Proceedings of the S4.04 Meetings on Forest Management Planning and Managerial Economics

19th IUFRO World Congress
Montreal, Quebec, Canada
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Publication No. FWS 1-91
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Virginia Polytechnic Institute and State University
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compiled by
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PREFACE

This volume contains papers submitted for three meetings on "Forest Management Planning and Managerial Economics" at the 19th World Congress of the International Union of Forestry Research Organizations, held on August 7, 1990. Papers are in the order that they appeared on the program. All material is reproduced in the camera-ready form submitted by authors who are solely responsible for the contents. Presentations published in the Divsion 4 Congress Proceedings are not reproduced here.

I am grateful for organizational assistance from Division 4 Coordinator Fred Kaiser, Subject Group S4.04 Leader Othmar Griess, and our Canadian hosts. The greatest thanks go to the authors of these fine papers for making our meetings such a success.

W. David Klemperer
Program Chairman
Blacksburg, Virginia
January 1991

TABLE OF CONTENTS

Planning and Policy Issues

Mathematical Programming and Planning

Management Issues and Forestry Investment Analysis

Harvest Scheduling and Related Topics

CAN NATIONAL FOREST PLANNING BE CONSISTENT WITH LEOPOLD'S LAND ETHIC?

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SUMMARY

Forest planning in the U.S. is grounded In the *utilitarian* ethic of Forest Service founder Gifford Pinchot. Aldo Leopold's Land Ethic is much more absolutist than Pinchot's puritanical utilitarianism, and emphasises the importance of *beauty* in the forest. Both of these approaches have strong political support. Jerry Franklin's notion of *New Forestry* provides a management option intermediate between intensive forestry and wilderness that appears to have been adopted as official Forest Service policy in the Pacific West and could potentially satisfy the Leopoldians. This has come about in conjunction with the controversy over the threatened spotted owl, but represents, a more general realization that, today, the public cares for the overall integrity and aesthetic appearance of the forest. In particular the public has decided that it deplores the demise of big trees and old growth forests. Yet, just 10 or 15 years ago professional foresters viewed all old trees as something to be gotten out of the way, to make room for a productive forest where all the trees were to be under the age of culmination of mean annual increment. *New Forestry* provides a means for protecting both spotted owls and huge trees, but an implication is the adoption of rotation ages perhaps *five* times those needed for maximum wood production. This lengthening of rotation age inevitably means reduced cuts which, in turn, means lost jobs in dependent communities. The situation is similar to Britain in the 1960s, when changing economic and environmental conditions necessitated the closure of coal mining communities. The solution at that time was to build new towns complete with new industry. Since a long-established role of government is to provide infrastructure, an effort of similar magnitude is called for in the present situation.

Keywords: Old growth, rotation age, new forestry, community stability.

INTRODUCTION

Since I first wrote the title and abstract for this talk last fall, I published in *Western Wildlands* an article with a very similar title. This paper was reprinted in the *Journal of Forestry* (McQuillan 1990). Rather than simply repeat what was said in that article, I will use it as a jumping off point today. In that piece, I pointed out that the current approach to planning for the national forests in the United States as practiced by the Forest Service is an approach designed to rationally maximize the net public benefits received from the forests, which is an approach grounded solidly within the *utilitarian* ethic. This is hardly surprising given the history of both the United States and the agency itself. The Forest Service is still very much the brainchild of its founder, Gifford Pinchot, who was a staunch utilitarian, following closely in the footsteps of the father of utilitarian philosophy, Jeremy Bentham.

Utilitarianism is a *severe* outlook on the world, always afraid of famine and scarcity, little concerned with joy and beauty -- things considered superficial or sometimes even sinful by puritan forefathers. It is also a reductionist philosophy willing to make tradeoffs and strike compromises in pursuit of the aggregate goal of maximizing a "social welfare function," however defined.

By contrast, the Land Ethic espoused by a brilliant writer and part founder of the science of ecology, Aldo Leopold, is much more absolutist and much less compromising than Pinchot's utilitarianism. Leopold's view is closer to that of the romantics such as John Muir. Leopold's land ethic, which has a strong following and has even been proposed for adoption by the Society of American Foresters (Coufal 1989), states in its essence that an action is right when it tends to enhance the stability, integrity, and beauty of the forest (or biotic community) and wrong otherwise (Leopold 1966).

In my earlier paper I delved into the implications of the words *stability* and *integrity*, but, today, I want to concentrate on the third leg of Leopold's triad, *beauty*. Beauty is the subject that represents the greatest gulf between utilitarianism and the Land Ethic. Utilitarianism has traditionally left very little room for the consideration of beauty, while it is a central focus of the Land Ethic. I suggested that since the two ethics are so fundamentally different, they could not be accommodated on the same ground at the same time. And, further, since there are no rational means for deciding between the two, and since both approaches have strong bases of support in the U.S., the best hope for a resolution of conflict lies, I suggested, in a shamelessly political division of national forest land between the two camps. I still believe that is true and I do not believe that would be such a bad thing.

NEW FORESTRY

A major event that has also occurred since I wrote the title for this talk almost a year ago is that Forest Service ecologist, Dr. Jerry Franklin's notion of *New Forestry* (Franklin 1989) has achieved a large following in the west and appears to have been adopted as official policy in the *New Perspectives* program of the Forest Service according to several presentations I heard at this year's meeting of Western Forest Economists.

This embracing of Franklin's *New Forestry* has come about in conjunction with the controversy over the northern spotted owl -- a species that apparently depends for its survival on the continued existence of large areas of contiguous old growth forest.

This controversy centers on Oregon, Washington, and northern California, but has gained attention in the national press -- *Time Magazine, Wall Street Journal*, and the *Washington Post* among others. As you know, the old growth forests of western North America are characterized by the presence of huge trees -- diameters of six, eight, ten feet (2 to 3 m) and larger are quite common in many places.

Now, although there exist fundamentally different philosophies of forest management within the U.S., a synthesis of national opinion nonetheless arises in one way or another and it is this possibility of an arising synthesis that I wish to address today. There has been a lot of change in what the U.S. public says it wants from its publicly owned forests in the past thirty years. In 1960, as evidenced by the Multiple-Use Sustained-Yield Act (16 U.S.C. 528), the public was mostly concerned with what it could get *out* of its forests in the way of goods and services. It viewed the forests, in true utilitarian fashion, as a factory for the production of benefits -- a diverse factory to be sure, producing flows of recreation, wildlife and water as well as timber and forage -- but a factory nonetheless.

Today, the public has realized that it is concerned with more than just what it gets *out* of the forest, it is also concerned with what the forest like; it cares for the overall integrity and appearance of the forest. This concern for aesthetics is not traditionally central to the utilitarian ethic, but it is central to Leopold's Land Ethic and it is a concern -- not new, but freshly acknowledged -- that has not yet been (and perhaps cannot be) adequately incorporated into our rational, reductionist approaches to forest planning. Today, the public deplores an ugly and wounded-looking landscape, and it resists all attempts at rationalization by a defensive forestry profession. Furthermore, the public has decided that it deplores the demise of big trees and of old growth forests in the Pacific West, one of the few temperate areas where they remain standing.

As recently as ten or fifteen years ago, most professional foresters viewed old growth as something to be gotten out of the way. The future forest was to be a productive one (in the sense of net growth) where all the trees were to be under the age of culmination of mean annual increment, or CMAI. In the Pacific West, the public has slowly become aware that traditional forestry with its acceptance of growth-maximizing rotation ages implies the inevitable demise of big trees. Managing forests for maximum average net growth and cutting the trees when they reach CMAI means cutting trees that are generally twelve to fifteen inches (30 to 40 cm) and seldom more than twenty or twenty-four inches (50 to 60 cm) in diameter at breast height. Quite recently, the public has stated loud and clear that it does not want its future forests to be the timbered equivalents of feed lots for the production of veal. Even outside of designated Wilderness areas, the public wants a significant portion of its publicly owned forests to contain a proportion of huge trees. It has also found ecological justification for this aesthetic desire in the writings and positions of ecologists such as Dr. Jerry Franklin (Franklin 1989).

Since there is no legislative mandate for the management of big trees (the closest the National Forest Management Act of 1976 came was in addressing species diversity), their supporters have taken the expedient route of declaring an inhabitant of large areas of big trees, the spotted owl, to be a *threatened species* in order to avail themselves of the protectionist provisions of the Threatened and Endangered Species Act of 1973 (16 U.S.C. 1531, amended 1978). This listing is based on recent research by Jack Ward Thomas and an interagency committee (Interagency Scientific Committee 1990). However, before the Forest Service chose it for use in the planning process as an indicator species for the health of old growth forests, no one showed very much concern for the northern spotted owl. And, the strategy could still backfire: if timber industry-sponsored researchers, for example, were to show that the owl survived quite happily in second growth forests, the public concern for the continued existence of biologically mature forests would in no way be alleviated. As Neil Sampson has said, "Many of the natural resource issues that divide Americans most bitterly are publicly argued on grounds that camouflage the real value differences involved." (Society of American Foresters 1990).

Spotted owls found surviving in young second growth forests would not eliminate the public desire to maintain the integrity of large areas of old growth forest for essentially aesthetic reasons. Supporters of this view find themselves, I believe, forced to argue their case in terms of instrumental values (for example, the potential yet-to-be-discovered genetic value of rare species) because arguments of an aesthetic nature have not yet achieved a sufficiently high legitimacy in our still-utilitarian-dominated national psyche.

Although I have not abandoned my position that a political compromise is necessary because I see no other way to allocate land between mutually exclusive philosophies or value systems in the area of land use, today I would expect to see this be a three way division. Between intensive timber management and wilderness on the extremes, *New Forestry* emerges as an intermediate choice. Unlike some advocates I have heard, I am not ready to acknowledge that *New Forestry*, the latest in an expanding range of management options, should be applied on every acre of national forest land. I believe that many of the more productive lands are suitable and still desirable for intensive timber crop production to meet commodity needs; so, an important role for intensive forest management yet remains. I also believe that *New Forestry*, which implies accessible forests with timber harvest activities virtually everywhere, is no substitute for another acknowledged need -- a national Wilderness system.

Furthermore, it is not desirable for a large agency such as the Forest Service to do a sudden about-face and rush headlong in a new direction without adequate testing of new and incompletely-defined technology. (This was the mistake made with the blanket adoption of the computer model FORPLAN for planning on each and every national forest without adequate prior testing). Sudden and radical blanket changes in policy are not prudent because they tend toward system instability and further erode public trust. However, I think there is a clear national consensus that in the Pacific West (where we still have the option available) the U.S. public wants to maintain significant areas of big trees, and *New Forestry* appears to be a means for achieving this desire.

POLICY IMPLICATIONS

Now, what are the implications of allocating a significant number of thousands of acres to *New Forestry*? As all forest managers know, the maximum average rate of wood production is achieved when the rotation age is set at culmination of mean annual increment, CMAI. And, this applies whether we are dealing with even-aged or individual tree selection systems of timber management. The National Forest Management Act of 1976 mandates that trees not generally be cut before reaching CMAI and, whether we use cubic or board foot measure, this translates in the Pacific West to about 50 to 100 year rotation lengths. We are *not* talking about reproducing big trees here; we are talking about maximizing the wood producing potential of the forest, as Franklin himself acknowledges.

To maintain old growth forests, we have to start talking about retaining trees until they are 300, 400, 500 years old and even older; 200 years would be a minimum. Herein, I believe, lies a fundamental difference in operating assumptions that separates the industrial foresters from the environmentalists and creates seemingly irreconcilable conflicts of perception, as seen for example in the Audobon Society film "Ancient Forests -- Rage over Trees." The two sides cannot reach agreement over the very basic question: Are we overcutting the forests? A primary reason for this lack of agreement lies, it seems to me, in different operating assumptions assumed by the opposing parties. If we continue to accept rotation ages set equal to CMAI, then, on public lands in the West, we are probably *not* overcutting most places most of the time. But, if we wish to maintain large areas of old growth, a concept not even broadly considered when current planning methodologies were formulated ten or fifteen years ago, then we probably have been overcutting. This is overcutting, not due to malfeasance or incompetence, but due simply to the fact that forest managers and planners have always been taught that something close to CMAI was the right rotation age for managed trees.

Very simply, if we wish to maintain old growth outside of wilderness areas, we will have to adopt rotation ages of perhaps *five* times those we need for maximum wood production. And, if we are to have trees around that are three hundred years old in perpetuity, it is logically necessary that we also have trees around that are 250, 200 and 150 years old -- all of them well beyond Mason Gaffney's age of economic maturity! (Gaffney 1957).

This lengthening of rotation age inevitably means reduced annual cuts or allowable sale quantities under sustained yield management principles. And here lies the hard truth: reduced cutting levels inevitably mean lost jobs. Just how many is subject to debate, but the figure I hear most often in relation to Oregon and Washington is on the order of 25,000 directly-related jobs. Whether we should tamper with an already fragile imbalance of trade, and further violate our professed national belief in the doctrine of free trade by banning the export of unprocessed logs from all types of land in order to support a faltering timber economy is also subject to debate. Economic change is as inevitable as night and day. If the U.S. economy is to compete successfully in an international market, it cannot forever ignore the dictates of economic efficiency. Yet, personally, I see no reason why the desire of the public at large to maintain significant areas of old growth forest on what is, after all, its own land, should be sacrificed in order to avoid disruption of a number of small timber dependent communities.

A theme that pervades Leopold's work is the need for a *holistic* approach to problem-solving. Here the views of Leopoldians converge with those of systems science and behavioral science as espoused by authors such as C. West Churchman (Churchman 1979). A truly holistic approach to forest planning mandates "an approach that treats people as if people really mattered." (Simmons, quoted in Society of American Foresters 1990). A national decision to reduce harvest levels and lengthen rotation ages on some public lands in the Pacific West in order to maintain in perpetuity what the public perceives as "real" forests is legitimate and acceptable. However, 25,000 lost jobs in timber dependent communities in my mind represents an unacceptable level of human suffering -- suffering that social workers know will be translated into shattered egos, increased alcoholism, beaten wives and abused children, not to mention the lost economic potential of workers to the nation.

I am reminded of Britain in the 1960s. When that nation decided that it was no longer in its best interests to support coal mining activities in small inefficient coal mines at a loss to the Treasury, and that it was no longer in its best interests to rely so heavily on coal as a source of fuel when it created so much air pollution, the National Coal Board was faced with closing hundreds of collieries, many of them in small one-hundred percent coal mining communities that had developed very strong, close social ties to the resource. The nation did not abandon these miners to unemployment; nor did it shy away from inevitable social change that was seen to be in the larger national interest. Instead, the government built brand new communities -- *new towns* -- complete with industry and jobs, housing, shopping, entertainment, transportation and communication facilities. This was a much greater undertaking than providing a few night courses in truck driving. This was a major relocation effort, and it was not without its own set of social problems. But, for all its problems, it was much more humane and productive than the alternatives of either turning thousands of miners out into the street, or perpetuating an industrial situation no longer in the national interest. I suggest that an effort of similar magnitude might be called for in the case of timber dependent communities in the western U.S. The recipe might be different in design, but the effort should be no less sincere.

This cannot be construed as a form of welfare. It is a legitimate and long-established central role of government to provide infrastructure. So, when certain economies are dependent on government activity and for whatever reason, the government decides that a significant change in policy and attendant activities is called for, then it is the job of government to provide new infrastructure as appropriate. In this way, the hardship on dependent timber communities would not be entirely eliminated, but it could be much reduced. If the public at large wish to retain old growth timber, as well they should, then they should not expect a few loggers and mill workers to bear the brunt of the social cost.

Ironically enough, this kind of holistic forest planning would not be at odds with the writings of Forest Service founder Gifford Pinchot. At the end of the letter that he wrote to himself on his inauguration, February 1, 1905 (for signing by his new boss, Secretary of Agriculture James Wilson) are the instructions: "Sudden changes in industrial conditions will be avoided by gradual adjustment after due notice . . . " (U.S. Forest Service 1978). In sum, these words imply, first, that government must permit structural change to occur when it is in the larger public interest, and, they further imply that socially conscious forest planning must take people into account and plan for change in a way that minimizes the suffering of those whose livelihood is to be adversely affected.

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THE POLITICAL ECONOMY OF TIMBER PRODUCTION ON THE NATIONAL FORESTS OF THE UNITED STATES

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SUMMARY

Political pressures exist to increase the economic efficiency of timber management and production on the National Forests in the United States. There is growing belief both outside and within the Forest Service that current levels of timber production, and most particularly uneconomic timber production, should be reduced. Many argue that eliminating uneconomic timber management programs will both save money and reduce environmental degradation. This paper traces the political and technical evolution of the focus on economic efficiency in timber production and explores economic and institutional factors that are shaping the current policy debate.

Keywords: below cost, economic efficiency, timber sales, National Forests, forest policy

INTRODUCTION

Each year, private companies bid for the right to harvest timber on all 123 National Forests in the United States. The volume of timber sold totals about 50,000,000 cubic meters and accounts for 20-25 percent of the nation's wood production. Unfortunately, many individual Forests are unable to recover the costs of producing the timber; they lose money and are called "below cost Forests." Timber production on National Forests that lose money has become a focus of political debate in the United States.

The purpose of this paper is to examine the issue of below cost timber sales (and below cost Forests) by tracing its historical antecedents and exploring economic and institutional factors that are shaping the current policy debate. The historical overview demonstrates that concern with making money through public timber production has been a long-term issue in American forestry. It is the specific interest groups involved and the public policy objectives they are trying to achieve that are new.

HISTORICAL EVOLUTION OF THE BELOW COST ISSUE: THE HERITAGE OF PINCHOT

When Gifford Pinchot was receiving his forestry education abroad during the late 1880s, one of his German mentors remarked that a system for managing forests to ensure continuous production would not be established in the United States until some experiment would "prove for America what is so well established in Europe, that forest management will pay" (Pinchot 1947, p. 15). When he returned to the United States and was hired to manage the forests of the Vanderbilt estate in North Carolina, Pinchot's central objective was to demonstrate that forest management could pay the owner while improving the land. The working plan he prepared in 1892 prohibited any improvement cuttings that would cost more than they would bring in (Pinchot 1947).

Pinchot carried his goal of making forestry pay into his job as the first Chief of the US Forest Service (which had been created in 1905). But in spite of all he could do, he was unsuccessful. During the early years of the agency, the gap between receipts and expenditures remained (Wolf 1989). Before Pinchot left the Forest Service in 1910 he adopted a new approach. He argued that "the National Forests exist not for the sake of revenue to the Government, but for the sake of the welfare of the public" (Steen 1976, p. 91).

The next two Chiefs of the Forest Service, Henry Graves and William Greeley, were also beset with concerns about the ability of the National Forests to pay their way. Largely responding to Congressional concerns over how the Forest Service was spending its appropriations and Congressional expectations that the Forest Service would become self-sustaining, Chief Graves in 1914 classified National Forests according to how many were self supporting, how many would always lose money, and how many could be brought into the profit column in one, two, and 25 years. After going through this exercise, he predicted that within three years the agency would return more to the treasury than it received (Steen 1976; Wolf 1989). Graves' solution to achieving a profitable program of timber production led to more timber sales and larger sale volumes (Clary 1986; Wolf 1989).

During the administration of Greeley (1920-1928), the agency began to look more closely at the economic values of uses of the National Forests other than timber production. It began to assign dollar values to recreation activities and wilderness resources. Eventually the agency announced that recreation and wilderness uses were more than paying the costs of supervision (Steen 1976). This focus on dollars was felt by some to have influenced the design of the recreation program. For example, although many felt it was contrary to the public interest to permit privately-owned summer homes to remain on the National Forests, it was reported that they were permitted to remain because fees paid by their owners provided a steady stream of revenue to the agency (Steen 1976).

The fees charged to ranchers who graze their livestock on the National Forests have been contentious since the Forests were established in 1891. In 1911 the government's right to levy grazing fees had been upheld by the US Supreme Court. In setting those fees, however, the Forest Service used a different method than that used for timber.

Before any bids were accepted for a timber sale, the Forest Service set an "appraised price." No lower bids would be accepted. These appraised prices were based, directly or indirectly, on current market conditions. However, fees for grazing on the National Forests were always lower than fees for grazing on privately-owned lands. Pinchot justified this difference asserting that owners of small herds of stock could not survive competitive markets (Steen 1976). From time to time the agency proposed higher grazing fees. For example, a 1920 agency study proposed that the agency "charge for National Forest ranges what they are actually worth." But stockmen have always been able to develop enough political support to resist such increases. To this day, grazing fees are substantially less than market rates and the grazing program continues to lose money.

Stimulated by World War I, timber production on the National Forests continued to increase, until it peaked in 1926. Also during the twenties and thirties, one of the central tenants of American forestry--sustained yield--changed from a biophysical concept to a socioeconomic concept. Rather than managing the National Forests to provide a continuous flow of raw wood, management would be focused on ensuring the continued viability of the industries that produced end products from the wood and the vitality of communities containing wood processing plants. This change was recognized in law in the Sustained-Yield Forest Management Act of 1944. Two types of sustained yield units were established in accordance with the Act. Lands from one National Forest in the state of Washington were combined with lands owned by a private company and managed as one unit by that company. In contrast, in Arizona, California, New Mexico, Oregon, and Washington, timber harvested from certain National Forest lands were sold only to selected sawmills (Schallau and Alston 1987).

