

Nicole H. Shrimpton

September 12,1990

For Tony and Ioan

ABSTRACT

In recent years, interest in uneven-aged forestry has been increasing in Britain, particularly for sensitive areas such as recreation and amenity forests. Literature on the economics of uneven-aged forestry is scarce and few operational, uneven-aged forests are available for study. Therefore, in order to quantify the operating costs associated with uneven-aged forestry, a modelling approach was chosen. The resulting model is written in **FORTRAN** and uses a series of square two-dimensional arrays to represent a block of forest. The block may then be managed by clearfelling and replanting at a specified age, or by a system of group management with a choice of four group sizes. The resulting model was then used to investigate the effect of the following management strategies on operating times:

1. Varying the scale of working (i.e. the group size and forest size) in the uneven-aged forest.
2. Using shortwood or pole-length harvesting systems and a range of machine types within each harvesting system.
3. Varying the length of time taken to transform the structure of the forest from even-aged to uneven-aged.
4. Varying the age of the trees when the transformation from even-aged to uneven-aged structure begins.

The results obtained from running the model show that the time taken to carry out an operation is influenced both by the absolute size of the group within the forest block and by the number of groups of that size within *the* forest block. This fragmentation effect explains why it is difficult to determine the absolute costs of working for a specific group size, because it is the combination of group size, number of groups and forest block size, which determines costs. Most of the results below are based on a range of group sizes from 1.000 ha. to 0.0625 ha., with a block size of 16 ha.

Forwarders were penalized when the group size was decreased to 0.0625 ha. (–12% increase over clearfelling), because very small groups do not contain full forwarding loads and a large proportion of total forwarding time is spent manoeuvring into and out of groups. However, the operating times for the three group sizes 1.00 ha., 0.25 ha. and 0. 11 ha. were very similar indicating that the group size can be quite small before any extra forwarding costs are incurred. On poor sites, the cost differential

between the largest and smallest groups is greater. In contrast to forwarding, skidders are most penalized with the decision to adopt an uneven-aged system, and once that decision has been made, there is not a clear increase in costs with decreasing group size.

During the transformation period, felling and thinning times in the uneven-aged system are significantly higher than those for the even-aged system, because trees are being harvested prematurely to create the early groups, but this difference is reduced once the forest is transformed. Felling and thinning times increase gradually as the group size decreases, because more care is needed for the felling operation and more time is needed for snedding coarse edge trees.

Replanting times for the uneven-aged forest are approximately **8%** - 14% higher than replanting times for clearfelling.

The results from the model were then analysed using the EXCEL spreadsheet programme to examine, among other things, the cost implications of varying group size, and the relative profitability of uneven-aged and even-aged management. First,optimum ages to begin transformation were found, which varied with the Yield Class and discount rate chosen. Then, the effect of the length of the transformation period was examined and a long transformation period (80-years) was found to be preferable to a short transformation period (40-years). The analysis showed that at high discount rates even-aged and uneven-aged management had similar Net Present Values, but at lower discount rates the even-aged system was preferred. The greatest financial penalty was incurred with adoption of an uneven-aged system, and reducing the group size had relatively little impact on Net Present Values.

Other costs and benefits, such as scenic beauty and recreation potential, could not be included in the model, because research relating these values to forest management variables has not been carried out. Therefore, these mostly non-financial factors were discussed for even-aged and uneven-aged forestry, based on a review of the literature.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION AND OBJECTIVES

1.1 WHY UNEVEN-AGED FORESTRY?

The trend, in many parts of the world, is towards large-scale forestry with fairly homogeneous stands of a few coniferous species and a relatively simple age structure. This trend is driven by market forces and, to a great extent, by economies of scale in the wood processing industries. The economies of scale in the pulp and paper industry, for example, are particularly pronounced, because there are a number of indivisibilities in the technological process (Westoby, 1987). Kauman (1987) predicted that by the year 2100 timber will mainly be obtained from fast-growing plantations and intensively managed secondary forests, which will enable rationalization of harvesting by facilitating the use of automated and robotized methods. This approach will produce stems of fairly uniform size and density which, in turn, lend themselves to further streamlining of the production process.