To achieve this new social goal of protecting timber companies, the Congress and the agency explicitly chose to underwrite monopoly situations for favored companies (Clary 1987). Supporters argued that eliminating competition and receiving lower prices for federal timber were more than offset by keeping mills open, avoiding social turmoil and unemployment, and the costs of welfare payments (Steen 1976). Nonetheless, it was an ironic choice; one of the principal driving forces behind the conservation policies of Pinchot and the conservation movement of the early 1900s had been to prevent monopolies from controlling natural resources.

Spurred on by a postwar housing boom, harvests from the National Forests began to play a more important role in the nation's overall timber supply picture. During the early 1950s, an official of the Forest Service wrote that revenues from timber sales had increased rapidly enough to provide a budget surplus. While the report included some questionable accounting practices, the article promised further increases in revenue from additional timber sales (Steen 1976). During Congressional deliberations over the Multiple-Use Sustained-Yield Act of 1960 the timber industry even argued that federal timber profitability should be the primary goal of the National Forests (Wolf 1989). If the cut were to be upped, however, it would have to be accompanied by an aggressive program of road building to provide access (Steen 1976, Clary 1986).

But by the late 1960s, it was recognized that then-current levels of timber harvest in the Pacific Northwest, the most productive forests in the nation, could not be sustained indefinitely under then-current timber management practices and environmental protection laws. At the same time, the agency recognized that shortening rotations, intensifying management, and accelerating road building in attempts to maintain harvest levels could have a variety of undesirable effects on the environment (USDA Forest Service 1969). The stage was set for a clash between desires to sustain high levels of timber harvest and the public's increasing concern for the environment (Reich 1962).

ECONOMICS IN THE ENVIRONMENTAL ERA

As the debates over timber harvest methods heated up in the late 1960s and early-to-mid 1970s, the issue of running the agency as a business and the unpleasantness of having expenditures that exceeded receipts again faced the Forest Service. This time, however, the debate was cast in environmental as well as economic terms. A wide array of interests would seek to define the issue and propose solutions. There would be those who believed that economics argued for reduced timber harvests, and those who believed that economics argued for increased timber harvests.

University economists were among the first to criticize the Forest Service for not paying enough attention to efficiency in management and for conducting an uneconomic timber program. For example, after a nationwide review of the economic characteristics of the National Forests, Clawson (1976) concluded that "a great national asset is poorly managed and unproductive." He observed that this was at least partly due to the attitudes of publicly-employed foresters:

> "They have emphasized ecological considerations, multiple use, sustained yield, even flow, community stability, and other concepts which....had little precise meaning to others or in practice" (p.766).

It is not necessary to accept or reject Clawson's conclusion of generally wasteful management to note that the ecological considerations and other "concepts" he mentions all limit the economic efficiency and profitability of timber sales. For example, Schuster and Niccolucci (1989) found that past receipts from timber sales in the Northern Rockies would have been 50 percent greater if non-timber resources had been ignored. This finding at least partly supports an argument repeated by Chiefs of the Forest Service for many years, at least since 1912: if the Forest Service stopped all non timber-related activities, then the National Forests could easily show a net profit (Steen 1976).

Economists may regret that economic efficiency does not play a more prominent role in timber production decisions. However, it was precisely because of criticisms charging that opting for the cheapest way of harvesting timber resulted in environmentally damaging clearcuts that the National Forest Management Act (NFMA) was passed in 1976. NFMA and the detailed regulations or "rules" for its implementation recognized that economic efficiency would be constrained in various ways. NFMA directs that plans to guide management must "...insure consideration of the economic and environmental aspects of possible schemes of management," but that "...the harvesting system to be used is not selected primarily because it will give the greatest dollar return" (NFMA, Sec. 6 g3 (A) and (E, iv)). The regulations introduce a new term of "cost efficiency." By definition, cost efficiency recognizes that "some outputs, including environmental, economic or social impacts, are not assigned monetary values but are achieved at specified levels in the least cost manner" (36 CFR 219.3)

While NFMA and its implementing regulations constrain actions to maximize economic efficiency, they are also notable for their emphasis on rational analysis, and particularly on economic efficiency analysis. This emphasis, no doubt, partly was in response to past criticisms offered by Clawson and other economists. Probably more important, however, was the election of a business-oriented president in 1980, Ronald Reagan. He appointed a lawyer from the Louisiana-Pacific Timber Company as the political head (called Assistant Secretary) of the Forest Service. The Assistant Secretary immediately announced that timber harvest levels on the National Forests should increase greatly. One action he took to bring this about was to direct the Forest Service to pay more attention to economics. He revised the regulations guiding forest planning in part by greatly expanding the role of economic analysis. Numerous economic analyses were to be conducted and the results were to be used in making decisions. And the analyses were to be made public. He firmly believed timber harvest levels would increase.

He was wrong. On the most productive Forests, environmental constraints led to few increases in production and numerous decreases. On many of the less productive Forests, the economic analyses showed then-current timber harvest levels were losing money. And since the information was made public, those who opposed timber harvesting and those who opposed losing money joined forces to attempt to bring about reductions in harvest levels.

While the Reagan Administration relied upon economic analysis to provide a rational basis to increase harvest levels on the National Forests, others proposed more radical changes. During the early 1980s, for example, "privatization" also gained currency as a policy concept. Some economists argued that public lands ought to be put into private ownership to reduce the national debt and eliminate the costs of federal management (Short 1989). So long as lands were kept in public ownership, privatizers called for user fees to reflect the actual cost of all goods and services provided by public lands--including recreation. One economist claimed that if user fees were increased by 2000%, the National Parks could become self sufficient (Short 1989). Another economist argued that the Forest Service be turned into a quasi-public corporation, its Congressional appropriations be altogether eliminated, and all its management activities be funded on a fee basis from all users (O'Toole 1988).

Nonetheless, privatizers have had difficulty building the necessary political support base. Environmentalists fear the adverse ecological consequences of private development. More surprising, however, not one commodity group has supported the privatizers. Ranchers, for example, fear they will not be able to afford to pay the prevailing rates to graze cattle on private lands. And the timber industry has been silent on the whole subject. As a result, even the pro-development, anti-government Reagan Administration backed away from the privatization argument during its eight years in office (Short 1989).

It was, however, expressions of dismay by environmental interest groups during the 1980s that elevated the issue of the economic efficiency of timber production on the National Forests to a major public policy debate, and sparked Congressional interest in the issue. The studies that gained the most attention were those conducted by the Natural Resources Defense Council. Comparing timber receipts with timber management costs, the Council examined individual sales as well as the entire Forest Service program. It also coined the term below cost timber sales to characterize what it saw as economically and environmentally undesirable timber practices. Related studies of below cost sales were made by Resources for the Future, a not-for-profit research foundation, and the Wilderness Society. Two agencies of the US Congress, the Congressional Research Service and the General Accounting Office, also made studies, and Congress held hearings. Basically all of the studies came to the same conclusion: many timber sales were losing the US taxpayer money (O'Toole 1988; Wolf 1989). A Forest Service study of four National Forests also found that less than desireable management activities were necessarily reducing the profitability of timber production (USDA Forest Service 1986).

The Forest Service responded with the rationale Gifford Pinchot had come to embrace: that "maximizing profit is not the primary objective of National Forest management and that public forests are managed for numerous values other than the money they can produce" (quoted in O'Toole 1988, p. 32). By the mid-to-late 1980s, however, arguments that uneconomic timber programs are in the national interest because they are used to improve wildlife habitat, or to further the health and productivity of forests, or to support rural employment and community stability had lost credibility and acceptability. There simply was no convincing evidence that commercial timber production makes significant contributions to improving most non-timber values, and it became unpopular to argue that taxpayers should continue to subsidize companies and communities when the federal debt was at record levels. To a skeptical public and environmental community, such arguments had simply become an excuse to rationalize the agency's bias towards timber production.

As the decade of the 1990s begins, it is clear that the pendulum has swung to the environmental side. Witness the growth in environmental group membership and in the field of environmental law. In 1975 there were 200 environmental groups with a total membership of 4 million; today there are 350 environmental groups with over 12 million members, In 1971, at the start of the environmental era, the Environmental Law Reporter carried 33 pages of environmental law, today it carries over 3,500; the number of environmental law attorneys has grown from a few hundred to over 20,000 (Gilbert 1990).

From the environmentalists' perspective modern economics is far different than it was in Pinchot's day. Today, environmentalists and preservationists argue that the economic values received from recreation and tourism exceed those from logging. The "greatest economic as well as ecological benefits can be derived by managing National Forests primarily for multiple uses other than timber" (Foreword by G. Frampton in Pinchot 1947, p. xxi).

Even voices within the agency have begun to question whether too much emphasis is being put on commodity production to the detriment of other resource responsibilities. In 1989 a new organization was formed by employees (Association of Forest Service Employees for Environmental Ethics) to press for greater agency sensitivity to ecological concerns. At the same time, Forest Supervisors from areas of the country where timber production is most important wrote three separate letters (later made public) to the Chief of the Forest Service to express their concerns that past and present forest practices were not meeting the quality standards of land management expected by the public and agency employees. They asked for more "balance," that is, for greater attention to the protection and development of non-timber resources.

The issue of below cost sales has also been recently addressed by Congress and the judiciary. While the President's political appointee was arguing for higher timber harvest levels, many in the Congress were not convinced. Congress was far more sympathetic to those who argued that harvest levels should be reduced, at least in part, because money was being wasted. Congress addressed the issue in several hearings. Arguments to maintain harvest levels as a source of employment in rural areas, regardless of cost, were made repeatedly. Because of the political power of this argument, and because of the general complexity of the issues surrounding below cost sales (Schuster and Jones 1985), there was no consensus. However, the Forest Service was directed to correct one deficiency: it was directed to design a new accounting system to report all costs and benefits of the timber sale program. This system, TSPIRS (Timber Sale Program Information Reporting System), is the first attempt in the federal government at cost accounting of a revenue-producing program (Schuster and Jones 1989). TSPIRS generally follows the accounting principles of annual corporate reports.

The first "official" TSPIRS report was released for 1989. It shows cash receipts for the right to harvest timber were about twice the costs of timber production (ignoring the cost to the federal government of "payments to states" or revenue sharing). However, more than half of the National Forests lost money on their timber programs. Critics claim TSPIRS still underestimates costs and that the entire timber program costs exceed receipts (e.g., Wolf 1989). The agency and others judge TSPIRS to be adequate (e.g., US General Accounting Office 1990).

Under instructions from the President's office, the Forest Service has proposed an experiment focused on below cost sales to the Congress. Money-losing timber sales are to be cancelled on nine below cost National Forests. To the extent feasible, replacement timber that could earn a profit will be substituted. Because there will not be enough profitable timber, overall harvest levels will have to be reduced. This poses three problems:

--(1) The timber industry may not have enough timber to process in their mills. No specific offsetting actions to benefit the industry have been proposed.

--(2) Employment in the timber industry may decrease. To mitigate such impacts, it is proposed that additional monies be spent developing recreational opportunities on the nine Forests. The hope is that additional recreationists will be attracted who will spend money for food and lodging and so forth in the nearby towns, thus stimulating employment in the recreation industry.

--(3) Revenue sharing of timber receipts would decrease. It is proposed that certain fees for recreational use of the Forests be increased, thus providing a basis for sharing revenues with the states.

At this time, it is unknown whether the Congress will agree that the experiment in replacing some timber production with increased recreation activities should be implemented.

Those opposed to currently planned levels of timber harvest have also taken their case to court, arguing that not enough attention has been paid to economic factors and to alternatives that call for relatively low timber harvest levels. A federal judge agreed this was true on the Rio Grande National Forest in Colorado. He found, in part, that the agency had focused almost entirely on sustaining a money-losing timber program and had not seriously considered lower levels of timber production. He directed that the agency study at least one alternative representing a profitable (and much lower) timber program. This is the first time the judiciary has ever stated that the Forest Service has an obligation to even consider a money-making timber production program.

CHANGING ISSUES, CHANGING STAKES

As the previous discussion demonstrates, concern about the economic returns of National Forest management have been expressed by a variety of interests throughout the agency's eighty-five year history. However, during that time economic arguments have been used differently by different interests. In the early years of the Forest Service it was the agency that was most concerned with demonstrating that forestry could pay. During the last quarter of a century, it has largely been external interests that have advanced arguments that decisions concerning the National Forests should pay greater attention to economic efficiency criteria.

However, the debate is not really about economic efficiency per se. Economic efficiency has been a surrogate issue for alternative visions of a desired end state. Various interests embrace or reject economic arguments in particular circumstances depending on whether or not the numbers and results will be in their favor.

For much of the history of the conservation and environmental movement, environmentalists worked to limit the application of economic criteria to resource decisions. They insisted values other than economics must be given full weight when decisions are made. One of the leading intellects in the history of natural resources, Aldo Leopold, for example, explicitly rejected public lands policy based on economics alone (Leopold 1966).

These arguments have been influential. Concern that the basis for federal development decisions had to be broadened beyond technical and economic criteria directly contributed to passage of the National Environmental Policy Act in 1969 and its requirements that federal agencies publicly disclose the negative environmental effects likely to result from their actions. And, the National Forest Management Act prohibited selecting a particular timber harvesting system solely because it was most efficient.

It is only recently that environmentalists have come to embrace economic efficiency criteria. Timber sales are being held up to strict economic tests in an effort to reduce harvesting and to preserve virgin lands from development. A premise of this approach is that in tomorrow's public market, non-commodity resources will be assigned higher economic values than traditional commodity resources, that is, there won't be harvesting on those lands in the future, either.

There are, however, dangers to a firm advocacy of an economic test for making natural resource management decisions. If today's below cost timber sales became tomorrow's profit-making timber sales (which has already happened to some extent as markets have improved), would environmental groups reverse themselves and support increased timber harvests? There is considerable evidence to the contrary. In the Northwest area of the country where timber harvesting produces considerable revenue, environmental groups are vigorously fighting plans to continue cutting old growth forests that are the habitat for the northern spotted owl.

According to the TSPIRS report, a relatively few Forests account for most of the revenues earned by timber sales. Seventeen of these highly productive National Forests are located in the West Coast states of Washington, Oregon and California. These Forests earned $611,000,000 U.S. from timber sales last year. In total, the other 106 Forests earned only about $130,000,000. However, the 17 Forests also contain northern spotted owls, which has been formally listed as a threatened species under the Endangered Species Act. Because of the environmental and public pressures to preserve habitat for this bird in the same stands that are most valuable as a source of commercial timber, timber harvest levels are expected to decline by perhaps one half on these productive Forests. Nowhere in the United States is the clash between environmental values and the values associated with development activities drawn more sharply.

It is likely that the public debate over the economic efficiency of grazing on the National Forests will soon intensify. If timber production should pay for itself, why shouldn't forage be sold at its market worth and the agency's range program make money? It is not clear, however, how far concerns over economic efficiency will extend. What about the other goods and services for which the National Forests are managed: recreation, wildlife, water, wilderness? Should recreational activities that bring in significant receipts receive higher priority than others? One bill introduced into Congress this year by a member from the Northwest would require that the dollar costs of each noncommodity to be produced--including the opportunity costs of not producing commodities--be made public.

As it did during the late 1950s and again during the Reagan Administration, industry is more likely to pay attention to profits and economic efficiency when they believe the numbers and results will be in their favor. They are likely to be less inclined to take such positions if it would result in reduced sales, which would be the result if a profitability test were currently applied (Wolf 1989). Faced with criticism that some timber harvesting both destroys scarce old-growth habitat and loses money, the industry has instead been just as likely to argue--as the Forest Service frequently argues--that other societal goals justify maintaining existing levels of timber harvests. In a report released last May, the industry states:

> Unfortunately, the valuation methods used in the 1990 RPA Program focuses solely on "does it pay?" This approach rejects out of hand the possibility that many individuals, classes of citizens, or communities may be treated unfairly....not considered are the ramifications of not offering the timber sale such as a displaced work force, the social costs of retraining the work force, and loss of receipts to local communities (National Forest Products Association 1990).

In the last few years, the timber industry has increased its claims that equity and the undesirable consequences of too little timber harvesting should lead to increased levels of harvesting.

There have been numerous alternative views about the legitimate role of the government in forestry. Markets exist within societies and it is the political process that determines which activities are legitimately performed by government and its agencies and which by markets (Alston 1983) The one thing that society has not done throughout American history is to assert that government programs have to pay for themselves. In fact, many natural resource programs were introduced because they were seen as necessary to promote certain social and economic interests. Federal water development programs, for example, were an integral part of the nation's economic development plan, particularly in the West. Federally subsidized power projects both provided cheap power and harnessed rivers for agriculture. Government actions have been seen as necessary when private sector actions will not give the desired result.

Governments build and maintain the social order in part by directly providing goods and services. But governments also need to maintain the political order. As political scientist Bruce Shepard has pointed out in commenting on the below cost timber sales issue, "furnishing goods and services to people below cost is an old recipe for maintaining political will and for stimulating bureaucratic growth" (Shepard 1990).

While government programs are still not expected to pay for themselves, the trend in the United States is to scale back on the size of the federal obligation. For example, in the area of water resources development, the federal government is moving away from fully-funded resource development programs; local beneficiaries are now expected to assume more of the costs. The political tendency to provide federal subsidies for social and political purposes is conflicting with the need to reduce the national debt. The federal government's growing unwillingness to maintain timber harvests to assure the economic vitality of communities that grew around and are maintained largely by timber harvesting from National Forests may be a similar trend in the forest policy area.

CONCLUSIONS

One of the criticisms Marion Clawson made in 1976 was that National Forests are wasteful in their use of capital because they hold timber inventories beyond accepted standards of economically optimum rotations. Stated Clawson: "One can readily imagine the reaction if every citizen of the United States was asked to contribute $3 annually toward the maintenance of an excess inventory of old trees that he might never see" (Clawson 1976 pp.764-765). Today, Clawson might receive a different reaction than the one he anticipated in 1976. This is especially so given the intensity of the debate about saving old-growth National Forests, which is cover news for national magazines, feature stories on the nightly network news, and a cornerstone of fund raising efforts for environmental groups.

The current debate about below cost timber sales is, in part, a continuation of long-existing concerns about the wise use of tax dollars on the National Forests. But in larger part, the current debate over the economic performance of timber production reflects a more fundamental struggle over land use. Politically, the United States is trying to decide how much timber harvesting on the National Forests is in the public interest, based on the values held today by its citizens. Concern over the economic efficiency of timber production has manifested itself in various ways over time. How the concept is advanced, by whom, and for what, is being fashioned by dynamics in the political arena more than in the marketplace.

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A STUDY ON MANAGEMENT

AND YIELD REGULATION OF UNEVEN-AGED FOREST

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SUMMARY

Through the study on uneven-aged forest stand in the past six years, the determination of an optimal management decision and an optimum yield regulation decision for uneven-aged forest stand can be formulated as a mathematical programming problem, and a problem of dynamic optimization. In this paper, we collected a lot of materials on growth, site quality, production cost, return investment of uneven-aged forest management in three regions. All of results were examined with softleaf-fir(Abies nephrolepis)stand of the Northeastern and Northwestern forest regions of China, and demonstrated that these results of research are of great value to forest managers in harvesting decision making and forecasting output of timber.

Keywords: Uneven-aged forest management, Yield regulation, Mathematical programming, Dynamic optimization.

INTRODUCTION

The study on forest management and yield regulation of uneven-aged forest can both explore the relation between the internal structure of uneven-aged forest and the purpose of its management, thus bringing its productive potential into full play, and provide the optimum management goal and the optimum regulation way for the actual forest.

The present international study on uneven-aged forest is still at an isolated stage of research on its individual factors, in spite of the introduction of system theory into forest yield regulation for 20 years, an integral management system of uneven-aged forest and the method of solving yield regulation have not yet been worked out.

Although some experts in forestry and ecology through research affirmed selection cutting system far exceeded clear cutting in both benefit and protection of forest resources, the study on selection forest in China still remains a gap. Because strategy departments have not completely understood the internal machanism of the reduction of forest resources, they did not pay enough attention to it. For example, in Heilongjiang Province where nearly one half of timber of China is produced, based on statistics, because of clear cutting, reforestation could not be conducted, or conducted untimely, including man-made or natural reasons, 851,000 ha of forest land area owned by the Forest Industrial Interprise Heilongjiang Province decreased within 10 years (1976-1986), approximately equal to three larger Forest Interprise If things go on like this, how many decades can the 40 Forest Interprise survive?

In view of the present situation, we started the research project---- "A Study on Management and Yield Regulation of Uneven-Aged Forest" from 1982. In 6 years, the fir forests in Northeast forest region and the main uneven-aged forest ditribution areas in the Northwest forest region were studied, and the research results passed appraisal in June, 1988. In the research, was discovered the law of dynamic change of uneven-aged forest through analysing and estiblishing models, and on this basis was also established the multi-goal optamization models of seeking the optimum management plan of uneven-aged forest, as well as the optimum control models of the yield regulation of actual forest. The chart of research procedure is illustrated with Fig.1.

METHODS OF RESEARCH

From systematic viewpoint, uneven-aged forest is a complex ecosystem , generated from selection cutting system. Both the age structure and the process of forest growth of uneven-aged forest are more complex than those of even-aged forest, mostly existing in the form of mixed forest, in particular, it is a sustained-yield working unit itself.

Because the position, stage of growth and the ability of competition of each tree in uneven-aged forest are random in certain period of growth, it may grow to greater diameter grade or remain in the initial diameter grade, or wither and die, or be cut. In addition, some ingrowth trees enter into system in the end of growing period. For this reason, probability was adopted to reflect the state of one tree in the future moment, and on the basis of ingrowth equation, the probability value of the the lowest diameter grade of system was corrected.

Taking the natural dynamics of the number of trees in a stand in one growing period as the basic constraint, and according to the cut not exceeding growth, cutting percent and diameter grade, ecology and regeneration-demands as a series of constraints, we set up 4 optimum management models respectively, i.e., of maximum total yield, maximum total money profit, maximum net profit, and optimum multi-goal, and the 4 models formed an integral theoretical system, thus providing the optimum management strategy, including the cycle length of selection cutting, optimum residaul number of trees and their distribution in the stand and optimum yield, for different stand conditions and management levels and demands, and also providing optimum objective function and circumstance analysis for regeneration conditions.

Because the actual uneven-aged forest falls far short of the requirements of optimum management models either in diameter distribution and the cycle length of selection cutting or in the composition of tree species, especially in diameter distribution, the main objective of our regulation lies in the quickest transition from irrational diameter distribution to optimum state, on the premise of making production bear the least losses. Although this has been the aim of forest yield regulation all along, internationally, it

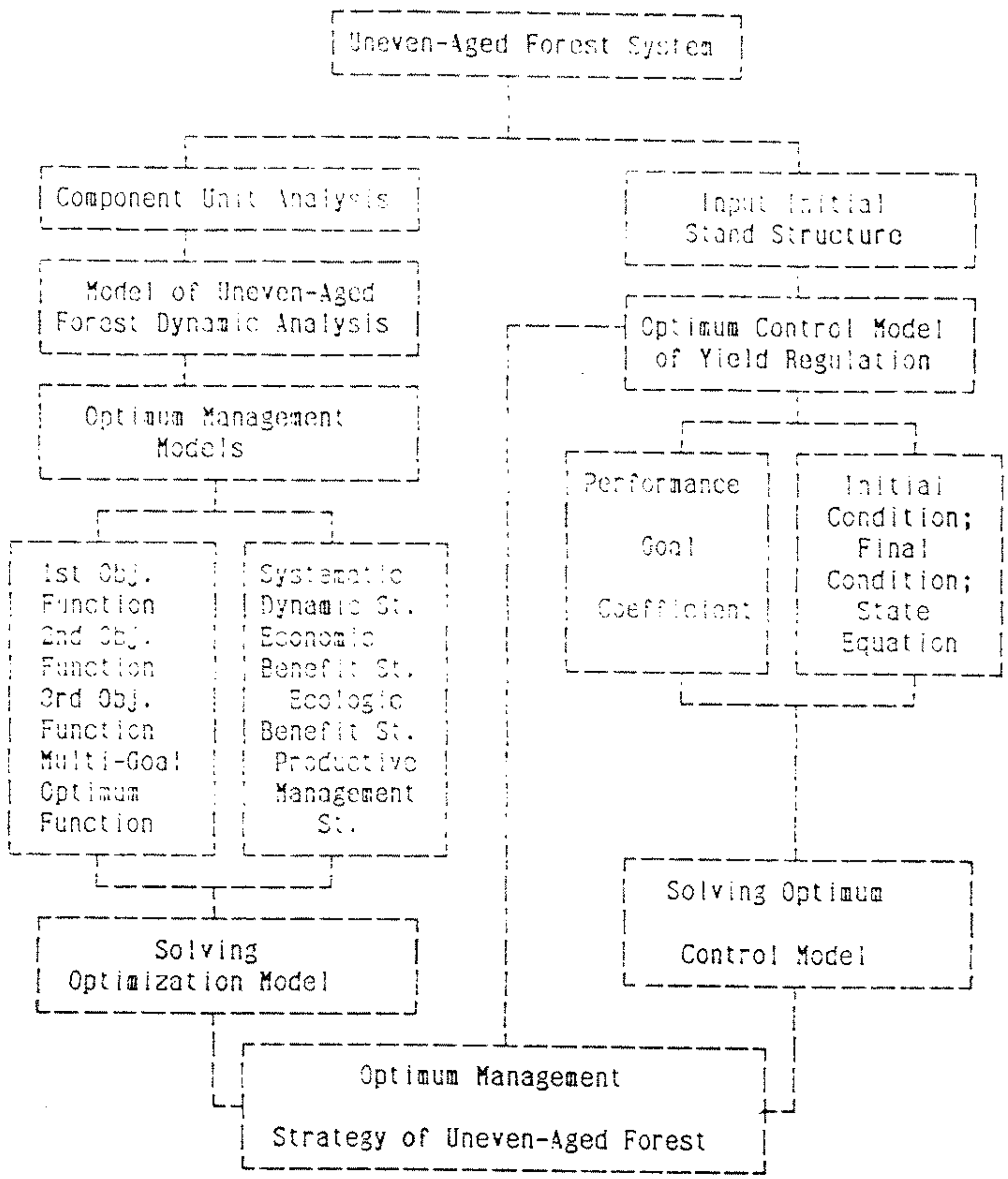

Fig.1 Chart of Management and Regulation of Uneven-Aged Forest

has not become quantitative yet, only expounded theoretically, but not implemented in practice. Through a great deal of analysis and study, it is considered that this problem can be solved by means of optimal control theory. The number distribution of actual uneven-aged forest can be taken as intial state, the diameter distribution of requirement in the models of optimization management as final state, the yield of different regulation stages as decision variables. Thus, the problem of yield regulation of uneven-aged forest can be considered as that of discrete-time optimum control, of which the initial state is unfixed, whereas the final state is fixed. Different regulation instalments in the regulation period are the time point of decision-making, and the changing law of the actual forest number is systematic state transition equation. From this, the length of instalments can be changed, and the regulation effects analysed, thus selecting corresponding optimal regulation way. Because the initial diameter distribution of stand has different possibilities, the optimal yield regulation way can be found for different initial state stands, through optimal regulation model. Detailed analysis and application of this method have been appraised and published.

Owing to the limited space of the article, the selection and match, analysis and proof of the model can not go into details. The skill to solve such an enormous optimal control model by computer can neither be expounded in detail.

Therefore, we give, respectively, a brief account of our research results of the spruce & fir forests in the Northeast forest region, the spruce forest in the central-east of Tianshan Mountains in Xinjiang Province and the fir forest in Gansu Province for the reference of different regions in management.

RESEARCH RESULTS IN DIFFERENT REGIONS

By the above-mentioned method, research was conducted on the management and yield regulation of the spruce and fir forests in the Northeast forest region, the spruce forest in the central-east of the Tianshan Mountains and the fir forest in Taohe in Gansu Province. The research provided optimal selection cutting cycle and stand structure for different objectives and for different types of uneven-aged forests, paving the optimum way for actual forest regulation.

Most of the uneven-aged forests in the northeast forest region grow on the gentle-slope watershed 600-1,400m above sea level. Their dominance is spruce (Picea koraiensis and P. jezoensis), with other accompanying species such as conifer and broadleaf trees. Here we chose natural mixed forest of midimum site class with predominant fir (Abies nephrolepis) as this type's typical representative for our research. The Northeast fir forest is an abbreviation for this type of fir in the following paragraphs. The representative type of uneven-aged forest in the alpine belt of our country is the pure conifer forest with the predominant Tianshan spruce(Picea schrenkiana var. tianshanica) distributed in Tianshan forest region in Xingjiang Province, and the conifer mixed forest with the composition of Minjiang River fir (Abies faxoniana) and Bashan Mountains fir (A. fargessi) in Taohe valley in Gansu Province. We made research on the spruce forest growing on the northern slope of Tianshan Mountains and the fir forest of Taohe in Gansu, all selecting the stand of medimum site class.

Most original data of research are derived from the materials of fixed sample plots through continuous inventory of resources in different regions. At the same time, some additional temporary sample plots are also established, including 51 plots in the northeast forest region (among them are 36 fixed sample plots), 52 plots in Xinjiang forest region, 30 plots in Gansu. The diameter grades of either fixed sample plots or temporary plots are regularized by a space of 4.0cm, with the lowest diameter of 6.00cm, the areas of sample plots varying from 0.08 to 0.12 ha, at the intervals of 5 to 10 years, and the diameter grades varying from 10 to 11.

Based on the above-mentioned materials of the sample plots of the three regions, after sorting out the materials, different concrete measures and ways were achieved for the management and regulation of the uneven-aged forests in the three regions. All the calculations were completed with the medimum typed computer M-340s at the Computer Centre of Beijing Forestry University.

I. The Stimulation Results of Growing Models

On the basis of ingrowth model formula ($I_t=\beta_0+\beta_1\sum B_i(X_{i,t}-H_{i,t})+\beta_2\sum(X_{i,t}-H_{i,t})$), the ingrowth models of the 3 regions are obtained as follows:

1. The Northeast fir forest:

$$I_t=183.03386-9.60326\sum_{i=1}^{n}B_i(X_{i,t}-H_{i,t})+0.16360\sum_{i=1}^{n}(X_{i,t}-H_{i,t})$$
$$(40.679)\quad(2.310)\qquad\qquad(0.028)$$
$$R=0.6432 \qquad (n=11)$$

2. The spruce forest in Xinjiang:

$$I_t=48.58777-3.52025\sum_{i=1}^{n}B_i(X_{i,t}-H_{i,t})+0.13854\sum_{i=1}^{n}(X_{i,t}-H_{i,t})$$
$$R=0.7590 \qquad (n=10)$$

3. The fir forest in Gansu:

$$I_t=94.30079-4.275357\sum_{i=1}^{n}B_i(X_{i,t}-H_{i,t})+0.09319\sum_{i=1}^{n}(X_{i,t}-H_{i,t})$$
$$R=0.66057 \qquad (n=10)$$

where:

- I_t: the number of ingrowth in one growing period;
- B_i: the average area of a tree in i.th diameter grade;
- X_i: the number of living trees i.th diameter grade before cutting;
- H_i: the number of cut at end of growing period;
- n: the number of cut;
- R: correlation coeffecient;

All the three models appear marked linear cross-correlation through cross-correlation test. Likewise, growing transfer matrix and constant vector C, after correction in different regions, can be obtained, and also, the mortality matrix of different regions.

Judged by the nature of transfer matrix after correction, it is not astringent. Consequently, we can infer that uneven-aged forest itself is not in the stablestate without any man-made interference, and this also shows that the present form is only a certain stage of natural succession, non-climax community. Man-made management control must be carried out so that the uneven-aged forest may remain in the optimal state of management.

II. Optimal Management Strategy

The management factors of uneven-aged forest influence one another, while the optimal management model is established on the a selection cutting cycle can take arbitrary multiple in growing period. But considering the check cycle of China's forest resources and management actual conditions, we chose 5-year multiple as selection cutting cycle. Owing to the difference of resources, economic conditions and the present situation of management in different region, we made definite analysis of optimum management strategy for different selection cutting cycles, and, through the comparison of objective function value of different selection cutting cycles, determined the corresponding optimum selection cutting cycle and optimum stand structure of different regions and different management goals. They are related respectively as follows:

1. The management strategy of maximum yield:

The production of timber is and will still be one of the major objectives of forest resources management at present as well as in some time of the future. The following formula is considered as the objective function

$$H=\text{Max}\sum_{i=1}^{n} V_i(X_i-H_i)$$

where:

H: maximum yield(m^3);

V_i: the average volume of a tree i.th diameter grade;

X_i: the number of living tree i.th diameter grade in begining of a cutting cycle;

H_i: the number of cut in a cutting cycle

solution of optimal management models. Owing to the limited space of the article, only the fir forest of the Northeast forest region is taken as an example to explain the method of solving and determining the optimal management strategy. Only the results are listed as follows:

Table 1. Optimum Stand Structure of Maximum Total Yield

Diameter Grade (cm)	Selection Cutting Cycle (yr.)					
	5	10	15	20	25	30
8	1055.6	549.4	262.4	154.1	123.1	101.2
12	722.3	408.4	196.3	127.8	111.1	99.5
16	619.1	384.4	165.9	107.6	94.9	86.9
20	241.4	295.8	140.5	90.0	73.0	74.0
24		208.9	125.5	80.8	70.0	62.8
28		82.4	119.3	76.8	67.1	53.8
32		11.2	90.3	76.8	61.0	49.6
36			33.1	56.8	41.7	35.0
40			5.1	28.1	26.7	27.4
44			0.1	8.1	16.7	21.5
48				3.5	18.0	26.5
Total Area(m^2/ha)	33.090	38.951	35.435	32.861	31.761	31.162
Total Number(n/ha)	2638.5	1939.3	1138.4	810.4	708.5	643.3
Total Volume(m^3)	220.94	294.90	294.31	286.70	282.78	281.22
Yearly growth(m^3)	11.783	10.314	6.868	5.018	3.959	3.281
Yearly growth rate	6.15	4.23	2.82	2.12	1.70	1.41

In Table 1, the optimal management strategy is listed when the selection cutting cycles are 5, 10, 15, 20, 25 and 30 years. The table shows that the maximum annual average yield is when the selection cutting cycle is 5 years. It is also proved that if the selection cutting cycle is continuously shortened, the annual average yield can be even greater, for the shorter is selection cutting cycle,the more timely eliminates mutual competition among trees, so that the retaining trees can fully grow, thus raising the level of annual average yield. If only considering the yield of timber, 5 years can be chosen as cutting cycle. But in practice, the shoter the cutting cycle, the higher the cutting cost, and the more intensive required.

The Table 1 shows that when cutting cycle changes from 5 years to 10 years, the annual average yield drops only by 1.469(m^3), while if the cutting cycle is 15 years, the annual average yield will drop from 11.783 (m^3) to 6.868(m^3); therefore, we consider it more suitable to choose 10 years as the cutting cycle in the local region. In this way, both the

Table 2. Cutting Tactics with Maximum Total Yield

Diameter Grade(cm)	Cutting Cycle(yr.) 5	10	15	20	25	30
	Resedual Stand					
8	1055.6	548.4	262.4	154.1	123.1	101.2
12	722.3	408.4	196.3	127.8	111.1	99.5
16	619.1	384.4	165.8	107.6	94.8	86.9
20	4	295.8	140.5	90.0	78.3	74.0
24		75.6	125.5	80.8	70.0	62.8
28			119.3	76.8	67.1	
32			2.8	76.8	5.8	49.6
36					41.7	35.0
40				1.3		
44						
48				3.5	18.0	26.5
Total Area(m^2/ha)	25.605	26.952	24.404	22.456	21.452	20.791
Total Number(n/ha)	2397.0	1717.5	1012.5	718.7	610.0	545.2
Total Volume(m^3)	162.03	191.78	191.29	186.35	183.80	182.79
	Cut Stand					
8						
12						
16						
20	241.4					
24		133.1				
28		82.4				58.88
32		11.2	87.55		54.3	
36			33.1	56.88		0.1
40			5.1	26.8	26.7	27.4
44			0.1	8.1	16.7	21.5
48						
Total Area(m^2/ha)	7.485	11.999	11.031	10.405	10.309	10.371
Total Number(n/ha)	241.4	226.7	125.9	91.7	97.7	107.8
Total Volume(m^3)	58.91	103.14	103.01	100.35	98.98	98.42
Yearly Yield(m^3)	11.78	10.31	6.87	5.02	3.96	3.28

cutting costs can be reduced, and the annual maximum yield considered . Consequently, we prefer to adopt the management strategy of 10 years' cutting cycle.

Here we can also consider the optimal management strategy of producing different timber species. The production of timber of either big-diameter, or medimum-diameter and small-diameter can only be solved by adding one constraint.

The management strategy of the maximum total yield in different regions can be obtained from the original materials of different regions(see Table 3).

Table 3. The Stand Structure of the Maximum Total Yield in Different Regions

Diameter Grade (cm)	Optimal Cutting Cycle in Different Region		
	Northeast Fir-Forest	Spruce For. in Gansu	Fir-Forest in Xinjiang
	10	10	15
8	548.4	1006.8	275.0
12	408.4	655.3	157.7
16	348.4	570.3	131.6
20	295.8	483.1	124.4
24	208.9	213.5	96.8
28	82.4		112.2
32	11.2		40.6
36			37.9
40			13.3
44			2.7
48			
Total area(m^2/ha)	38.951	48.770	30.254
Total Number(n/ha)	1939.3	2929.0	1032.5
Total Volume(m^3/ha)	294.90	310.88	248.97
Yearly Yield(m^3/yr)	10.314	7.663	6.636

Table 3 shows that the optimal structure of stand in the 3 regions is different, and so is cutting cycle, and that the yield of fir forest is by far greater than those in Xinjiang and Gansu Provinces. In the optimal structure of stand, the big -diameter trees are dominant in Gansu fir forest, while in Xinjiang spruce forest, the small-diameter trees are dominant, and the fir forest in the Northeast is comparatively moderate. Table 4 shows that the cutting percent of Gansu fir forest is the greatest, up to 40.0%, and that of Xinjiang spruce forest, the smallest, only 24.6%, whereas the fir forest in the Northeast accounts for 34.9%; and that the number of trees in residual stand and the level of growing stock degree are also very different. It is obvious that the uneven-aged stands, though with the same management goals, are of marked difference in management strategy.

2. The mnanagement strategy at the maximum present net worth of the total profit:

Owing to this goal relating discount rate and simple interest of the present credit in China, there is no standard value of discount rate. We can

Table 4.The Management Strategy of The Maximum Total Yield

Diameter Grade (cm)	Northeast Fir-Forest (C=10)		Spruce-Forest in Xinjiang (C=10)		Fir-Forest in Gansu (C=15)	
	Res. Stand	Cut Stand	Res. Stand	Cut Stand	Res. Stand	Cut Stand
8	548.3		1006.8		274.7	
12	408.4		655.3		157.5	
16	348.4		570.3		131.5	
20	295.8		483.1		124.3	
24	75.6	133.11		213.5	96.8	
28		82.4			31.4	80.8
32		11.2			40.6	
36						37.9
40						13.8
44						2.7
48						
Total Area(m^2/ha)	26.952	11.990	39.111	9.659	19.270	10.981
Total Number(n/ha)	1712.5	266.7	2715.5	213.5	856.8	135.2
Total Stock(m^3)	191.76	103.14	238.26	76.63	149.44	99.53
Yearly Yield(m^3)		10.314		7.663		6.636

only assume some discount levels, and the optimum management strategy of different discount rates can be obtained by the following formula:

$$T=\sum_{i=1}^{n} \frac{P_i(X_i-S_i)}{(1+r)^{k\theta}-1} - P_iS_i$$

WHere:

T: the maximum present net worth;

Pi:the average price of one tree i th dimeter grade;

r: the discount rate;

k: the multiple of growing period θ;

θ: the length of growing period.

But because China has not carried out the system of forest value, this goal makes no sense to China's forest management for the time being.

3.The Management Strategy of the Maximum Forest Net Profit:

Taking the following formula:

$$E=Max\sum_{i=1}^{n} \frac{P_i(X_i-S_i)}{k\theta} - FC/k\theta \quad\text{.............................(4)}$$

Where:

E: maximum forest net profit;

FC: Fixed costs;

as the objective function, the optimum management strategy can be determined at the given cost level. Formula (4) shows that only one cost differs between forest net profit and total profit. Here, we calculated the net profit, taking as a unit the cost invested per ha within one cutting cycle. Suppose the fixed cost FC=0, the net profit will become total profit, that is, when other conditions are the same, the cutting strategy of maximum total profit and maximum net profit changes its length of cutting cycle with the amount of fixed cost. So long as the value of FC is given, the optimum objective value of the net profit determined on the basis of the maximum total profit can be obtained.

Table 5 The Management Strategy of Maximum Net Profit

Diameter Grade(cm)	Northeast Fir-Forest (C=10)		Spruce-forest in Xinjiang (C=10)		Fir-Forest in Gansu (C=15)	
	Res. Stand	Cut Stand	Res. Stand	Cut Stand	Res. Stand	Cut Stand
8	548.3		850.7		197.7	
12	408.4		552.1		115.3	
16	348.6		480.7		95.9	
20	295.8		336.4		90.7	
24	75.6	133.1		166.1	70.6	
28		82.4		35.1	113.5	
32		11.2			58.1	
36						68.7
40						23.1
44						3.9
48						
Total Number(n/ha)	1712.5	226.7	2221.9	202.1	741.8	95.7
Total Area(m^3/ha)	26.952		30.754		21.923	
Total Stock(m^3)	191.03	10.314	182.40	78.207	178.32	98.071
Total Profit(yuan)	12814		26352		21965	
yearly net Profit (yuan)		1002.7		774.4		1066.8

In Table 5, is given the management strategy of the maximum net profit at different fixed cost levels in different regions.