At the same time, however, there is a growing awareness of the need, in certain situations, for an alternative small-scale approach in order to avoid the disadvantages of large-scale felling and large areas of uniform woodland. The two extremes of the large-scale and small-scale approach are characterized by different silvicultural systems. Therefore, before the special situations where a small-scale approach is appropriate are discussed, the definitions of different silvicultural systems are presented.

1.1.1 SILVICULTURAL SYSTEMS

A silvicultural system may be described as "the process by which the crops constituting a forest are tended, removed and replaced by new crops, resulting in the production of woods of a distinctive form" (Troup, 1928). Silvicultura1systems are generally defined as even-aged or uneven-aged, depending on the spatial distribution of the age classes: even-aged systems produce stands containing trees that are of approximately equal age, whereas uneven-aged systems produce stands containing trees of many ages (Van Lear, 1981). Within each of these categories there are several silvicultural systems:

Even-aged Systems:

1. Clearfelling (Clearcutting)

   The mature crop is cleared in a single felling and the new stand develops by natural regeneration, direct seeding or planting. There is, technically, no upper limit on the size of the felling area and clearfelling areas are often extensive. Conversely, the felling areas may be quite small and distributed in patches or strips.

2. The Seed Tree System

   Instead of completely clearing the mature crop, a few good seed-producing trees are left to regenerate a new crop, The seed trees, which me often valuable, may, or may not, be harvested once the new crop has become established.

3. The Shelterwood System

   The mature crop is cleared by two or more successive fellings, resulting in a crop which **is** more or less even-aged.

Uneven-aged Systems:

1. The Single-Tree Selection System

   Felling and regeneration is distributed continuously over the whole area with individual trees being harvested as they mature.

2. The Group-Selection System

   Felling and regeneration is carried out in small groups, distributed continuously over the whole area, so that the full range of age classes to maturity are represented. **A** group selection system using large groups may merge into a patch clearfelling system provided that, in the clearfelling system, the full age-range to maturity is represented.

The words "uneven-aged" and "irregular" are often used synonymously in the forestry literature and this may lead to confusion. "Uneven-aged" is a term which refers purely to the structure of the forest whereas the term "irregular" is sometimes applied to 'the composition of species and/or the forest structure. Since it is the forest structure I **am** most concerned with (because this is the main determinant of increased costs), I will use the term uneven-aged throughout the thesis, unless I am specifically referring to a mixture of species as well as an uneven-aged structure.

The situations where an uneven-aged silvicultural system may be appropriate are:

1. Recreation and amenity forests.
2. Farm forests and small private woodlands.
3. Protection forests.
4. Forests in areas with small-scale site variations and forests where variation has been imposed by windthrow.

These situations are considered in turn.

1.1.2 RECREATION AND AMENITY FORESTS

Urbanization, mobility, and increased leisure time have brought forestry into the public eye and pressure is building for changes in forest management to favour aesthetics, wildlife habitats and species conservation. Evidence of this can be seen in many parts of the world. In the United States, for example, the USDA Forest Service has classified 12% of its commercial forest land (more than 2.7 million hectares) as a "special category" where it is willing to accept higher costs and/or lower timber production, in order to increase non-timber outputs (Fight and Randall, 1980). For these "special category" forests and forests in high use recreation areas, travel influence zones and scenic view areas, a more sensitive approach is needed. Alexander (1977) suggested that single-tree selection, group selection and modified shelterwood cutting are appropriate for such areas.

Similarly in Europe, Bol and Leek (1984) stated that society is demanding increased nature values and increased recreation values from the forests. This is not only in large public forests, but also in farm and village forests in the North Temperate Zone where recreation is becoming more important and agriculture less important (Ostrom, 1966). This is leading to modification of the silvicultural systems used (Hofstad, 1976) and particularly to a decrease in the size of individual clearcut areas (Heij, 1984). In Scandinavia, where large-scale forestry has dominated for the last thirty to forty years, there has been an increasing demand for alternative management methods to be used in urban forests and alpine forests, for wildlife and flora protection (Lundquist, 1984). And, in Japan, non-clearfelling areas now make up more than 60% of the total area cut in the National Forests (Inoue *et al*, 1981).