The table shows that the Northeast fir forest FC=2786.40(yuan), Xinjiang spruce forest FC=3128.28(yuan) and Gansu fir forest FC=5962.40(yuan).

In the table we can see that the range of timber prices and porduction cost, and site conditions have a direct influence on the amount of net profit. When FC changes, we can only obtain the total profit value in the length of different cutting cycles to get the optimum value of net profit and corresponding management strategy.

In addition to the above-mentioned three objective functions,we determined the optimum management strategy by taking the maximum forest price as a goal, and obtained the optimum cutting cycle of Gansu fir forest still being 15 years. The structure of stand approximates to maximum volume yield. Both the range of interest rate and fluctuations in standing timber lead to the change of management strategy. Whichever of the goals may be taken as the pursuing aim of concrete stand should depend on the relation btween supply and demand, the biological characteristics of species as well as economic conditions. Once the management goal is determined,the above-mentioned corresponding optimum management strategy can be chosen.

III. THe OPtimum Regulation Strategy

When the structure of optimum stand of different management goals is obtained, this stand structure can be taken as optimum state. The stand of different initial structures is adjusted to the ideal state by regulating models, that is, the transition from the unreasonable state of actual uneven-aged forest to the optimum state is made as soon as possible, under given constraints. Here only the yield regulation process of the Northeast fir forest and Gansu fir forest is listed(see Table 6). In the table the initial state is X1=(281.0,209.0,130.0,85.0,57.0;37.0,21.0,17.0,14.0,7.0)^T. The optimum regulation channel of the Northeast fir forest, see Table 7.

Table 6. Yield Regulation Table of Uneven-Aged Forest

Instalment(yr)	1th		2th		3th		4th		Final States
Diameter Grade (cm)	Trees Number X1	Cut Number H1	Trees Number X2	Cut Number H2	Trees Number X3	Cut Number X3	Trees Number X4	Cut Number H4	
8	281.0		326.5		335.6		330.7	56.0	274.7
12	209.0		178.2		185.8		157.5		157.5
16	130.0		152.1		152.1	48.1	145.5	14.0	131.5
20	85.0		127.7		139.8	1.4	124.3		124.3
24	57.0		30.1		102.0		96.3		96.3
28	37.0	34.6	63.1	58.1	95.1	57.5	119.3	88.4	31.4
32	21.0		19.7		26.2	26.2	40.5		40.6
36	17.0	15.7	16.6	16.6	16.5	16.5	18.3	18.3	-
40	14.0	14.0	7.0	7.0	5.9	5.9	1.8	1.8	
44	7.0	7.0	1.7	1.7	1.3	1.3	0.0		
48									
Total Area(m^2)	20.12	6.55	22.94	7.02	26.42	9.28	27.37	3.10	19.27
Total Number(n)	858.0	71.3	977.7	93.4	1060.3	156.9	1035.3	178.5	85.8
Total Stock(m^3)	160.11	60.28	180.66	63.02	209.83	81.69	219.69	70.24	149.44

In the table, X1 is initial state. In Table 6 and Table 7 we can see that the regulation stage lengths and the concrete cutting plan established by different initial states and goals differ greatly. It is the same that the maximum total yield in regulation stage is taken as the goal, and although the number of regulation stages is the same, the number of years is different, for example, Gansu fir stand is of 4 regulation instalments, 60 years altogether, while the Northeast fir stand is also of 4 instalments, 40 years altogether. Even with the same goal, and with different initial stand states, the optimum regulation channels are different. But whatever the stand initial states may be, finally, they will tend to the optimum stand structure by means of regulation.

In addition, regulation plan can also be changed in the light of concrete conditions. Suppose in a certain forest region, where the present economy is in difficult conditions, and more timber meeds to be cut, the method of weighted multi-goals can be used not only to ensure the present task of timber production, but also, fianlly, for the stand to reach the optimum structure state. This is of greater significance to the present economic crisis of the forest regions of China.

Table 7. Yield Regulation Table of Uneven-Aged Forest

Diameter Grade (cm)		8	12	16	20	24	28	32	36	40	44	48	
1th Period	Total Number	498.0	243.0	147.0	89.0	59.0	35.0	23.0	11.0	7.0	5.0	3.0	
	Cut Number	0.0	0.0	0.0	0.0	12.6	35.0	23.0	11.0	7.0	5.0	3.0	73.4
2th Period	Total Number	592.3	358.4	231.77	145.6	92.3	51.1	17.4	2.1	0.0	0.0	0.0	
	Cut Number	0.0	0.0	0.0	0.0	92.3	51.1	17.4	2.1	0.0	0.0	0.0	77.5
3th Period	Total Number	643.0	427.0	311.6	217.3	134.5	54.5	8.9	0.0	0.0	0.0	0.0	
	Cut Number	0.0	0.0	0.0	0.0	123.4	54.5	8.9	0.0	0.0	0.0	0.0	82.6
4th Period	Total Number	615.38	453.8	362.3	276.5	187.1	83.2	16.1	0.5	0.0	0.0	0.0	
	Cut Number	0.0	39.0	0.0	29.0	187.1	83.2	16.1	0.5	0.0	0.0	0.0	137.8
5th Period	Total Number	584.3	437.0	362.0	295.8	208.9	90.5	15.1	0.0	0.0	0.0	0.0	
	Cut Number	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6th Period	Total Number												
	Cutted Number												

CONCLUSION

The research on the management and yield regulation of uneven-aged stand by the theory of optimization and optimum control proves that the introduction of optimization techniques to the uneven-aged stand management, the introduction of modern control theory to yield regulation, and decision-making with the help of computer are an effective method to seek the optimum management and regulation plan of uneven-aged forest.

Through the analysis and application of models, we have come to the conclusion as follows:

1.By the simulation of uneven-aged stand growth dynamics, we hold that to study on the model of forestry management, models close to reality should be adopted, that too much time should not be spent on the high precision of models , and that the method, simple, direct and easy to be realized, should be made the widest possible use of, on the premise of ensuring the required degree of accuracy. We made a comparison between the linear model and non-linear model of the growth dynamics of uneven-aged stand and discovered that although accuracy of the latter was a little higher than that of the former, model solution and the establishment of optimum model made very high demands to the computerinner memory, moreover, the latter could not be popularized in the basic units of production, whereas the former, simple and direct and easy to be used, could completely meet the demands of forestry management, although its accuracy was a bit lower than that of the latter. The views on this question are also changing internationally; the day of only attaching importance to the accuracy degree of model will be gone.

2. Applying the methods of optimization and optimum control to the study of structure of uneven-aged stand shows that the optimum stand structure is not always inversed " J " shape referred to in the past. Different management goals should have different optimum stand structures. This is not consistent with the model of normal forest model.

3. The theory of the introduction of optimization and optimum control into uneven-aged stand is almost a gap in China. The theory proves, after all, both in theory and in practice, to be a new effective method, that will come into use.

4. Through the analysis of the application of model, we made the management suggestions for the three regions as follows:

(1). Taking the maximum volume yield as the goal in the fir forest of the Northeast fir forest region, we should adopt 10 years as the cutting cycle. The structure of stand, see Table 3 and Table 4. If the maximum net profit is taken as the goal, the cutting cycle should also be adopted as 10 years. The optimum stand structure, see Table 5.

(2). Taking the maximum volume yield as the goal in the spruce forest of Xinjiang forest region, we should adopt 10 years as the cutting cycle. Stand structure, see Table 3 and Table 4. If the maximum net profit is taken as the goal, the cutting cycle should be adopted as 30 years. The stand structure of management strategy, see Table 5.

(3). Taking the maximum volume yield as the goal in Gansu fir forest, we should adopt the cutting cycle as 15 years. The stand structure, see Table 3 and Table 4. If the highest net profit or the maximum forest value is taken as the goal, the cutting cycle should be adopted as 15 years. Management strategy, see Table 5.

(4). The optimum regulation strategy of the forests of different types can be changed according to the concrete conditions and concrete demands of management. Under normal conditions, in the forest regions of Gansu and the Northeast, the plan of Table 6 and Table 7 should be adopted.

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RESOURCE ALLOCATION CONCEPTS FOR MULTI-PURPOSE MANAGEMENT IN JAPANESE NATIONAL FOREST

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1. Introduction

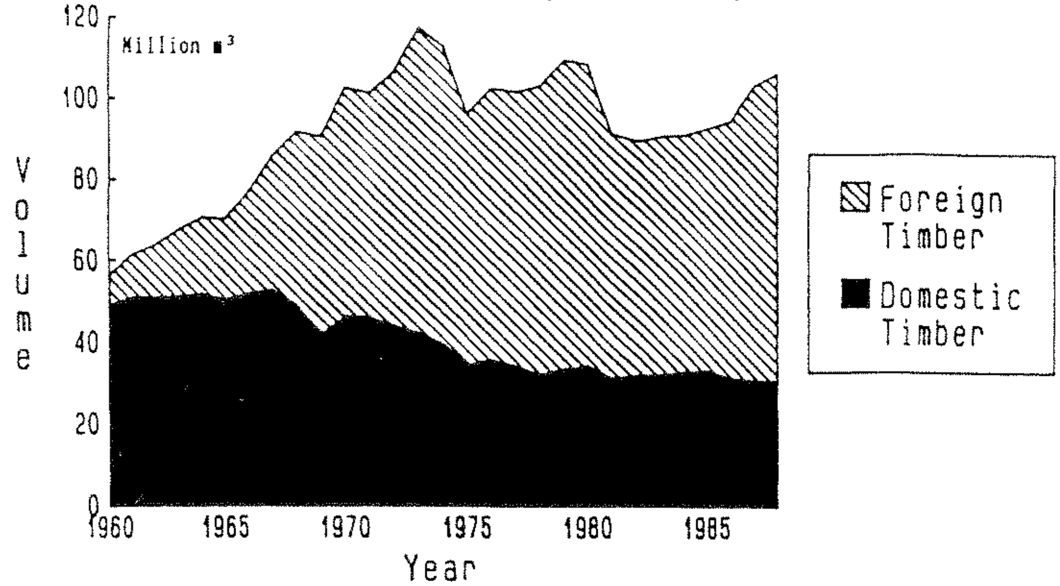
Until now the principles guiding the management of Japanese national forests has been based on a sustainable timber yield, taking only volume yield into account. But the situation surrounding national forests has drastically changed over the last decade. It has become increasing important to understand and predict the reaction of the public to forest management activities. The public has gained an interest in forestry and people sometimes insist on the delay or cancellation of forest plans and projects when they are apprehensive of the ecological, visual and social welfare effects of such forestry activities.

This paper is devoted to the research and development process in forested land management when the decision is to allocate each stand for different purposes. The primary aim of the approach is to adjust the level of timber yield in relation to other purposes to which the forest may be put; watershed protection, soil erosion control, recreational use and environmental conservation.

2. Forest Policy in the Past

Japan was a timber exporting country until 1920. Then, as a result of the Tokyo earthquake in 1923, Japan began to import timber from North America. Several years later the Government placed a duty on imported timber because of oversupply in the timber market (Handa, 1988). After that the Japanese timber market was almost totally supplied by domestic timber. However, the domestic timber supply was not sufficient to satisfy the growth in the timber market after World War II. Therefore, in 1959, the Government decided to open the timber market to foreign countries. As shown in Figure 1, domestic suppliers have seen their share of the market decline since 1960. Imported timber accounted for a little more than 70% of the market in 1989.

Fig. 1 Timber Supply Trends by Year



There are a number of laws concerning forest policy. The Forest Law, the most fundamental part of forest policy, was initially enacted in 1897. However, in 1951 the old law was abolished and the current law enacted. This is still in force after several revisions. The law is the basis of the policies concerning forest resources and it provides for such features as the formulation of forest plans, the establishment of protection forests and the use of forest land.

The Forestry Basic Law emphasizes the economical role of forest resources and was enacted in 1964. It provides for the development of forestry, the intensive utilization of forest land for forestry, the improvement of timber productivity, the encouragement of technical progress in forest technology and the stabilization of supply and demand.

These laws are all strongly oriented towards timber production. In accordance with these laws, the Government's forest policy since World War II has been one of continuously pursuing high productivity in Japan's timber resources. Specifically, low productivity natural forests have been converted to fast growing man-made forests with the aid of subsidies. About 10 million hectares of man-made forests have been established. These forest resources will be physically sufficient to supply domestic timber demand in the near future. But these laws have not been able to respond recent public demands for different types of forest use.

3. Recent Public Needs with regard to Forest Resources

A survey, consisting of a questionnaire which was answered by 2,358 people, was carried out by the Prime Minister's Office in 1989. Its aim was to ascertain the public's requirements with regard to forest resources. The results show that the public expects more non-timber

Table-1 Image of the ideal forest use

Erosion control	68.1%
Water resource conservation	53.8%
Wildlife habitat area	41.3%
Purifying the atmosphere	36.1%
Timber production	27.5%
Field education	16.8%
Recreational use	15.2%
Minor forest products	11.3%
Others	14.8%

Figures do not sum to 100% because of multiple answers.

production from forests than timber production - see Table 1. In an earlier questionnaire, carried out in 1984, 19.4% of those answering expected forests to produce timber. In the recent survey, however, the proportion of those answering who expected forests' main aim to be production of timber had fallen to 11.3%.

Table - 2 On the management of forests

1.Ought to manage forests for erosion control, protection from natural hazard etc. taking no account of economical efficiency.	79.3%
2.Ought to manage forests considering economic efficiency and in recognition of timber resources	10.6%
3.Others	0.2%
4.Don't know	9.8%

On the other hand, the majority of those answering wanted forests to serve a more environmental role, providing such services as erosion control, water resource conservation, provision of wildlife habitat, etc. Because of the recent stagnation of timber prices in Japan, many forests have not been well managed. Thus, as Table 2 shows, the public feels that forests must be managed from the social welfare point of view rather than for timber production. The results of the questionnaire imply that the forests should be managed for their non-timber value supported by the non-timber sector.

Another question concerned the financing of forest management. The results are shown in Table 3. Half of the respondents considered that the Government should provide subsidies for forest management. The public requires the Government aggressively to support forest management geared towards non-timber values by incentives programs. These results are manifestations of the public's recognition of the cost involved in producing non-timber services from forests.

Generally, natural forests have a higher potential for the generation of non-timber effects than do man-made ones. Nowadays the proportion of man-made forests to total forest land in Japan is 40.4% in Japan. Thus, the majority of respondents to the questionnaire do not want an expansion of the areas of man-made forests - see Table 4.

The Government has invested a huge amount of money in the expansion of man-made forests in order to improve forest productivity. Nevertheless, the public's requirements from the forest resource have drastically changed.

Table 3 Who should bear the expense of forest management ?

1. A subsidies by the national and local governments	47.8%
2. Beneficiaries pay their share of forest management costs	18.1%
3. Donation by the public	14.5%
4. Forest owners	11.0%
5. Others	0.2%
6. Don't know	8.4%

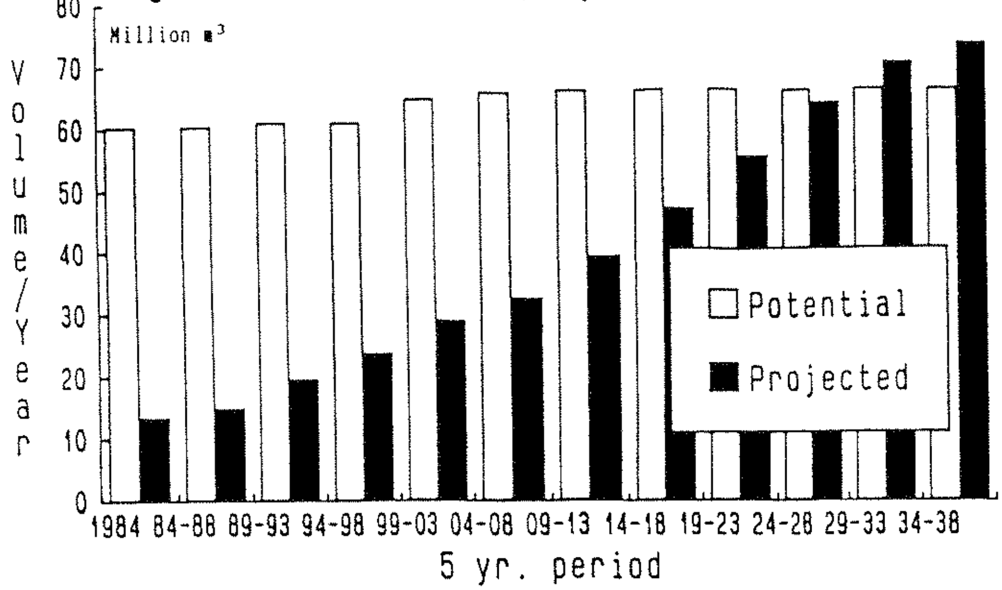
Table 4 The proportion of natural and man-made forests

1. Ought to increase natural forests	33.8%
2. Maintain the status quo	28.2%
3. Ought to increase man-made forests	31.0%
4. Don't know	7.1%

4. Man-made Forest's Potential for Timber Production

The forest resources have been investigated from the point of view of timber. A preliminary analysis of the timber supply potential from man-made forests has been implemented using linear programming. The optimal solution under the sustainable yield constraint shows that man-made forests will be able to provide more than 60 million m3, which is sufficient for the softwood timber market. The calculated figures significantly exceed the timber supply projections calculated in the official long-term forest plan in Japan - see Figure 2. The difference between the LP solution and the timber supply projection is caused by the poor productivity of logging and afforestation in Japan compared to other countries. Man-made forests can not economically provide timber to the market at the present low timber price. So there is a surplus of man-made forests compared to the size of the domestic softwood timber demand in the recent timber supply and demand conditions.

Fig. 2 Potential and projected timber supply



5. New Forest Planning System

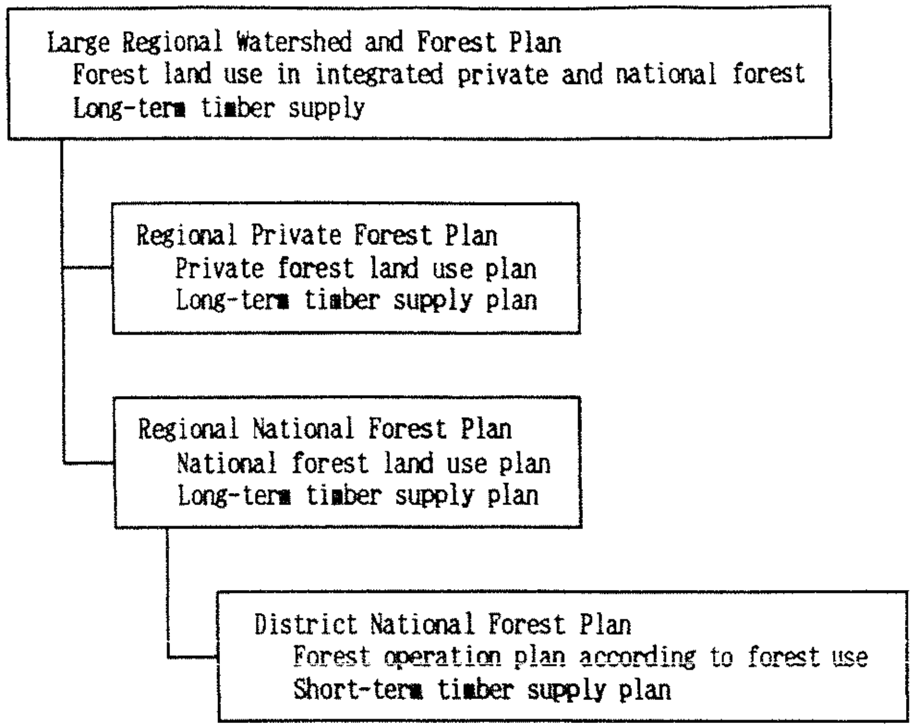
The environment potential of forests can be captured through appropriate silvicultural intervention. But the present forest planning system is strongly oriented towards timber production. So the appropriate operational scheme for the non-timber use of forests is not clear to either the public or to foresters. As described earlier, the public demand has changed from timber to non-timber uses for forests. Also, the timber supply situation indicates that whole areas of productive forests are not required for timber production. It is sufficient to use only some parts of the man-made forests for timber use. The forest planning system will be changed in two points;

1) the integrating of the private forest plan and the national forest plan,
2) the assigning of a single use for each stand instead of multiple uses.

5.1 Integrating the Private and National Forest Plan

If forest plans are set separately for the national forest sector and the private forest sector in a given area, it is difficult to provide sufficient non-timber effects for the public. This is because non-timber effects often cross the boundaries between national and private forests. Thus, the new Forest Planning System establishes a higher level plan, the large Regional Watershed and Forest Plan, which integrates the private forest plan and national forest plan. In the new Forest Planning System, all forests are considered to contribute to watershed resource protection. In order to assist watershed management, the forest planning units are set to coincide with the watershed management units. The outline of the new Forest Planning System is shown on Fig. 3.

Fig. 3 The new forest planning system

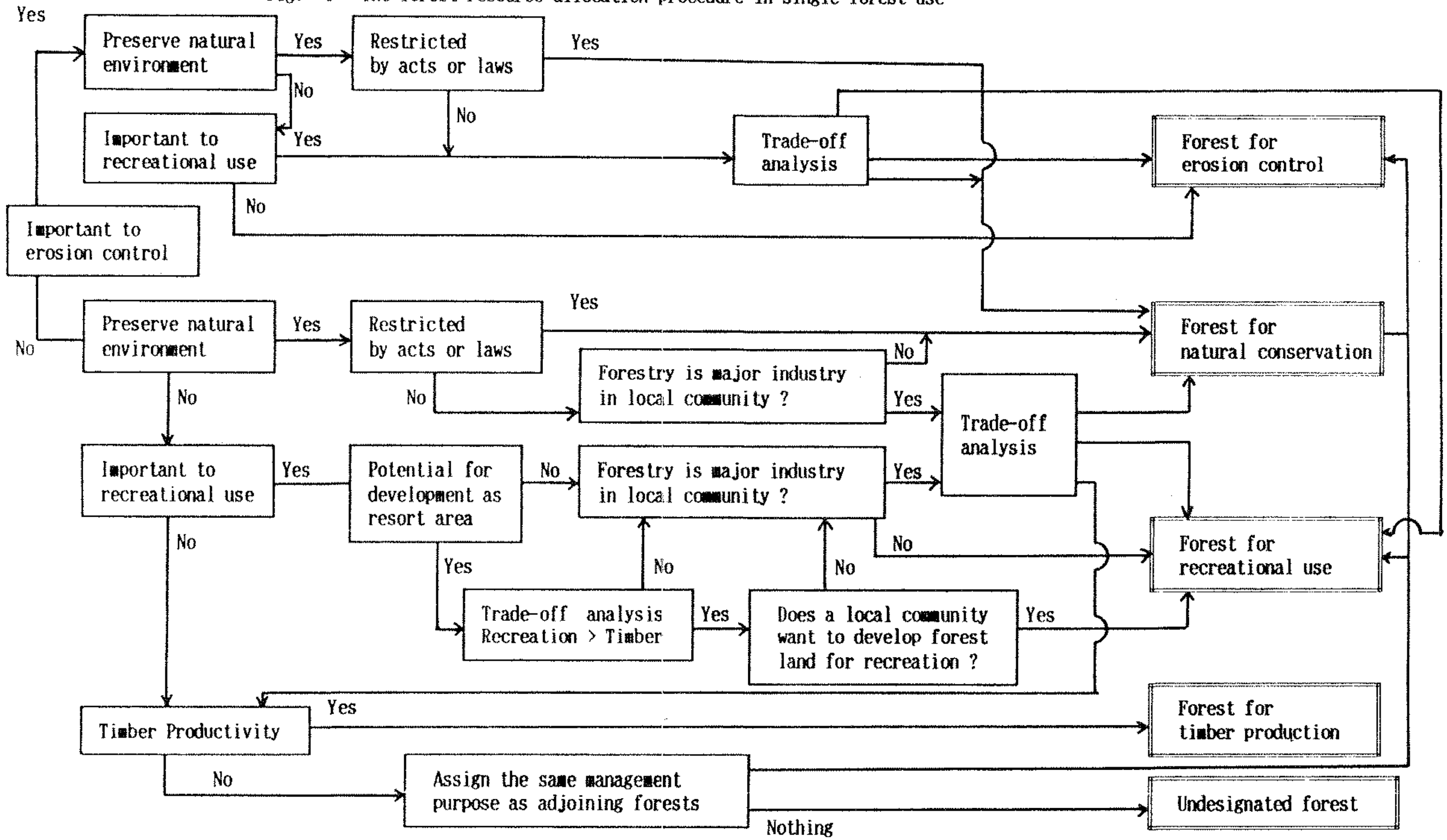


5.2 Assigning a Single Use for Each Stand Instead of Multiple Uses

Generally, forests has been managed to provide multiple uses and sustained yield. But many foresters have recently recognized the difficulties associated with multi-purpose forest management. If both timber and non-timber uses are expected from a given stand, the timber use is apt to become the primary purpose. This is because the primary indicator of the forest plan is timber supply. There are many discussions on more promising techniques which can enable the guaranteeing of the utilization of the forest for non-timber purposes. Specifically, the new Forest Planning System avoids assigning multiple uses to a given stand except in areas of watershed conservation. According to this plan, the careful planning of management programs and activities will be carried out in order to assure the sufficient utilization of the non-timber value of the forest. Thus, the concept of the new Forest Planning System is one of single use rather than multiple use at the stand level.

The concrete forest resource allocation procedure is shown in Figure 4.

Fig. 4 The forest resource allocation procedure in single forest use



6. Discussion

In view of the inherent complexity of the forest use, comprising both timber and non-timber sectors, planning for their efficient use and effective management has become an increasingly difficult task. Especially, in order to decide on the appropriate non-timber use of forest land the planner must assess the human needs for goods and services as well as the productivity of the forest land. Therefore, the decision maker has to collect a broad range of information covering not only the nature of the forest resources but also human activities which relate to the non-timber uses of the forest. But there is, as yet, no experience in the forest sector of including such social-environmental information in the forest resources database. Moreover, some forest uses are frequently in conflict and there is no common measure that can be used to evaluate all of them satisfactorily. Economic value can be attached to timber outputs, but there is presently no sound way of evaluating economic costs of the social welfare effects of the forest.

Therefore the New Forest Planning System has at present two main tasks to complete;

(1) to establish a new database corresponding to non-timber forest uses and valid for both private and national forests,

(2) to develop the appropriate trade-off analysis criteria between conflicting forest uses.

Now the research into these topics is being rushed through as the new system for the national forest planning will be used from 1991.

Acknowledgment

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A SPREADSHEET MODEL FOR PLANNING THE SUSTAINABLE MANAGEMENT OF MALAYSIAN FORESTS

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SUMMARY

A spreadsheet model was developed to determine the cutting limits and cutting cycles for Malaysian forests managed under the Selective Management System (SMS). Cutting limits are determined such that (a) sufficient volumes are harvested to attract harvesting enterpreneurs, (b) adequate residual trees are left to form the next crop, and (c) the percentage of Dipterocarp species in the residual stand is at least the same as that in the original stand. The model simulates a harvest of the forest and project the residual stand by applying tree growth and mortality, at 10-year intervals. Subsequent harvests are simulated when the stands are ready for reharvest. The results indicate that the major forest classes can be managed on a sustained basis at cutting cycles ranging from 30 to 50 years. The model provides a useful framework for the analysis of the sustainability of forest management in Malaysia. The estimates of future yields should improve the forecast of future timber production from the forests and facilitate timber management planning.

Keywords: stand table projection, forest management

INTRODUCTION

The Selective Management System (SMS) to manage the forests of Peninsular Malaysia was introduced and implemented in the 1970's (Forestry Department Peninsular Malaysia 1972; Mok 1977; Griffin and Caprata 1977; FAO 1978; Thang 1985; Yusuf, Ashari, Shukri and Kamis 1986). It involves the selection of a management regime for a particular forest being planned for harvest. The management regime consists of cutting limits and cutting cycles, in addition to the sequence of silvicultural operations prescribed for the forest.

Cutting limits are determined using manual calculation (Forestry Department Peninsular Malaysia 1985) or a FORTRAN programme (Thang, Yong and Hasanuddin 1988). A simpler version of the procedure, also written written in FORTRAN, was developed by Mohd Ridza (1988) as part of a BS thesis at Universiti Pertanian Malaysia. The simpler version was rewritten as a LOTUS spreadsheet model by Mohd Ridza and Yusuf 1988).

Cutting cycles are currently estimated on the basis of the size and projected growth rates of the trees in the residual stands. The guidelines for the determination of SMS cutting limits give possible cutting limits for three forest classes. In an average to good forest, the 30-45 cm dbh trees in the residual stands would require between 25 and 30 years to grow sufficient timber volume in merchantable tree sizes. In a marginal forest, the available regeneration are smaller, mostly in the 15-30 cm dbh class, and would require a longer cutting cycle of about 42 years. A poor forest would not have advanced regeneration and has to rely on small seedlings, and would therefore require cutting cycles of longer than 42 years as in the Malayan Uniform System (MUS), which has been employed successfully in managing the lowland forests. The above cutting cycles imply a dbh growth rates of about 0.8 cm/yr.

Cutting cycle lengths could be determined more efficiently using a stand projection model. Such a model, based on LOTUS spreadsheet, was developed by Abdul Rahman (1989) as part of a MS thesis at Universiti Pertanian Malaysia. Abdul Rahman's (1989) model was, in turn, based on earlier models by Kofod (1982) and Korsgaard (1984, 1988).

This paper described a model to plan the management of Malaysian forests on a sustainable basis. The model is a combination of the models by Mohd Ridza and Yusuf (1988) and Abdul Rahman (1989). It enables the determination of both the cutting limits and cutting cycles.

METHOD

Model Structure

The model consists of two LOTUS spreadsheets, one to determine cutting limits and the other to project the residual stand and determine cutting cycle. The former is adapted from the model developed by Mohd Ridza and Yusuf (1988) and the latter from the model by Abdul Rahman (1989). A flow chart of the model is shown in Figure 1.

The model accepts the structure (stand table) of an initial stand. It then 'normalizes' the stand to fit the structure where de Liqourt theory of normal uneven-aged forest could be applied[1]. The model simulates the first harvest by 'removing', from the stand table, trees equal to and greater than the cutting limits. The minimum dbh

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1 The theory states that, in a normal uneven-aged forest, the ratio of the number of stems in two successive dbh classes tends to be constant. This ratio is used to estimate the ingrowth and the number of stems in the smallest dbh class.

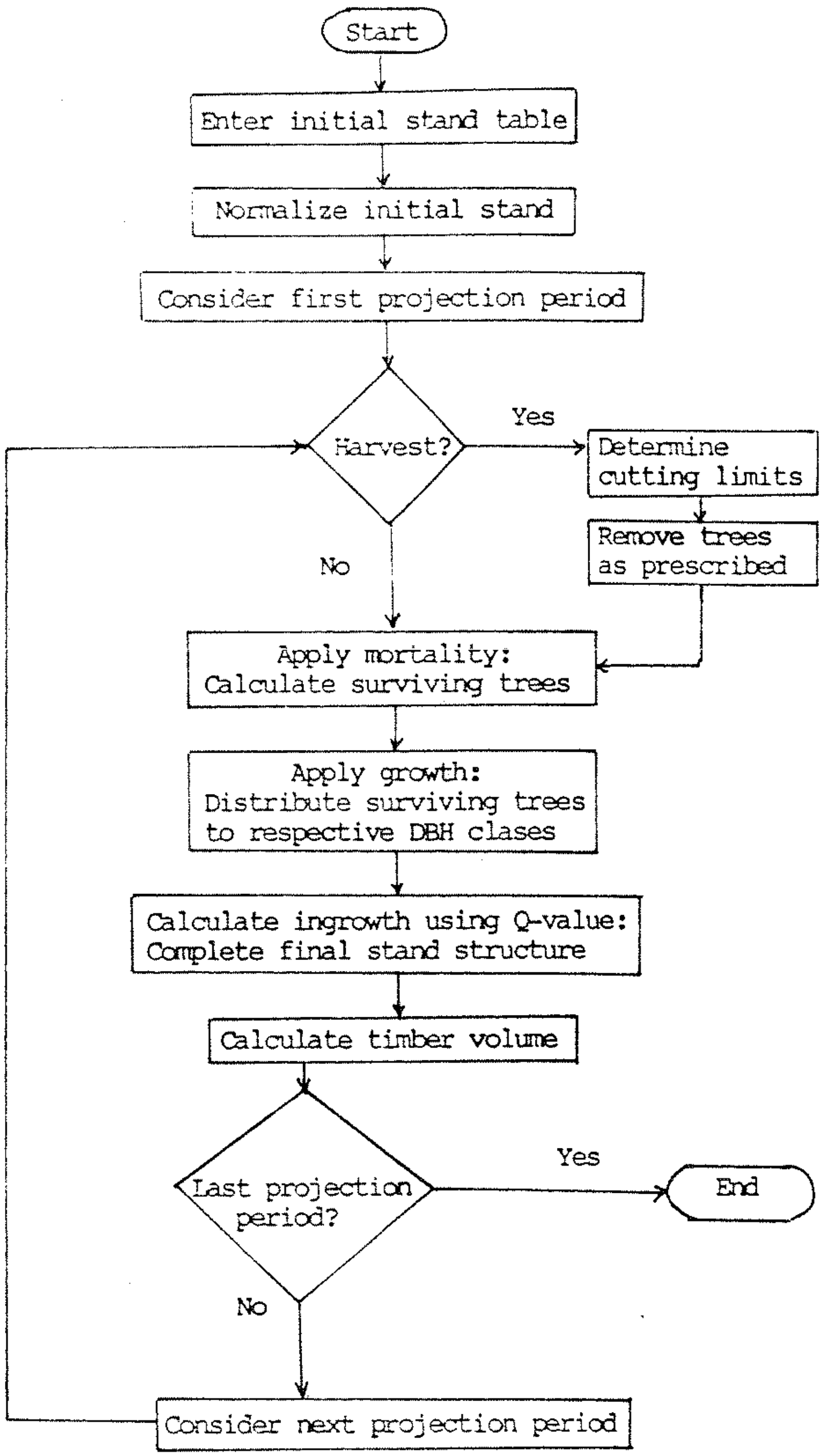

Figure 1. Flow chart of the stand projection model

limits are determined by simulating the various possible alternative cutting limits and selecting the cutting limits which satisfy the following three criteria:

(a) the harvest volume must be greater than an 'economic cut' of about 30 cu. m/ha.

(b) At least 32 stems/ha must be left in the residual stand. The trees are usually in the diameter class 30-45 cm, but other trees are also considered. A tree with dbh greater than 45 cm are considered as equivalent to three trees in the 30-45 cm dbh class, and a tree smaller than 30 cm in dbh is considered as equivalent to only 1/3 of tree in the 30-45 cm dbh class.

(c) The percentage of Dipterocarps in the residual stands must be at least equal to that in the pre-felled forest.

If there are more than one cutting limits satisfying the above criteria, the one which produce the highest harvest volume is selected. This cutting limit should yield the greatest value to society because other criteria pertaining to the adequacy of regeneration for future crop and species composition of the residual forests have already been taken care of.

The model projects the residual stand and determines its structure at intervals of 10 years. Beginning with the first projection period, it applies mortality rates to calculate the number of stems surviving at the end of the period. The model distributes the surviving trees to their respective dbh classes at the end of projection period based on the growth rates of the trees. The model calculates a growth index for each dbh class, indicating the percentage of trees moving to the various classes at the end of the projection period. The index is caculated as

I = (annual growth rate)*(period length)/dbh class interval.

The decimal part of the index indicates the percentage of the trees to move. The number before the decimal point determines the destination of those trees; trees grow to one class greater than the digit. The remaining percentage goes to the class preceeding the destination of the above trees. For example, a growth index of 0.90 for the 15-20 cm dbh class means that 90 percent of the surviving trees grow up to the next (20-25 cm) dbh class. The ramaining 10 percent remains in the same class at the end of the projection period. Similarly, an index of 1.03 for the 20-25 cm dbh class indicates that 3 percent of the trees grow through two classes to the 30-35 cm dbh class while the remaining 97 percent grow to the next class.

The model estimates the number of stems in the smallest class which include ingrowth, stems growing into the smallest dbh classes, in addition to slow-growing stems that remain in that class. The model estimates the stocking in the smallest class by multiplying the stocking in the second smallest class by de Liquort Q-value. Q-value is the proportion of trees in adjacent dbh classes in a normalised stand. Ingrowth can be estimated as the difference between the stocking in the smallest class and the trees remaining in the class at the end of the projection period. The estimation of ingrowth completes the structure of the final stand for the first projection period.

The final stand from the first projection period becomes the starting stand in the second period, and the process is repeated for every period, except when the trees are reharvested. Two criteria are used to determine when the forest could be reharvested:

(a) sufficient volume of trees in merchantable size (dbh) are available for harvest, and

(b) leaving the trees for another period of years will not produce acceptable increase in volume.

After the stand is harvested, the residual stand becomes the starting point for the next projection. The time period from the start of the projection to the harvest is then the cutting cycle.

Data Collection

Stocking data of the initial stands were obtained from a forest inventory conducted for Peninsular Malaysia conducted in 1981-1982 (FOrestry Department Peninsular Malaysia 1987). The data are for four major forest classes: Superior, Good, Moderate and Poor forests.

The second set of input data consists of average dbh increments for the various dbh classes. The growth rate assumed in the model is the average rates reported for Gunung Tebu Forest Reserve in the state of Terengganu (Tang 1976; Tang and Wan Razali 1981; Thang and Yong 1988) (**Table 1**). The model further assumes that these average growth rates apply to the Good Forest. The Superior Forest is assumed to grow 10 percent higher and the Moderate and Poor Forest 10 and 20 percent lower than these rates, respectively. The actual differences in growth rates between the forest classes are not known; this 10 percent differentiation is an attempt to simulate the relative growth rates of the forest classes.

Annual mortality rates of 3, 2 and 1 percent for the first, second and subsequent decades after harvest were assumed. The initial, high rate is due to the damage caused during harvesting operation. When the trees recover from the shock of canopy exposure and harvesting damage, mortality is assumed to decrease and eventually stabilizes at one percent. Thang and Yong (1988) cited mortality rate of 4.9 percent for all trees 10 cm and above from research by Tang (1976) and Tang and Wan Razali (1981). They also cited lower mortality rate of 0.9 percent for trees above 30 cm dbh in continuous inventory plots and experimental and/or silvicultural treatment blocks in harvested forests, reported by FAO (1987).

Table 1. Diameter increment assumed in the model

Diameter Class (cm)	Diameter Increment (cm/yr)
10-20	0.41
20-30	0.47
30-40	0.51
40-50	0.61
50-60	0.83
60-70	0.60
70 +	0.77

MODEL APPLICATION

Applying the model to the four forest classes indicates that sufficient volumes are available for reharvests in the near future (Table 2). The Superior forests, after being harvested witha cutting limit of 45 cm dbh, are able to yield 50.5, 60.3 and 59.3 cu. m/ha at 30, 60 and 90 years after the first harvest. The good forests, with the same cutting limit and cutting cycle, are expected to produce 40.4, 50.1, and 48.1 cu. m/ha. The harvests from the moderate forests could be about 44.5 and 61.8 cu. m at 40 and 80 years after the initial harvest. The Poor forests would aonly be able to be harvested once more in the 90-year period; a volume of 32.4 cu. m/ha is expected to be harvested at 50 years after the initial harvest.

Table 2. Harvest volumes for the various forest classes

Year	Superior	Good	Moderate	Poor
	(cu. m/ha)			
0	108.3	88.1	65.8	37.4
10				
20				
30	50.5	40.4		
40			44.5	
50				32.4
60	60.3	50.1		
70				
80			61.8	
90	59.3	48.1		

DISCUSSION

A model such as this could be used to analyse the sustainability of forest management in Malaysia and other forests in the tropical region. Data are not yet available in sufficient detail for the development of more sophisticated growth models. Additional data could be incorporated into the model as they are available, and detailed models could be developed when there are sufficient data.

The results above are preliminary and should be reassessed when more reliable data, especially on growth and mortality, are available. Such data are crucial in the ongoing debate on the merits and demerits of the Selective Management System. The Forestry Department Peninsular Malaysia lists advantages of the SMS as follows: (a) it is flexible to manage highly variable forests and changing socio-economic conditions, (b) its is based on the inherent characteristics of the forest and prevailing socio-economic condition, (c) it permits the attainment of the goals of economic cut, sustainability of the forest, and minimum development costs (Thang 1987). The International Institute for Environment and Development (1988) described SMS as "the most encouraging and complete theoretical system for operational management in the region" (p. 17). It provides for stand modelling based on adequate inventory, and various kinds of silvicultural operations can be applied.

Some critics raised doubts about the system. Wyatt-Smith (1987), for example, pointed to the problem of harvesting damage in a polycyclic silvicultural system with short cutting cycles. Although there will be sufficient timber volume of preferred species in the second harvest, he expects the third harvest to consist of less desirable species and smaller stems. Tang (1987) questions the ability of the advanced growth in the residual stand to produce a new timber crop in a 30-year cutting cycle. He estimated the average dbh increment over the 30-year period to be about 0.5 cm/year. While agreeing that the cutting cycle may range from 20 to 60 years, he suggested that longer cycles of 50 to 60 years should be adopted, to enable the advanced growth consisting of the generally slower growing non-dipterocarp to produce a new crop.

A stand projection model is the best way to resolve the validity or otherwise of these doubts about the Selective Management System. Additional information from studies carried out in the last several years, especially on growth, mortality and harvesting damage could be incorporated to project the residual forests and monitor the structure of the stands at various intervals in the future.

CONCLUSION

A spreadsheet model to determine cutting limits and cutting cycle for a forest planned for harvest has been developed. It could complement the computer programme currently employed by the Forestry Department Peninsular Malaysia, which only determines cutting limits. The model would also be useful as a framework to analyse the development of residual forests after being harvested under the Selective Management System. With additional, detailed data on growth and mortality, it would be able to indicate the direction in which the Selective management System need to be refined to be more effective and efficient in management of the Malaysian forests on a sustainable basis.