1.1.3 FARM FORESTS AND SMALL PRIVATE WOODLANDS

In the last few years there has been an increased emphasis on the importance of management of small private woodlands and farm forests, because they are considered to be an under-utilized resource. Uneven-aged systems of silviculture are particularly appropriate for such woodlands because the appearance of the forest and personal recreation in the forest are often the main objectives for non-industrial, private forest owners. Some of these owners are not averse to harvesting and production forestry but a major deterrent is the belief, based on observation of large-scale felling carried out by commercial companies, that harvesting inevitably leads to devastation (i.e. large amounts of logging debris, unharvested whips and blackened stumps) (MacArthur, 1974; Young and Reichenbach, 1987). Therefore, systems involving permanent forest cover will be more appealing and in Canada, for example, many small private forests are now managed using selection systems (Bjerkelund, 1974).

1.1.4 PROTECTION FORESTS

The practice of irregular forestry in Europe developed as a reaction to the difficulties experienced in the management of uniform forests (Thallon, 1979). Some of these difficulties included disruption caused by windthrow, problems of soil erosion and avalanches on steep terrain, and loss of productivity over time on some sites (Matthews, 1986). It is with regard to protection that some European countries have created laws which prohibit large-scale clearcutting. In Austria, for example, clearcutting areas greater than two hectares or strips wider than fifty metres are generally prohibited (Eckmueller, 1966), and in the Bavarian mountain forests it is forbidden to clearcut areas greater than 0.5 hectares (Brinkmann, 1987).

1.1.5 SMALL-SCALE SITE VARIATIONS AND VARIATION IMPOSED BY WIND

In Scotland, a complex mosaic of small-scale topographic and soil variations is present on many upland sites. These variations, usually resulting from the fluvo-glacial drift geology, lead to large variations in tree growth over areas as small as 0.2 hectares (Paterson, 1975). Osmaston (1968) also noted that in very intensive even-aged forestry individual stands of one age may need to be as small as 0.1 to 0.2 hectares in order to take full advantage of small-scale variations in site.

Furthermore, in many forests in Scotland, small pockets of windblown trees have been replanted as the windblow has occurred as an alternative to felling a whole stand prematurely. Uneven-aged forests have thus been created by responding to site variation and local catastrophes.

In both these cases, accepting the uneven-aged structure and managing accordingly may be preferable to forcing such forests into regularity.

1.2 THE HISTORY AND STATUS OF UNEVEN-AGED FORESTRY

1.2.1 EUROPE

Early records of forest utilization in Europe indicate that a crude form of selection working was the common practice. This method of utilization involved felling stems throughout the stand, as they were required, with no consideration given to regenerating a new stand. These fellings were known as jardinage or furetage in medieval France (Malcolm and Taylor, 1979).

As early as the thirteenth century the deterioration in the forests caused by this exploitation was recognized in Germany and restrictions on timber use were introduced. These restrictions included prohibition of the felling of certain species and the exclusion of grazing animals from felled areas until the regeneration had grown above browse height. The Thirty Years War (1618-1648) put a halt to these preventative measures and the forests of Germany were brought to the edge of ruin. The most valuable forests were overcut to pay war indemnities, cutting regulations and grazing restrictions were ignored and the practice of raking up the forest litter became widespread (Heske, 1938).

After the Thirty Years War, numerous forest ordinances were promulgated in order to rehabilitate the forests. These ordinances included restrictions on cutting and requirements for reforestation. The developments in German forestry were paralleled in France, with Colbert's 1669 Forest Ordinance which introduced the tire et aire system. Under this system a forest was divided into blocks, with cutting confined to one block at a time and seed trees left unharvested to regenerate a new crop (Brown, 1883). The various pieces of legislation tended to impose a more regular structure on the forests and the trend towards regularity continued until the nineteenth century.

In nineteenth century Germany there developed a preference for tree species producing valuable timber over tree species producing firewood or other end products. This led to an increase in pure stands of Norway spruce, at the expense of beech. It was when these stands of pure spruce were extended and grown on unsuitable soils that problems with disease and storm damage were encountered. In the latter part of the nineteenth century, in response to these problems, both Gayer and Gurnaud advocated a more natural approach to forest management and called for the development of more irregular forests with mixed species and age classes.