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OPTIMUM MANAGEMENT STRATEGY FOR SCARLET AND BLACK OAK STANDS

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SUMMARY

An optimal management strategy was developed for a hypothetical even-aged 240-acre forest of scarlet (Quercus coccinea Muechh.) and black oak (Quercus velutina Lam.). Lumber yield data collected from long-term thinning research plots composed of even-aged stands were assimilated with other information and used in conjunction with a system of models to develop management strategies. Linear programming was used to explore the interactive effects of various management strategies comprised of different frequencies and intensities of thinning upon development of four hypothetical forest stands over a 33-year period. The linear model selected the stands for harvest, the acres to be treated, and identified the management regime each stand should receive over time in order to maximize net present worth.

Key Words: Quercus coccinea, hardwood management, linear programming

INTRODUCTION

Linear programming was utilized to develop optimum strategies for the management of scarlet (Quercus coccinea Muechh.) and black oak (Quercus velutina Lam.) stands in the Missouri Ozarks. Four hypothetical stands were modeled with the objective of maximizing net present worth in a 240-acre forest over a 33-year period. All stands were 30-years old, initially, and comprised of small trees (mean dbh 4.7 inches) primarily scarlet and black oak, southern red oak (Quercus falcata Michx.), white oak (Quercus alba L.), post oak (Quercus stellata Wangenh.), and mixed hickories (Carya spp.). The stands were categorized as fully stocked with a basal area of 62.0 ft^2 and 516 trees per acre. The management model was constrained by stand size and volume requirements over time. The linear model selected the stands for harvest, acres to be treated, and specific management regime each should receive in order to maximize net present worth.

MANAGEMENT REGIME DEVELOPMENT

Forty-three individual stand management regimes were developed for determining an optimum approach to the management of the hypothetical forest. Each stand was represented by a tree list developed from a set of research treatment plots established in southeastern Missouri in 1953 to evaluate the long-term effects of different crop tree thinning and pruning treatments on the quality of scarlet and black oak stands (Dwyer 1988). Five treatments were applied to the research plots and also were applied to the hypothetical stands at age 30. In all treatments except the heavy 50 thin, where 50 crop trees were selected, 100 crop trees were chosen to form the nucleus of the final stand at harvest. Treatments included a control, a light thin (12 sq. ft. basal area per acre removed), moderate thin (17 sq. ft. basal area per acre removed), heavy 100 (38 sq. ft. of basal area per acre removed), and heavy 50 (20 sq. ft. of basal area per acre removed).

A random sample of crop trees from each replicated 1-acre experimental plot was harvested, measured, cut into log lengths, graded, and sawn in a circular sawmill in July 1985. This produced a sample size of 162 crop trees - 90 scarlet oak and 72 black oak. At each step in the production process the individual board cut from a log was coded to a particular log in a tree and the experimental plot from which it came. An individual-tree growth and yield model -- TWIGS (Shifley 1987) -- was used to project the growth and yield of black and scarlet oak stands over time, and to explore the consequences of various intermediate thinning treatments on stand productivity. The resultant yield information was used in conjunction with linear programming in development of optimum timber management strategies.

Assumptions

Since the original research project lacked intermediate treatments following the initial treatment at age 30, several key decisions regarding future management of the stand were made. The rotation length for each stand was chosen to be 63 years based upon Mark Twain National Forest data and an economic study of the feasibility of thinning 22- and 40-year old black and scarlet oak stands in the Missouri Ozarks by Dubois (1984). The study showed that thinning to reduce stand densities to 70 and 80 percent stocking on 10-year intervals to a rotation age of 60 years on site 70 land produced stands with the largest net present worths using a real discount rate of 7.125 percent. The quantity of basal area harvested was determined from stocking charts developed by Rogers (1980).

In the interest of maintaining the stand beyond the final harvest, at age 60 a group selection harvest system was adopted that calls for the creation of small openings very similar to a shelterwood cut in all thinning regimes for the stand (Johnson, et al. 1986). A brush control treatment would be applied following the harvest at age 60, with artificial regeneration to supplement natural regeneration if needed, and removal of the overstory at age 63.

TWIGS Model

Five alternative treatments were formulated for each stand. Subsequent management treatments stemming from treatment at age 30 resulted in the 43 management regimes. Following the initial thinning at age 30, 10-year increments of stand growth were estimated using TWIGS, and the data on stand table projection and volume yield for each thinning regime were recorded. These data were later used to calculate logging costs using equations developed by Brock, et al. (1986) and Miller and Sarles (1986). A grade for each harvested tree was determined by using equations developed by Dale and Brisbin (1985) to predict tree grade distribution by diameter class for each alternative management decision. Tree grade, dbh, and merchantable height were input to a program which utilized multiple linear regression techniques to predict the lumber tally volume and value by selected lumber grade groups for each tree (Yaussy Brisbin 1983).

Stumpage Valuation

Market prices were taken as the average prices of 4/4 (four-quarter or 1-inch) rough, air-dried, and graded lumber over the period from January, 1982, through August, 1987, f.o.b. mills in the Johnston City, Tennessee area as reported in the Hardwood Market Report (Lemsky 1987). Red oak prices were used for scarlet, black, and northern red oak; white oak prices were used for post oak. Stumpage prices in the Ozarks for cordwood range from $3.00 to $6.00 per cord; the higher price was used in this analysis and was held constant for all management regimes. For analytical purposes, the first thin conducted at age 30 was non-commercial and reflected the actual costs of thinning the original research plots in 1954. All of the subsequent thins were commercial. An annual inflation rate of 8 percent (Durham 1982) was assumed for the non-commercial thinning costs to reflect current value. Producer net stumpage values and associated production costs were calculated for each management regime at each thinning decision.

In addition to production costs, to calculate the value of the standing timber, a return to the mill operator and logger for profit and risk was included. It was assumed that the percentage of margin was 15 percent for the mill operator and 9 to 12 percent for the logger which included a range to reflect the size of the trees in the stand.

Operator net revenue represents the return to the logger and mill operator for profit and risk. After production costs and operator net revenue are subtracted from the gross lumber revenue the residual value represents the net return to the timber grower for the standing timber. The total net stumpage revenue for all

43 management regimes which were analyzed ranged from a high of \$1,207.58 per acre to a low of \$845.28 per acre.

Economic Analysis

Producer net stumpage revenue generated from each management alternative at the different stages along with those costs directly attributable to the thinning alternatives were utilized to determine the net present worth (NPW) of the stream of cash revenues generated from each management alternative. Costs include precommercial thinning, harvesting, manufacturing, and transportation. Land and other annual fixed expenses were excluded from the economic analysis in order to maintain the thinning alternative as a separate investment. The analysis was conducted using a real discount rate of 4.62 percent. The use of a real interest rate produces a NPW which is exclusive of the effects of inflation. The beginning of cash flows for the investment analysis was time zero. This corresponded with a beginning stand age of 30, and terminated at time 33 which corresponded to stand age 63. All costs incurred prior to age 30 were excluded from the analysis.

LINEAR PROGRAMMING APPLICATION

Objective Function

The objective of the harvest scheduling analysis was to maximize the total NPW from the management of the four timber stands over a 33-year planning horizon. The decision variable $X_{s,t,k}$ denotes the total volume per acre available from stand s, in time period t, from management treatment k. The volumes generated from each thinning regime were multiplied by the stumpage price P_t in time period t. Revenue was then discounted to the present using interest rate i (4.62%), and precommercial thinning costs ($C_{t=1}$) subtracted to determine NPW. The linear programming notation for the objective function is:

$$\text{Max } Z_{npw} = \sum_{s=1}^{4} \sum_{t=1}^{5} \sum_{k=1}^{43} \frac{X_{s,t,k} \times P_t \times A_{s,t,k}}{(1+i)^t} - C_{t=1} \qquad (6)$$

where: Z is the maximum NPW from management of all the stands over the planning horizon.

Constraints

The first set of constraints in the harvest model deals with the physical size of the resource. Since an even-aged silvicultural system was used in this analysis, one decision involves the area to be thinned or harvested. More precisely, the variable $A_{s,t,k}$ represents the area (in acres) to be cut from stand s, in time period t, using management treatment k, where s, t, and k are integer subscripts:

$A_{s,t,k}$ = number of acres to be harvested
s = stand area, 55, 75, 65, and 45 acres
t = age at harvest - 30, 40, 50, 60, and 63 years
k = type of management regime - 43 available

There are four hypothetical stands in the forest comprising a total of 240 acres. These stands represent four hypothetically manageable units which illustrate the modelling approach. The area managed in each stand type cannot exceed the area available for that type; i.e.:

$$\sum_t \sum_k A_{1,t,k} \leq 55 \text{ acres for stand type 1}$$

$$\sum_t \sum_k A_{2,t,k} \leq 75 \text{ acres for stand type 2}$$

$$\sum_t \sum_k A_{3,t,k} \leq 65 \text{ acres for stand type 3}$$

$$\sum_t \sum_k A_{4,t,k} \leq 45 \text{ acres for stand type 4}$$

The upper bound for the right-hand side in the model represents the acreage available in each stand type. Therefore, the first set of constraints states that the area cut from each stand throughout the planning horizon must be equal to or less than the area available in each stand. The second set of constraints applies to the forest-wide harvesting goal per period.

The decision variable $X_{s,t,k}$ denotes the volume per acre available from stand s, in time period t, from management treatment k. Thus the harvest flow constraint can be represented as:

$$\sum_s \sum_k A_{s,1,k} X_{s,1,k} \geq 8{,}635 \text{ cubic feet at age 30}$$

$$\sum_s \sum_k A_{s,2,k} X_{s,2,k} \geq 27{,}350 \text{ cubic feet at age 40}$$

$$\sum_s \sum_k A_{s,3,k} X_{s,3,k} \geq 51{,}625 \text{ cubic feet at age 50}$$

$$\sum_s \sum_k A_{s,4,k} X_{s,4,k} \geq 220{,}395 \text{ cubic feet at age 60}$$

$$\sum_s \sum_k A_{s,5,k} X_{s,5,k} \geq 140{,}130 \text{ cubic feet at age 63}$$

The basis for the harvest levels (except for the non-commercial harvest at age 30) represents the merchantable volume available for harvest with a landowner goal of increasing periodic revenue over time for the purposes of retirement and, appreciation of land and estate. For this constraint, the lower bound on the right-hand side of the model is represented by the minimum amount of volume required from each time period t. Not all management regimes were considered at each time period, for example, 19 management regimes did not include a thin at age 30.

Solution

The linear programming solution for the harvest scheduling model was a NPW of $72,558.64. This value represents the highest return from the management of the four stands over the planning horizon given the constraints. The solution of the harvest model is shown in Table 1. The negative NPW at age 30 for stand A reflects a non-commercial thin which was conducted on 32 acres in that stand.

The tabulation below shows the non-zero dual prices for the row formulation of the problem set:

Stand	Stand Age	Dual Price ($ per acre)
A	60	350.27
B	40	11.00
B	50	14.00
B	60	307.00
C	50	47.00
C	60	274.00

The higher prices at age 60 would be reflective of the higher quality and quantity of timber which, if available, would increase the objective function value. Moreover, the higher quality is a direct result of a significant increase in the production of hardwood grades No. 1 and No. 2 common lumber (Dwyer and Lowell 1988) because of the specific management regime which was adopted.

CONCLUSIONS

Two sets of conclusions may be drawn from this study - one set relating to timber management, which is not fully addressed in this paper and another set relating to the optimization problem which is the primary theme of the paper.

From a management standpoint, it was found that thinning significantly increased the size of scarlet oak crop trees. Thinning was responsible for a significant increase in the production of higher quality lumber; crop trees in a thinned stand were over twice as valuable after treatment as crop trees not in a thinned stand.

Relative to development of the optimization problem it was demonstrated how a system of models could be linked to provide production data, costs and revenues associated with specific management strategies. The information developed from this linkage was then used to develop a management plan comprised of various timber management strategies that maximized net present worth to the forest under different resource constraints.

Table 1. Forest management schedule for four scarlet and black oak timber stands.

	Stand age (years)				
	30	40	50	60	63
<u>Stand A</u>					
Treated acres	32	23	55	55	55
Total harvest volume yield (cubic feet)	8,635	11,443	17,434	51,345	41,032
Net present worth ($)	- 2108.57	1086.09	2157.06	5652.06	7668.51
Residual stocking(%)	52	65	71	41	<20
<u>Stand B</u>					
Treated acres		75	75	75	75
Total harvest volume yield (cubic feet)		37,875	32,550	51,450	52,425
Net present worth ($)		3594.75	3183.75	7056.00	10,418.25
Residual stocking(%)		65	58	38	<20
<u>Stand C</u>					
Treated acres			65	65	65
Total harvest volume yield (cubic feet)			53,105	60,840	43,550
Net present worth ($)			5118.75	7244.25	8511.10
Residual stocking(%)			68	40	<20
<u>Stand D</u>					
Treated acres				45	45
Total harvest volume yield (cubic feet)				79,830	30,150
Net present worth ($)				6310.80	6035.85
Residual stocking(%)				37	<20

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ECONOMIC PROBLEMS OF FORESTRY IN HUNGARY

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Nowadays the faults of the recent past and their correction possibilities are the main topic of everyday talks in Hungary. The nation and all sectors of the economy, however, need by all means long-term programmes which could mobilize the whole society. Our great national green programme can be considered as such.

This programme consists of two separate afforestation projects. One of them accepted already by the government sets out the afforestation of 150 thousand hectares in the years between 1991 and 2ooo. The other one is a long-term plan proposed jointly by the Ministry of Agriculture and Food and the Hungarian Academy of Sciences; it suggests another 7oo thousand hectares of new forests to be established on lands not suitable for agriculture.

Our great national green programme joins well to the great international movement which considers the protection and development of the environment as the most important task all over the world that must not be deferred any longer. In this respect forestry, the protection of the existing forests and the establishment of new forests, plays a prominent role. It's worth refering to M.PAVAN's statement (Italian professor of forestry, member of the Roman Club) saying. Ruthless exploitation of forests is a very convenient management practice. It results, however, in the degradation of the soil of exploited forests that has to be reclaimed and reforested. It is therefore recommendable to agree on global scale on a reasonable forest ratio that has to be preserved. If mankind does really care for its future, then a global action plan should be formulated for the rehabilitation and preservation of the environment and utilize the ecological basis so as to make it possible for mankind to live on our globe for ever.

In the establishment of new forests, if I may say, Hungary stands on the first place on a global scale. Since the First World War we have established the largest area of new forests in relation to the forest area that existed then. At the end of the First World War our forest area was 1.1 million ha. It amounted to 1.7 million ha by now and through the implementation of the great green programme it may be increased to 2.5 million ha by 2o5o. The extension of our forests within the present boundaries of the country might have been the same as that during the reign of our king Joseph II. when our forests had been mapped for the first time.

At that time the natural environment had been relatively favourable as far as the forests and waters are concerned. Lateron, however, extensive forest exploitations following the emancipation of serfs and the great water-regulation and flood-control projects caused rapid and mostly adverse changes in the environment. The originally natural regions of the country had been converted into cultural ones at that time.

The implementation of the great national green programme will result in an increase in the forest area to 2.5 million ha. This together with the area of orchards and vineyards (186 thousand ha) gives a total of 2.7 million ha, which had been the forest area of the country at the time of Joseph II. Thus, when new forests are established purposefully so as the natural environment be also improved by them, then the relatively favourable ecological conditions that prevailed two hundred years ago could be mostly reconstructed.

In Hungary, trees and forests being able to absorb carbondioxyd might be of crucial importance for the efforts to abate thee greenhouse effect. As a result of the greenhouse effect the frequency and strength of droughts is increasing, certain maize growing regions might get into the absolute irrigation zone. This may affect also poplar, willow and black locust varieties grown in an intensive way.

It is the basic objective to improve the balance of the emission and absorption of carbondioxyd.

More than half of the new forest establishments (475 thousand ha) will be made with native oaks and other deciduous species. The naturelike forests of the past domestic regions are attempted to be reconstructed by this way. At the same time special-purpose forests will also be established: 3o thousand ha for producing veneer logs of hard broadleaved and poplar species; 14o thousand hectares of high-yield coniferous plantations to replace imported sawn softwood; 65 thousand hectares of fodder forests to produce fodder for domestic animals and big game; 6o thousand ha of black locust forests of late-flowering varieties for increasing the commercial honey production; 4o thousand ha of energy forests to supply, primarily, the village population with fuelwood. All these make a total of 335 thousand ha new forests.

Thus, the implementation of the great national green programme is of historical importance in view of the improvement of the environment; at the same time it is an approach to make the country self-sufficient in wood products by export earnings compensating for the costs of imports. In addition, it facilitates the alternative use of the lands of cooperative and state farms and private farmers unsuitable for efficient agricultural cultivation by establishing forests on them that equals to a really up-to-date conversion of the production structure.

In consequence of the change in the political system and the development of a social market economy it has to be reckoned with a radical change in the ownership structure and the size of land properties of the Hungarian agriculture. Afforestation might be an essential opportunity for the development of countryside. It can also be assumed that the establishment of new forests made by private farmers can be less expensive than by agricultural cooperatives and state farms. In addition, employment of the agrarian population might become more important than the use of high-productivity machines applied by now.

This 6o-year programme requires 57 billion Hungarian forints worth financial support by the government, calculated on the basis of the present costs of afforestation. This is a rather small amount of money compared with the costs of the Bos-Nagymaros power plant project. The establishment of naturelike new forests serving the improvement of the environment should be financed entirely by the State. For establishing plantationlike new forests competing with agriculture domestic and foreign entrepreneurs' funds should be used. The idea of establishing a National Afforestation Fund, mainly from the duties to be levied on timber imports, has also been raised.

It's another great task to get the population's sympathy for this programme. In this respect the statement made in 1927 by Károly KAÁN, who initiated the afforestation programme of the Great Hungarian Plain in the 192os, deserves special attention. It says: "It is necessary that every Hungarian citizen be aware of the great importance of this issue that will increase the strength of the nation and the national economy as well. The government, in turn, after overcoming the legal difficulties and launching adequate grant aid should encourage and support the population in implementing this well intentioned programme.

In the last ten years the Forest Service induced the forest and wood-working enterprises to concentrate wood cuttings in the best stands and develop wood-processing plants the most to obtain high annual profit. Consequently, silviculture became a neglected, secondary activity. It is of high importance to make a stop to this exploitation type management and restore the appreciation of silviculture without any delay. This is an indispensible precondition of the great green programme to be realized.

Forestry research being responsible for the future of forestry should deal with the achievements and researchs, by which the longterm interests of the nation would be benefitted and the increase in the forest resources and their multiple-use could be supported.

The great green programme is not only a matter of forestry and agriculture but it is for the whole nation. It results not only in the expansion of the forest area and the wood raw material resources, but it forms, improves and enriches the environment with trees, the most specific components of the natural landscape. It is not only an economic objective, but it is the programme of those who believe in future, it is the programme of the youth and hope.

ESTIMATING TIMBER VALUE GROWTH RATES IN NEW ENGLAND

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SUMMARY

Analysis of remeasured plot data show that between the last two forest inventories of New England, compound rates of value change in timber stands averaged 4.2 percent and ranged from -26 to +43 percent. Faced with this kind of variation, resource planners and managers can use help in determining financial rates of return for the region's woodlands. Multivariable analyses of several tree and stand characteristics produced guides that use tree species, size, merchantability class, and stand density as key variables for estimating change in timber value.

Keywords: Compound interest, financial objectives, hardwood and softwood forests

INTRODUCTION

Many things affect changes in timber value--tree species, size, and quality; stand density and site productivity; markets and accessibility; insects and disease; even weather. So rates of growth in the value of standing timber can vary greatly from stand to stand and from tree to tree. For example, a recent study shows that compound annual rates of change in value for forest stands sampled in Maine between 1971 and 1982 ranged from -12 to +43 percent. (Gansner et al., in press) With this kind of variation, forest managers can use all the help they can get in determining financial rates of return for their woodlot. To help meet this need, we analyzed recent forest-inventory measurements in New England to quantify changes in tree and timber stand value there. Our ultimate goal is to provide practical guides for estimating timber value growth rates in the region.

APPROACH

Data

The USDA Forest Service updates statewide timber resource information approximately every 10 years. Part of the updating process includes remeasuring a network of permanent forest-inventory plots in each state. Plots (0.1 to 0.2 acre) that were previously measured in New England during the early 1970's were remeasured from 1982 through 1985 (Powell and Dickson 1984; Frieswyk and Malley 1985; Dickson and McAfee 1988). Data from more than 1100 of these plots were used to analyze value growth. We included only those plots that remained relatively undisturbed, i.e., had less than 15 percent of their original basal area removed between inventories. These plots accounted for more than three-fourths of the total area sampled. The analysis incorporated more than 27,000 trees that were alive and 5.0 inches or larger in d.b.h. (diameter at breast height measured 4-1/2 feet above the ground) at the time of the initial inventory, plus another 20,000 trees that grew to 5.0+ inches between inventories.