In Switzerland, clearfelling led to a dramatic decrease in the proportion of beech and silver fi in the Norway spruce/European silver fir/beech forests, because these two species are sensitive to frost in the seedling stage (Matthews, 1986). Swiss foresters experienced similar problems as their German counterparts, with disease and storm damage in the resulting pure spruce stands and they (notably Biolley) were willing listeners to Gayer's ideas about irregular systems.

It is in Switzerland, in the Jura and the Emmental, that the largest areas of forest managed by selection systems are currently found. Norway spruce/European silver fir/beech selection forests are also found in Austria and the Southern German states of Baden, Württenberg and Bavaria. Although the most well known examples of selection forestry are with the spruce/fir/beech forests, examples occur with other forest types, notably the selection system used for beech in Hautfays, Belgium.

1.2.2 THE USA

Selection systems are traditionally viewed with suspicion in the United States because single-tree selection has, historically, been a disguise for high-grading. High-grading is the sequential removal of the largest trees in a stand, with no regard for the future development of the stand. This favours the growth of advanced-age, undesirable, shade tolerant species from the lower crown canopy and has been a particular problem in Eastern hardwoods and Rocky Mountain coniferous forests.

Single-tree selection is currently not widely practiced, but it is often applied in the Northern Hardwood forest type. It is successful here, because sugar maple ***(Acer***

saccharum), beech ***(Fagus americana),*** hemlock ***(Tsuga canadensis)*** and red spruce ***(Picea rubens***), which are the climax species of this forest type, are able to develop in the small openings created by removing single trees. This silvicultura1 system is considered to be appropriate for owners of small woodlands who want a regular income from timber along with little change in the appearance of the woodland.

Small group fellings are found in the Ponderosa pine forest type, mainly along highways and waterways where æsthetic considerations are most important. Also, the use of group management ,with group size ranging from 0.25 acres (0.09 ha.) to 5 acres (1.84 ha), is becoming increasingly popular for coastal Douglas fir, particularly on public lands. The use of group systems in western conifers is hampered by the presence of dwarf mistletoe ***(Arceuthobium*** spp.). Infection by dwarf mistletoe is the single most important disease problem in western conifer forests (French and Cowling, 1982) and the spread of infection from diseased overstory trees may preclude the use small group fellings.

1.2.3 BRITAIN

British forestry also has a history of exploitation felling which produced large areas of unproductive forests by the beginning of this century. Early British foresters, such as Schlich (1840-1925), trained in Germany and therefore learned the principles of irregular forestry. One of the earliest examples of irregular forestry in Britain is the conversion of beech forests on the Parmoor estate in the Chilterns by Bourne (one of Schlich's students) begun in 1924 (Matthews, 1986). Another notable example from the early part of the century is the experiment with group management in a stand of mixed species and age on the Dartington estate begun by Hiley in the 1940's. It was only in the 1950s that uneven-aged forestry really started to develop in Britain, and it did so in two different directions. Firstly, it was introduced on some private estates in England with the aim of rehabilitating unproductive broadleaved woodlands (Matthews, 1986), and at the same time M.L. Anderson, Professor of Forestry at Edinburgh University, instituted trials of the group selection system for conversion of even-aged stands of conifers to an uneven-aged structure. These trials at Glentress, Faskally, Corrour, Cawdor, Dalmeny and elsewhere, are described in Appendix A. Also, during the 1950's a systematic uneven-aged system was developed on Lord Bradfords estate at Tavistock (See Appendix A). Some of these trials have been more or less abandoned (e.g. Corrour) whilst others (e.g. Glentress and Tavistock) are now approximately half-way through the transformation period. In the latter case the group structure is becoming evident and interest in these mals is increasing.

Evidence of this increased interest includes the first Discussion Group on Uneven-Aged Silviculture (Cahalan, 1986) in October 1986, with 58 participants. Papers were presented on the history of uneven-aged forestry, and personal experiences of managing both conifers (Tavistock Estate) and broadleaves (John Workman's beeches) by uneven-aged systems were recounted. These papers were followed by two on the economics of uneven-aged systems and by papers on the growth of trees in mixtures and the development of ground flora under a selection system. Two main points arose in the generai discussion:

1. The need to identify all the current uneven-aged forestry experiments and to compile a register of such experiments.
2. The need to make uneven-aged silviculture acceptable to the forestry authority.

This latter point may now have been tackled, because the latest Forestry Commission grant scheme document (Forestry Commission, 1988) states:

> "the production of utilisable timber must be one of the [management] objectives, although it will not necessarily be the principal objective. The [principal objective] could, for example, be to create a woodland which makes a positive contribution to the landscape and which is designed to create a diversity of wildlife habitats."

It is interesting to consider whether these changes will lead to an increase in the number of forests managed by uneven-aged systems. Although forest managers who are using uneven-aged systems appear to be happy with the associated costs and returns, forest managers who are undecided about introducing such systems have little quantitative information on which to base this decision. The research which forms the basis of this thesis was designed to respond to this apparent need and, to identify and evaluate the economic consequences of uneven-aged forestry.

1.3 REVIEW OF THE LITERATURE ON THE COSTS OF MANAGING UNEVEN-AGED FORESTS

The literature on the relative costs of managing uneven-aged forests compared to even-aged forests is characterised by a lack of concensus between the few authors who have written on the subject and the absence of any significant quantification.

Of the few authors who have written on the subject of the relative costs of uneven-aged forestry most agree, in fairly general terms, that operations in an uneven-aged forest are more expensive than in an even-aged forest, but they have made no attempt to quantify these costs. Newton (1985) noted that most tasks in an uneven-aged forest take *a little longer* because of the time spent in locating groups and moving between them, and the extra care needed during harvesting operations to avoid damage to trees in the surrounding groups. This view was shared by Johnston, Grayson, and Bradley (1967) who felt that the complex or scattered working in an uneven-aged forest *tends to increase costs* , but they decided that it is rarely possible to quantify such effects. Similarly, Risvand (1971) pointed out that cutting spread throughout the forest leads to increased costs due to increased transportation, administration, and inspection needed. Seal (1979) concluded that amenity forests could add to the quality and interest of upland forests at a *very reasonable cost.*

Apart from the increased costs due to scattered working, several authors have identified increased costs associated with the scale of individual cutting areas. Osmaston (1968) found that the smaller the unit of treatment the greater the complications and skill needed in felling and extracting timber without damage to the residual trees. Small tracts are more costly to plant because, according to Guldin (1983), time is spent moving the crew and laying out the job at each area.

Most attempts at quantification of the costs involved have been based on estimates rather than experiments or real world data, and here there is not even general agreement. For example, the **USDA** Forest Service (1983) estimated that the range of increased costs relative to clearcutting, for preparation and harvest, is 6% for shelterwood and 10% for selection cutting. Rickard et al (1967) also used estimates for logging costs in their economic evaluation of silvicultura1 alternatives for old-growth Douglas **fir** landscape management. Although they acknowledged that the exact dollar differences between alternatives were not known, they used a value of 12% for the increase in costs of partial cutting compared to clearcutting. However, at the other end of the scale Bol et al (1981) reported that the relative increase in costs associated with a group selection system using groups of less than one hectare will be measured in tens of percents. The costs considered in this study were those for stand establishment and harvesting operations, and the cost of transport between treatment areas.

In contrast to the previous findings, Leak and Filip (1975), carrying out experiments in the Bartlett Experimental Forest in New England, reported harvesting costs for single tree/group selection methods of $17.63 per 100 cubic feet and $17.75 per 100 cubic feet when using clearcutting. These results came from direct measurements, but it was noted that all the compartments were near truck roads. Helliwell (1982) also concluded that in Britain, the overall savings in cost associated with clearfelling are likely to be small.

The only reference to the cost of uneven-aged forestry which was based on empirical evidence was the Leak and Filip report describing harvesting experiments in Northern Hardwoods.

1.4 OBJECTIVES OF THE RESEARCH

Quantification of costs of uneven-aged forestry in Britain is hampered by the limited number of examples of forests in operation and available for study. Also, if costs are available, they are often too aggregated to be of much value.