Analysis

Rates of change in stand and tree value were based on measured changes in tree diameter, merchantable height, and quality. Compound annual rates of value change (r) were obtained using the expression:

$$r = (Vn/Vo)^{1/n} - 1$$

Where n is the number of years between measurements, Vn is the value of a stand or tree after n years, and Vo is its initial value.

Dollar values for hardwood sawtimber trees were based on tree-value conversion standards (DeBald and Dale, in preparation). These standards represent consistent regional measures of a standing tree's net value (marginal value product or shadow price) in the production of 4/4-inch lumber, allowing for the cost of conversion. They account for a tree's species, diameter, merchantable height, and tree grade (based on butt-log grade measures). For example, a 16-inch diameter red oak with a grade 2 butt log and merchantable height of two logs was valued at $29. For trees other than hardwood sawtimber, merchantable height, d.b.h., and cull estimates were converted to net volumes (Scott 1981) and assigned value based on recent local stumpage price reports. For example, white pine sawtimber stumpage averages about $70 per thousand board feet, and spruce and fir pulpwood averages about $10 per cord.

The same dollar-value standards were applied to both initial and current measurements to evaluate stand and tree development, thereby eliminating valuation items that were irrelevent to biological change. This ignores unpredictable effects of inflation and changes in timber prices and markets, but does account for the value of biological change in tree diameter, merchantable height, and tree grade. The few trees that were harvested between inventories were assigned the same value for both occasions.

The combined influence of tree and stand characteristics on rates of change in timber value was studied by Automatic Interaction Detection (AID) (Songuist et al. 1973). More than 40 variables thought to be related to value change were anlayzed. These variables incorporate measures of species composition, tree size, stocking, site productivity, physiography, timber volume, tree quality, and timber value. The AID technique searched these characteristics of the trees and timber stands for the best predictors of value change. Starting with the entire sample in one group, the stands and trees were partitioned through successive two-way splits into series of subgroups. The splits occur so that at each step, the chosen predictor variable forms two new groups that cause the greatest reduction of variance in the dependent variable (value change). The result is a best set of predictors selected by the AID algorithm, and presented as a branching diagram that details the rate of value change configuration for individual stands and trees as they responded to timber stand dynamics between the New England forest surveys.

RATES OF VALUE CHANGE

T r e e s

Between the last two forest inventories of New England, the annual rate of change for all trees in our sample averaged 3.2 percent. Multivariable analysis of several tree and stand characteristics identified four that are significantly related to change in tree value: tree species, size, merchantability class, and stand density.

Species.--Compound rates of value change for individual timber species ranged from 5.8 to 0.5 percent (Fig. 1). White ash, red oak, and white pine, known for their vigorous growth, had the highest rates. At the other end of the scale are beech, fir, and white oak, which have suffered through outbreaks of Nectria complex, spruce budworm, and gypsy moth, respectively.

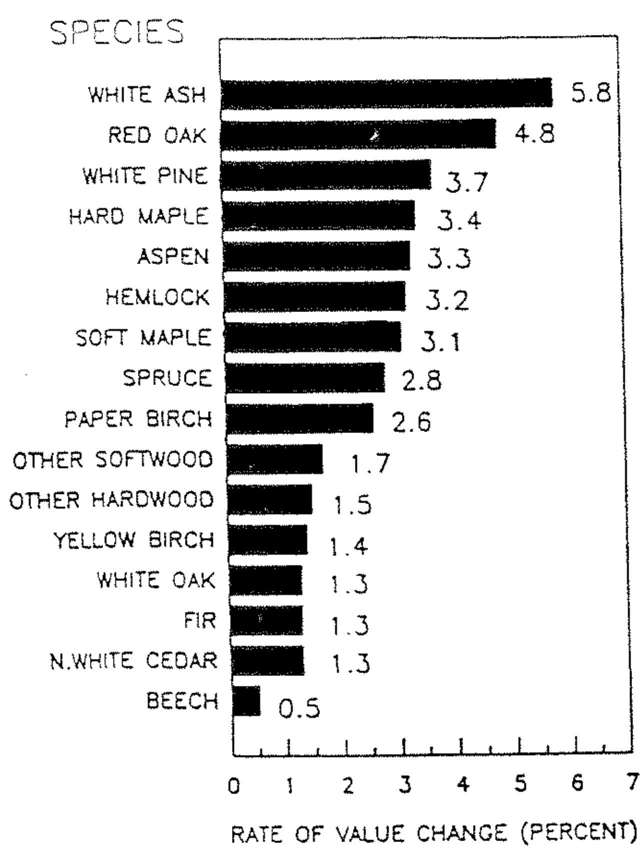

Figure 1: Compound rates of value change for individual tree species in New England.

Diameter.--Value change rates increase through the 8- to 10-inch diameter classes before declining in the larger diameters. The high average rates for 8- to 10-inch trees are due in large part to their growth into higher valued sawtimber-size material:

Diameter class (inches)	Rate of value change (percent)
<8	3.5
8-10	4.0
12-14	3.5
16-18	2.7
20 +	1.0
All trees	3.2

The base or initial value of trees is important to the relative differences in their rate of change in value. Consider, for example:

Initial value (V_o)	End value (V_n)	Value change	No. of years	Rate of value change (percent)
--------(dollars)--------				
1.00	2.00	1.00	10	7.2
5.00	6.00	1.00	10	1.8

In both examples, value increased by $1. But the smaller initial value in the first example ($1 versus $5) yields a much greater rate of value change over the 10 years.

Tree class.--Tree class reflects tree quality and quality correlates directly with rate of value change. Because of higher mortality rates and declines in quality, nongrowing-stock trees recorded negative rates of change.

Tree class	Rate of value change (percent)
Growing-stock	3.3
Rough	-1.6
Rotten	-2.4
All trees	3.2

Growing stock trees are those of commercial species that are merchantable for sawlogs now or in the future. Rough trees are unmerchantable for sawlogs because of roughness, poor form, or unacceptable species. Rotten trees are unmerchantable for sawlogs because of rot.

Stocking.--As undisturbed forests mature, they tend to form more densely stocked, slower growing timber stands that also contribute to a slowdown in rates of value change for individual trees. Value growth rates for trees in stands with fewer than 60 square feet of basal area are more than double those for trees in stands with more than 140 square feet:

Basal area/acre (square feet)	Rate of value change (percent)
<60	4.4
60-99	3.6
100-139	2.9
140 +	1.9
All trees	3.2

Timber Stands

Compound annual rates of value change for sample plots representing timberland in New England ranged from -26 to +43 percent and averaged 4.2 percent--thus reflecting the great amount of variability in value change for forest stands in the region. Note that the average rate of change for all stands is greater than that for all trees (3.2 percent). Ingrowth accounts for the difference. Rates of change in stand value include trees that grew into merchantable size (5.0 inches or larger) between inventories, but change in tree value was based only on trees that were already merchantable size at the time of the initial inventory.

About 8 percent of the forest had enough mortality and degrade to register negative rates of growth (Fig. 2). These stands evidence the detrimental effects of spruce budworm, gypsy moth, and other destructive agents at work during the 1970's and the early 80's. But most of the other woodland fared relatively well. One-fourth of all stands recorded rate increases of 6 percent or more; one-eighth of them earned better than 8 percent. Such rates are impressive when you consider they are for forest land that had virtually no human disturbance or improvement cutting between inventories.

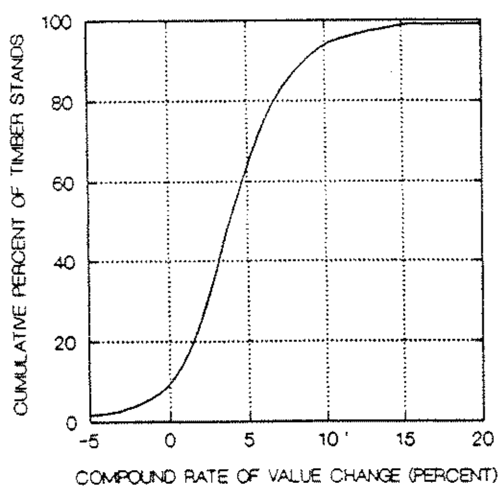

Figure 2: Compound rate of change in value for New England timber stands.

GUIDES FOR ESTIMATING VALUE GROWTH

The AID technique produced some fairly simple guides for estimating value change for trees and timber stands in New England. Analysis of the rate of value change in individual trees generated 17 classification groups and the average rate of value change for each group (Fig. 3). Each tree is a member of one of the groups. Only four of the many tree and timber stand characteristics analyzed as predictor variables were retained in this value growth rate classification system: tree class, species, diameter, and stocking. Their inclusion makes good intuitive sense. White pine growing-stock trees less than 9 inches in diameter and growing in stands with fewer than 80 square feet of basal area per acre (Group 16) have the highest rate of value change, 19.2 percent, compared to 3.2 percent for the total sample. On the other hand, as testimony to high mortality rates and declines in quality, rotten trees have the lowest rate of value change, -2.4 percent (Group 7).

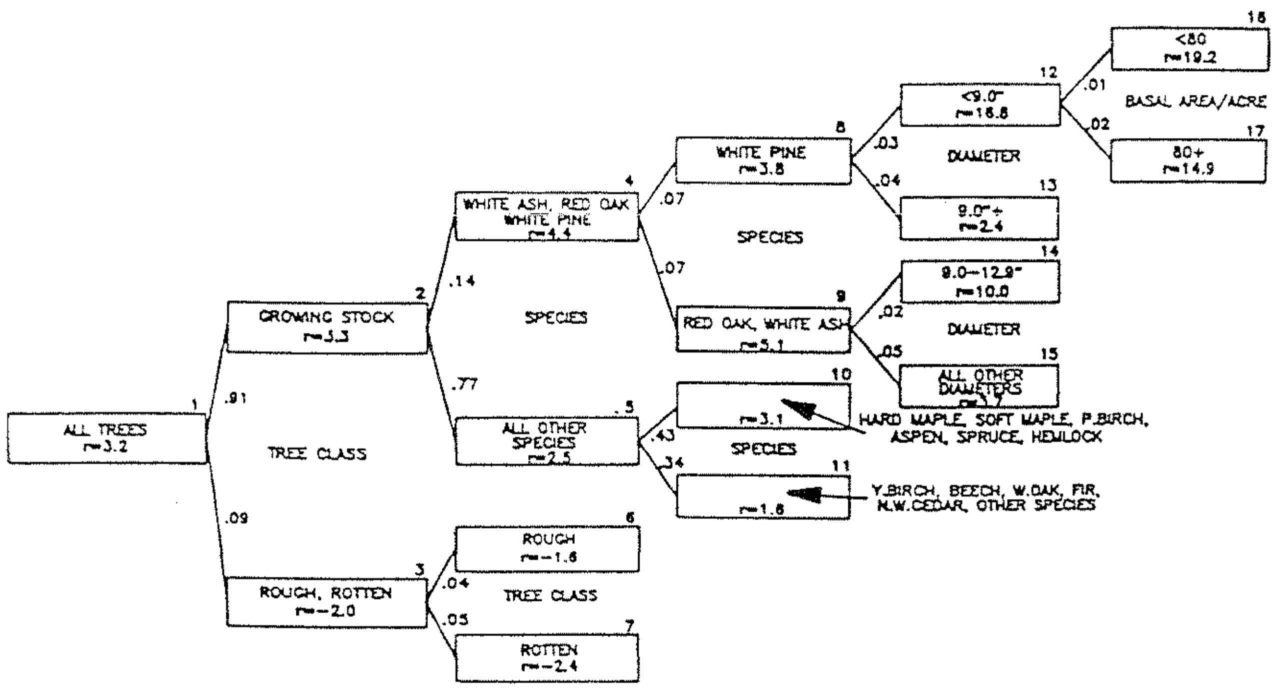

Figure 3: Guide for estimating rate of value change for individual trees. Any tree can be assigned to a value-change group on the basis of the characteristics of that tree. The average rate of value change (r) is shown for each group. Decimal fractions on each line connecting groups indicate the portion of the New England sample in that group.

A similar analysis of sample plots generated 27 value change classification groups for timber stands (Fig. 4). Rates of change for the 27 groups range from 2.1 to 15.1 percent. Stands in the group with the highest average rate have less than 10 square feet of basal area per acre in softwood species, less than 20 square feet per acre of total basal area, and tree of average basal area less than 6 inches in diameter. These conditions identify them as members of group 15. Stands like this accounted for 2 percent of our sample. At the other end of the scale are stands in Group 16, where rates of value change average only 2.1 percent. Stands in this group represent one-fifth of New England's timberland.

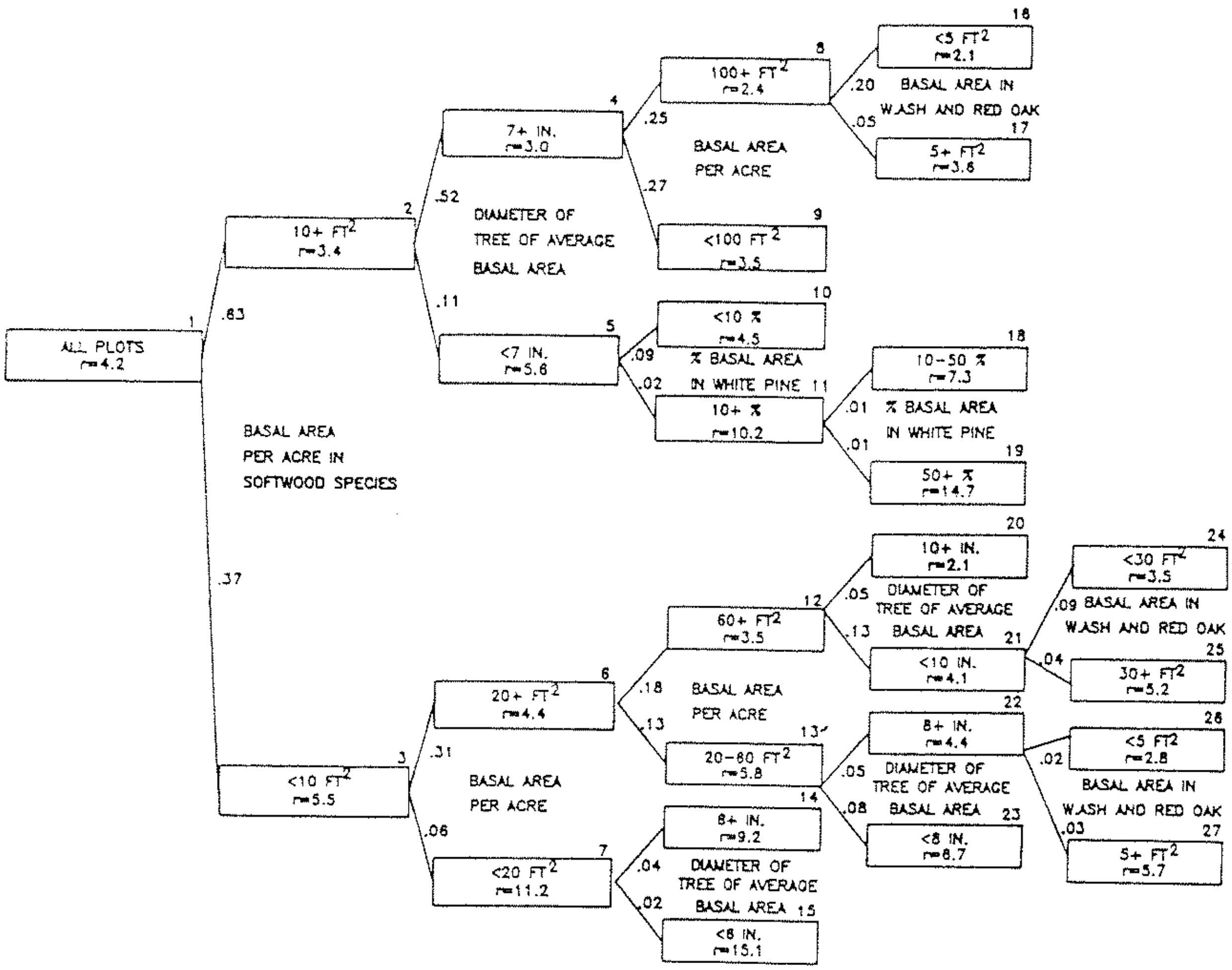

Figure 4: Guide for estimating rates of value change for New England timber stands. A stand is assigned to a value-change group on the basis of characteristics of the stand. The average rate of value change (r) is shown for each group. Decimal fractions on each line connecting groups indicate the portion of the New England sample in that group.

These estimates provide useful baseline indexes for comparing the economic potential of trees and timber stands and prospective stand management options. Further analyses will focus on rates of value growth in other areas of the Northeast. Our prime purpose is to gain a better understanding of the relationship between timber stand characteristics and value change so as to develop improved methods for predicting rates of value growth.

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EVALUATING FORESTRY LAND DURING INFLATIONARY TIMES

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SUMMARY

The Faustmann formula has been used since 1849 to calculate the value of forestry land. It was developed in a static financial environment, however, and is no longer suitable for land valuation in today's dynamic financial environment. This formula is adjusted to provide for the variable behaviour of different prices, as well as for tree species such as *Eucalyptus grandis* for which coppice regeneration is occasionally used.

Keywords: Faustmann, land expectation value, inflation, real price changes, coppice regeneration.

INTRODUCTION

Traditionally the maximum price to be paid for bare forestry land was determined by calculating the so-called Land Expectation Value (*LEV*) with the Faustmann formula (Gregory 1972). In a Faustmann calculation all the items in the cash flow of a forestry project, except the cost of land, are compounded to the end of the rotation. The net value of this terminal amount is then discounted to the present time as if the forestry project will be repeated infinitely. This net present value then forms the *LEV* and gives an indication of the maximum price payable for the land. In its simplest form the traditional Faustmann formula can be written as:

$$LEV = \frac{\sum_{t=0}^{n} P_t (1+i)^{n-t}}{(1+i)^n - 1} - \frac{E}{i} \qquad \text{(Uys 1988)} \qquad (1)$$

where

P_t = net cash flow in year t (land cost and general annual cost excluded);

E = general annual cost;

n = rotation age;

i = discount rate.

The purpose of this paper is (a) to adjust equation (1) to accommodate real or relative price changes and (b) to further adjust it to suit forestry projects involving coppice regeneration.

ASSUMPTIONS IN THE FAUSTMANN FORMULA

The utility of any financial criterion depends on how realistically its implicit assumptions tie in with the problem to be analysed. The traditional Faustmann formulation implies the following assumptions (Leuschner 1984):

- The land value is zero;
- there are no forest stands or other crops on the land;
- the land will be used infinitely for forestry;
- and the cash flow of the forestry project will be repeated unaltered in each of the successive rotations.

The first three assumptions do not restrict the use of this formula for land valuation purposes.

The last assumption is inacceptable and leads to the Faustmann formula in its original form losing its usefulness. According to the Forestry Price Index (*FPI*) double digit inflation has been experienced in the RSA since 1973, with the exception of a few years (Central Statistical Services 1989). General inflation causes a continuous rise in forest industry prices. It is therefore unrealistic to assume that prices remain constant.

Real or relative price changes also make the assumption of identical cash flows in each successive rotation unrealistic. Inflation is measured by the changes in general price indices, such as the Consumer Price Index (*CPI*), the Production Price Index (*PPI*) or general indices for a specific industry such as the Forestry Price Index (*FPI*). General price indices represent the weighted mean of prices of a large number of goods and services. Changes in a general price index therefore do not accurately reflect changes in the prices of specific goods and services (Leuschner 1984). It is theoretically possible for the rate at which the price of each item in the cash flow of a forestry project changes to differ from the rate of change in a general price index. The *nominal rate* at which the price of a single item changes is therefore a combined rate composed of a *general inflation rate* and *a real rate* of change. According to Davis and Johnson (1987) the following multiplicative relationship exists between the three rates mentioned:

$$(1 + h) = (1 + r)(1 + f) \qquad (2)$$

where

h = nominal rate of price change;

r = real rate of price change;

f = inflation rate according to a general price index.

The last two columns of Table 1 show the results of an analysis of the behaviour of prices of individual items in the cash flow of a *Eucalyptus* project. The *FPI* according to Central Statistical Services (1989) was used as deflator. The prices of the items were obtained from the cost monitoring system of the South African Timber Growers' Association (SATGA) and represent the average prices for *Eucalyptus* projects in Natal (Rusk 1978 and Rusk *et al.* 1989).

Table 1: Real price changes of individual items in the cash flow of a *Eucalyptus* project.