One possible approach to assessing the economics of uneven-aged forestry would be to study a single uneven-aged forest, making measurements of operations and collecting data on volumes of timber removed. The results could then be compared with published values for even-aged forests, of which there are plenty. However, because no even-aged forests have been completely transformed to an uneven-aged structure, only a brief portion of the transformation period could be assessed using this method. Also, the results of such a study would be limited because they would be unique and difficult to project to any other uneven-aged forest. The results would not have a widespread application because the management of an uneven-aged forest is complex and the results from a single forest would be determined by a long list of variables, including:

1) Tree Species
2) Site Quality
3) Terrain Characteristics
4) Forest Size
5) Harvest Systems
6) Timing of Operations
7) Group size

By developing a model, however, each of these factors can be isolated, investigated, and the importance of each determined, which was why a modelling approach was chosen for this research. A model also allows alternative management strategies to be examined which would be impossible if results were based on one or several forests.

The three major objectives of the research are detailed below:

The first main ojective was to compare the time needed to carry out operations in the even-aged and uneven-aged forest. The following management variables for the uneven-aged forest were selected for further investigation and comparison.

1. Varying the scale of working (i.e. group size and forest size) in the uneven-aged forest.
2. Using different harvesting systems and a range of machine types within each harvesting system.
3. Varying the length of time taken to transform the structure of the forest from even-aged to uneven-aged.
4. Varying the age of the trees when the transformation from even-aged to uneven-aged structure begins.
5. Varying the tree species and Yield Classes.

In order to achieve the objective of comparing operation times, a model of forest operations was needed. Such a model could then be used to examine the relationship between the silvicultura1 system and the time needed to carry out each operation. By this means, some of the general statements found in the literature, such as that operations "take a little longer", could be quantified. The following forest operations were considered:

1. Felling (shortwood and pole-length)
2. Extraction (shortwood forwarding and pole-length skidding)
3. Replanting
4. Weeding
5. Pruning
6. Brashing

The second major objective was to further analyse the results from the model (i.e. the operational times for the two management approaches) in order to carry out financial analyses of the two systems.The cash flows from even-aged and uneven-aged forests are very different. The even-aged system has large initial establishment costs, low or moderate revenues from intermediate thinnings and a substantial positive net cash flow when the crop is liquidated. The uneven-aged system, on the other hand, has the same initial establishment costs (if considering the development of an uneven-aged forest from bare land), increasing positive net cash flows during the transformation period and equal positive net cash flows every felling period (to infinity), once the forest is transformed. Using the model output to generate these cash flows and to calculate Net Present Values for the two management systems was, therefore, the second objective of the research.

Section 1.1 of this chapter considered the places where uneven-aged management systems might be appropriate. For some of these categories (particularly recreation and amenity forests, farm woodlands, and small private woodlands) financial considerations may be secondary to consideration of the other values of a silvicultura1 system, such as scenic beauty values or wildlife habitat quality. Also, although (for example) the question of the quality of timber obtained from the two systems is certainly a financial consideration, the data needed to compare timber quality for the two systems is not available and could not, therefore, be included in a financial analysis.

The third objective was, therefore, to compare the following topics (which were not included in the model or in the financial analyses) for the two silvicultural systems:

1) Scenic beauty
2) Recreation
3) Wildlife habitats and Conservation
4) Pests, Diseases and Biotic damage
5) Wind stability
6) Weed growth
7) Timber quality
8) Marketing
9) Management costs

1.5 ORGANIZATION OF THE THESIS

The thesis is structured around the three main objectives described above. Chapters 2, 3 and 4 are concerned with the modelling of forest operations. In the first part of Chapter 2, the development of the model is discussed and the assumptions and constraints are presented. This is followed by a discussion of the sources of data used to build up the model and the final part of Chapter 2 presents the detailed structure of the model.

In Chapter 3 the individual forest operations are outlined along with the corresponding subroutines in the model. Flowcharts for each operation are presented and the data inputs are discussed. The results obtained from running the model are presented in Chapter 4. This chapter follows the same pattern as Chapter 3, with each section containing the results from a single forest operation.

Chapter 5 contains the financial analyses of the model outputs. Calculations of Net Present Values for different management regimes (using a range of discount rates) are presented and discussed.

The non-quantified values associated with the different silvicultural systems and management regimes are discussed in Chapter 6 and Chapter 7 provides a summary of the thesis and recommendations for future research.