Item	Price 1976	Price 1988	Nominal Change (%)	Real Change (%)
Forestry Price Index	63,8	290,9	13,48 = General forestry inflation	
	(R/ha)	(R/ha)		
Land preparation, planting blanking and fertilising	158,84	730,71	13,56	0,07
Clearing trash and brushwood and coppice reduction	21,58	163,46	18,38	4,32
Weeding	16,84	82,67	14,18	0,62
Brashing	7,74	22,96	9,48	-3,52
Protection and maintenance	13,13	78,77	16,10	2,31
Administration	29,41	141,17	13,96	0,42
	(R/ton)	(R/ton)		
Harvesting	2,58	10,72	12,60	-0,78
Transport	2,22	10,67	13,98	0,44
Pulpwood delivered at mill	11,81	59,51	14,43	0,84
Mining timber delivered at mill	10,52	50,55	13,97	0,43

A third factor which makes the assumption of identical cash flows in each successive rotation unrealistic in certain cases is the use of coppice regeneration for tree species such as *Eucalyptus grandis*, for instance. In the RSA a seedling rotation is usually succeeded by two or more coppice rotations (Schönau and Stubbings 1987). The activities involved in coppice rotations differ from those in seedling rotations, which means that identical cash flows are not repeated in each rotation.

ADJUSTMENT OF THE FAUSTMANN FORMULA

Adjustment for Inflation and Real Price Changes

In its traditional form the Faustmann formula consists of two formulas for compound interest, namely:

- Present value of a perpetual periodic annuity:

$$V_o = A \frac{1}{(1 + i)^n - 1} \quad \text{(Leuschner 1984)} \tag{3}$$

- and present value of a perpetual annual annuity:

$$V_o = \frac{A}{i} \quad \text{(Leuschner 1984)} \tag{4}$$

where

V_o = present value;

A = periodic or annual annuity;

i = discount rate;

n = number of years between annuity payments (rotation).

Equation (3) is used in the Faustmann formula to discount to the present items which occur once only or intermittently during a rotation and which have already been compounded to the end of the rotation. Equation (4) is used to discount to the present general annual cost which occurs continuously in a rotation.

Equations (3) and (4) do not provide for the effect of price changes and have been adjusted as follows to take price changes into account (Flick 1976):

- Present value of a perpetual periodic annuity:

$$V_o = A \frac{(1 + h)^n}{(1 + i)^n (1 + f)^n - (1 + h)^n} \tag{5}$$

provided that $(1 + h) < (1 + i)(1 + f)$,

- and present value of a perpetual annual annuity:

$$V_o = A \frac{(1 + h)}{(1 + i)(1 + f) - (1 + h)} \tag{6}$$

provided that $(1 + h) < (1 + i)(1 + f)$,

where

i = real (inflation-free) cost of capital;

h = expected nominal annual rate at which A changes;

f = expected annual general inflation rate.

Other symbols have the same meaning as in equation (4).

Equations (5) and (6) can be simplified by substituting $(1 + h)$ according to equation (2) for $(1 + r)(1 + f)$. In such instances the general inflation factor $(1 + f)$ appears in the numerators and denominators of equation (5) and (6) and cancels out to yield real term formulations.

Equation (5) becomes:

$$V_o = A \frac{(1 + r)^n}{(1 + i)^n - (1 + r)^n} \tag{7}$$

provided that $r < i$,

and equation (6) becomes:

$$V_o = A \frac{(1 + r)}{(i - r)} \tag{8}$$

provided that $r < i$,

where the symbols have the same meaning as defined earlier.

In this form equation (8) can be used to discount general annual cost in a Faustmann calculation. Equation (7), however, can only be used to discount a single cash flow item which occurs in year n, that is, at rotation age. This equation therefore needs further adjustment for use in a Faustmann calculation.

Adjusting for real price changes

An intermediate cash flow item which occurs in year t must not change at a real rate (r) over n years (the entire rotation) but only over t years. The term $(1 + r)$ in the numerator of equation (7) must therefore be raised to the power t and not to the power n.

Adjusting for the time value of money

In the numerator of equation (7) compounding does not involve the real cost of capital since the single item (A) already represents a terminal value in year n. However, items which occur in year t must be compounded with the real cost of capital from the year of occurrence (t) to rotation age (n). An additional term, $(1 + i)^{n-t}$, which fulfils this compounding function must therefore be added to the numerator of equation (7).

With these adjustments equation (7) changes into:

$$V_o = \sum_{t=0}^{n} \sum_{j=1}^{m} P_{tj} \frac{(1 + r_j)^t (1 + i)^{n-t}}{(1 + i)^n - (1 + r_j)^n} \tag{9}$$

provided that $r_j < i$,

where

V_o = present value;

P_{tj} = j-th cash flow item in year t, expressed in today's prices;

r_j = real rate of change of cash flow item j;

i = real (inflation-free) cost of capital;

n = rotation age;

m = number of cash flow items in year t.

A complete Faustmann formulation can now be obtained by subtracting equation (8) from equation (9). This yields an *LEV* equation which provides for price changes of individual items in an infinite series of rotations:

$$LEV = \left[\sum_{t=0}^{n} \sum_{j=1}^{m} P_{tj} \frac{(1 + r_j)^t (1 + i)^{n-t}}{(1 + i)^n - (1 + r_j)^n} \right] - \left[E \frac{(1 + r_e)}{(i - r_e)} \right] \qquad (10)$$

provided that $r_j < i$ and $r_e < i$,

where

LEV = Land Expectation Value;

P_{tj} = j-th cash flow item in year t, expressed in today's prices (land cost and general annual cost excluded);

E = general annual cost, expressed in today's prices;

r_e = real rate of change of general annual cost.

Other symbols have the same meaning as in equation (9).

Adjustment for Coppice Regeneration

Equation (10) is suitable for forestry projects where pine species are planted and each rotation is established anew with seedlings. In such cases the same activities are repeated in every rotation. However, before equation (10) can be used for projects involving coppice regeneration, it needs further adjustments. In such projects a rotation as well as a cycle can be identified. For the purpose of this paper *rotation* is defined as the planned period between regeneration and clearfelling. *Cycle* is defined as the planned period which elapses between establishment with seedlings and clearfelling of the last coppice rotation, that is, before establishment with seedlings starts anew. A cycle therefore involves a number of rotations and can typically consist of one seedling rotation followed by two coppice rotations. The existence of a rotation as well as a cycle necessitates a distinction between two types of cash flow items besides general annual cost:

- Items which occur at the same age in each rotation within a cycle; and
- items which do not occur in every rotation within a cycle, as well as those occurring in all the rotations within the cycle but not at the same age in each rotation.

The first term of equation (10) can be used to discount the first group of items since they are repeated in every rotation within a cycle. The second term of equation (10) is likewise suitable for the discounting of general annual cost. In order to discount the second group, however, another term must be added to equation (10). The most convenient way to deal with this group of items is to compound each from its year of occurrence to the end of the cycle. These terminal values are then discounted to the start of the cycle as if the cycle will be repeated infinitely. With the additional term fulfilling this function, equation (10) now changes into:

$$LEV = \left[\sum_{t=0}^{n} \sum_{j=1}^{m} D_{tj} \frac{(1 + r_j)^t (1 + i)^{n-t}}{(1 + i)^n - (1 + r_j)^n} \right]$$

$$+ \left[\sum_{t=0}^{kn} \sum_{j=1}^{m} S_{tj} \frac{(1 + r_j)^t (1 + i)^{kn-t}}{(1 + i)^{kn} - (1 + r_j)^{kn}} \right]$$

$$- \left[E \frac{(1 + r_e)}{(i - r_e)} \right] \qquad (11)$$

provided that $r_j < i$ and $r_e < i$,

where

D_{tj} = j-th cash flow item which occurs in year t of each rotation within the cycle, expressed in today's prices (land cost and general annual cost excluded);

S_{tj} = j-th cash flow item which occurs in year t of the cycle and which is not repeated at the same age in each rotation, expressed in today's prices (land cost and general annual cost excluded);

k = number of rotations within each cycle.

Other symbols have the same meaning as in equation (10).

AN EXAMPLE

The following example is hypothetical in the sense that it does not apply to a specific stand but is typical in that the cost of activities and the prices of roundwood were obtained from the cost monitoring system of the South African Timber Growers' Association (see Rusk *et al.* 1989).

Basic Information

Species:	*Eucalyptus grandis*
Region:	Natal
Product mix:	65 % Mining timber, 30 % pulpwood and 5 % waste
Rotation:	11 years
Cycle:	33 years (one seedling rotation of 11 years followed by two coppice rotations of 11 years each)
MAI:	25 m^3/ha

Financial Environment

Expected average rate of general inflation (f)	= 14% per annum
Nominal cost of capital (k)	= 20% per annum
Real cost of capital (i) = $[(1 + k)/(1 + f) - 1]100$	= 5,26% per annum
Real price changes	= (as in Table 1)

Cash flow for one cycle in today's (1988) prices

Age	Activity	Amount (R/ha)
Seedling rotation:		
0	Land preparation, planting blanking and fertilising	(710,35)
0,5	Weeding	(82,67)
1	Weeding	(82,67)
4	Brashing	(22,96)
11	Chainsaw felling, manual debarking, tractor and trailer extraction	(2 382,60)
11	Transport to mill	(2 074,33)
11	Sales: Pulpwood (delivered mill)	3 653,93
	Mining timber (delivered mill)	6 724,58
Annually	Protection and maintenance	(78,77)
Annually	Administration	(141,17)
Two coppice rotations:		
0	Clearing trash and brushwood	(29,06)
0,5	Weeding	(82,67)
1	Coppice reduction	(67,20)
2	Coppice reduction	(67,20)
4	Brashing	(22,96)
11	Chainsaw felling, manual debarking, tractor and trailer extraction	(2 382,60)
11	Transport to mill	(2 074,33)
11	Sales: Pulpwood (delivered mill)	3 653,93
	Mining timber (delivered mill)	6 724,58
Annually	Protection and maintenance	(78,77)
Annually	Administration	(141,17)

Results

(a) *LEV* calculated with equation 1 (that is, with the traditional Faustmann formula which ignores real price changes and does not take into account the differences between the activities in coppice rotations and those in seedling rotations) = R1 575,17/ha;

(b) *LEV* calculated with equation 10 (real price changes are taken into account but the activities in a coppice rotation are assumed to be identical to those in a seedling rotation) = R2 562,20/ha;

(c) *LEV* calculated with equation 11 (real price changes and the differences between coppice and seedling rotations are taken into account) = R2 362,20/ha.

DISCUSSION

The Land Expectation Values obtained with equations (1), (10) and (11) differ considerably. The results obtained with equations (1) and (10) are wrong because the implicit assumptions in these two equations do not apply to the problem being analysed. The incorrect *LEV* (R1 575,17/ha) calculated with equation (1) can prevent the acceptance of a profitable project because too low a purchase price for land was calculated. The incorrect *LEV* as calculated with equation (10), on the other hand, can result in too high a price being paid for land. This would change a potentially profitable project into a non-profitable one. The most realistic results in land valuation for *Eucalyptus grandis* pulpwood and mining timber projects in the RSA will be obtained with equation (11).

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ASSESSING FORESTRY INVESTMENT POTENTIAL: A CASE STUDY ON THE ISLAND OF ARRAN

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SUMMARY

Since the fiscal changes announced in the 1988 Budget private investment in forestry has declined dramatically. The objective of this paper is to review the factors influencing forestry investment in Scotland and to describe a methodology which identifies the economic potential for commercial forestry with reference to a case study on the Island of Arran. On land where new planting was possible, the real Internal Rate of Return to capital (IRR) from forestry investment was calculated and a theoretical land price for forestry investors derived, based on timber revenues, establishment costs and the physical capability of the land to produce a tree crop. The assessment of the likelihood of afforestation actually occurring, based on an analysis of factors likely to influence the supply and demand of suitable forestry land, formed the second part of the study. Four categories of forestry land were identified ranging from very poor (IRR <3%) to good (IRR >9%), with only the better quality sites (IRR 6-9%, IRR >9%) likely to be attractive to forestry investors. Supply of suitable land is influenced by farm viability, landowners objectives and wildlife and archaeological designations. Future forestry investment demand for land is uncertain due to changes in the financial support for forestry.

Keywords: economics; investment appraisal

INTRODUCTION

Since the end of the First World War and the creation of the Forestry Commission (FC) in 1919 by the government there has been a vigorous programme of reafforestation in the UK. Total afforested area has increased from 1.21 m ha in 1918 (Edlin 1969) to 2.14 m ha by 1989 (FC 1989) with the majority of new planting carried out by the FC. In the 1980's most new planting was concentrated primarily in Scotland and averaged approximately 25 000 ha per year with the private sector contributing the greater proportion of the total (Figure 1). The stimulus for increased private investment activity was primarily fiscal concessions to high income individuals who were able to offset taxable income from other sources against costs associated with forestry planting (Lynch 1989) and planting grants administered by the FC. In 1987 the governments target rate for new planting was increased from 30 000 to 33 000 ha per year.

In the Budget of 1988 the fiscal advantages of forestry were removed mainly as a response to political concern over environmental protests about the afforestation of areas of high conservation value in the hills and uplands. Government support for further afforestation was however maintained, with the introduction of the Woodland Grant Scheme which replaced both the Forestry Grant Scheme and Broadleaved Woodland Grant Scheme and incorporated substantially improved planting grant payments. To help reduce agricultural production, especially of cereals, new planting of up to 36 000 ha over a 3 year period on better quality land was also being encouraged through planting grants and annual payments in the Farm Woodland Scheme.

Despite this commitment to further new planting by the Government, confidence in forestry investment has been shaken and with the FC restricting its new planting programme to around 5000 ha per year rates of new planting are expected to decline dramatically over the next few years to less than half of the average rate of the last decade. Considerable uncertainty therefore prevails in all sectors of the forest industry over future planting rates and new investment in downstream processing could be threatened.

The attractiveness of any investment in forestry is determined by a wide range of factors which can include the general location and amenity of the land and its wildlife or sporting potential. In the context of commercial forestry schemes the decision to invest is underpinned by the likely financial return on capital invested. The returns available from a forestry crop are determined in part by its physical performance in terms of growth rate, windthrow risk and ease of establishment and by economic factors such as establishment and harvesting costs, purchase price of the land, timber values and planting grants. Environmental and agricultural constraints on land use change to forestry can have a major impact on forestry investment opportunities by restricting the area of land available for afforestation and by preventing or delaying planting grant approval by the FC.

The purpose of this paper is to review the major physical, economic and environmental factors which influence forestry potential in Scotland, and to describe a methodology for assessing the prospects for forestry investment with reference to a case study on the island of Arran.

FACTORS INFLUENCING FORESTRY INVESTMENT

Physical Potential

The growth rate of the timber crop has the greatest single influence on physical forestry performance. The major environmental factors influencing tree growth in Scotland are topographic exposure, temperature, soil type and rainfall. In the UK the classification of growth rate is based upon the estimation of yield class (Rollinson 1986) which can be defined as the maximum average annual rate of volume increment for the crop expressed in $m^3ha^{-1}yr$ (Edwards and Christie 1981). The risk of windblow in a forest crop can severely reduce financial returns by curtailing thinning programmes and forcing premature clearfell. Crops exposed to strong winds and planted on poorly drained soils such as peat are most at risk. Ease of establishment influences both the costs incurred in the investment and the initial growth rate of the crop. Establishment difficulties include vegetation control, particularly of heather, infertile soils requiring fertilisation and browsing damage by red deer.

Financial Appraisal

The real Internal Rate of Return (IRR) for a forestry investment is defined as the real interest rate which equates the Net Present Value of the cost (establishment, land, management and maintenance) and the revenue (grants and timber) streams. The most significant components of the cost stream are establishment operations (ploughing, planting, fencing, etc.) and land price. The price of land is dependant on its value for alternative uses, which in Scotland is normally agriculture. Planting grants and timber represent the two major sources of revenue associated with a forestry investment. Under the Woodland Grant Scheme conifer planting over 10 hectares receives a grant of £615 per hectare payable in three instalments during the first 10 years. Annual payments for the first 20 years are also made in the case of the Farm Woodland Scheme (FWS) for conifer crops. Planting under the FWS restricts the total area that can be planted to only 40 ha and the scheme has a correspondingly limited application to large scale afforestation. Revenue from timber, which is a function of timber volume and price, can be obtained from thinnings and at clearfell. In forestry investment appraisal, estimates of future timber volume are based on predicted yield class (Edwards and Christie 1981) and timber price estimates based on the Forestry Commission's long run price model for standing sales. Conventionally, timber price is assumed to remain constant in real terms over the rotation period (Busby and Grayson 1981).

Land Availability and Planting Grant Approval

New forestry planting does not require planning permission but the FC can, by withholding grant payment from the forestry applicant, deter planting or ensure modifications to plantation design on environmental or agricultural grounds. Forestry planting without planting grants is possible on land where there are no legal constraints such as apply to Sites of Special Scientific Interest (SSSI's) and crofting areas but returns to capital are considerably reduced and it is estimated that over the past decade only 1% of total planting has been carried out without grant aid (FC 1989). The FC carries out direct consultation on individual planting grant applications with various relevant interests. These include: the Department of Agriculture and Fisheries for Scotland (DAFS) where new planting is proposed on prime quality agricultural ground (Land Capability for Agriculture (LCA) Class 1, 2 and 3.1) or on land of importance to the local agricultural economy; local planning authorities in areas of particular sensitivity in respect of conservation and water catchment interest; The Nature Conservancy Council (NCC) in respect of applications falling within a National Nature Reserve (NNR) or SSSI; The Scottish Development Department (SDD) on all sites of scheduled Ancient Monuments; and The Countryside Commission for Scotland in respect of landscape and amenity considerations.

Investment Demand

The viability of a forestry investment depends on the ability of the potential investor to bid a higher price for the land than other competing users such as agriculture or sport. For forestry a theoretical bid price for land (Expectation Land Value) can be determined from the discounted cash flow at a specified rate of return (Busby and Grayson 1981). Knowledge of investment demand is required to identify what this rate of return might be. The highly taxed individuals prominent in new afforestation prior to 1988 will no longer find forestry attractive (Crabtree and Macmillan 1989) and there is little experience of the post-1988 investment situation to identify potential forestry investors. Any planting that has been carried out since the budget changes in 1988 has been small scale or carry over from planting schemes approved before 1988 and still eligible for tax relief. The largest group of potential investors are, however, likely to be untaxed institutions and in particular pension funds. In the past, these have been active in new planting to a limited extent but could be attracted to forestry if returns were sufficiently favourable. To be considered an attractive investment forestry is normally required to exhibit a premium over index-linked government stocks because of its less favourable risk and liquidity characteristics. The return from long-term index linked securities in 1989 was 3.6% (CSO 1989) and therefore a return of around 6% would seem necessary to attract new forestry investment (Crabtree *et al.* 1990).

THE POTENTIAL FOR NEW PLANTING ON ARRAN

Arran is an island located off the south-west coast of Scotland covering an area of approximately 425 km^2. It is a particularly useful location for a forestry investment appraisal study since it combines a favourable environment for tree growth with a complex range of factors likely to influence the transfer of land to forestry. The island has seen considerable planting activity primarily by the FC and almost one quarter of the island is now afforested or has been approved for planting. The most extensive forestry planting is found in the south of the island on what was previously hill sheep ground.

The assessment of further planting opportunities on Arran was based on a three stage approach:

(1) Define the available area for afforestation based on known land use constraints
(2) Assessment of the physical and economic potential of new planting
(3) A review of the factors most likely to influence new investment.

Available Area

Only 28% of the island is considered to be available for further planting due to environmental and agricultural designations or because it is already afforested (Figure 2). Tourism is the most important industry to the economy of Arran (CDD 1988) and its popularity is based primarily on scenic quality and opportunities for hiking and cycling. The northern half of the island, which is dominated by high mountain ranges, is also highly valued for conservation and is protected from afforestation by a series of conservation designations (Arran has 1 NNR and 8 SSSIs). Quality agricultural land on Arran is rare but the best of it (LCA Class 3 and 4), scattered around the coastal communities, is considered worth protecting to maintain the dairy industry and safeguard the future of the island's creamery (CDD 1988).

Forestry Potential

The forestry potential of land still available for afforestation was determined using physical data assembled within a 1 km point database. These points were used as the input data to a forestry investment model (Macmillan and Chalmers 1990) which identifies the preferred species, yield class, windthrow hazard class (Miller 1985) and the maximum IRR. Guidelines for yield class prediction were based on Worrell (1987) adjusted for local conditions. Timber prices were obtained from the Forestry Commission Average Timber Price size curve for Scotland (87/88) and establishment costs based on private forestry figures for 1987/88.

Four categories of forestry performance were recognised; Good (IRR>9%), Moderate (IRR 6-9%), Poor (IRR 3-6%) and Very Poor (IRR < 3%). The individual performance at each location is shown in Figure 3. These categories were then mapped based on a series of decision rules derived from the forestry performance/site relationship at each location using the 1:250 000 soil unit as the basic mapping unit. The mapped units are shown in Figure 4.

The general pattern of forestry performance exhibited in the study area is typical of western Scotland. In the more sheltered lower slopes and river valleys higher temperatures and greater topographic shelter result in high rates of predicted growth, lower establishment cost and more stable crops. As altitude increases however, forest potential diminishes due to greater exposure, lower temperatures and more infertile soils. There is also a general trend of improved forestry performance from west to east due to diminishing exposure to salt-laden westerly winds. For most site conditions Sitka spruce was the most suitable species.

On Good forestry land yield class will often exceed 18 $m^3ha^{-1}yr^{-1}$ and windthrow risk will be low. Covering roughly 7% of the study area, this land is mainly located on the bottom and lower slopes of well sheltered valleys on the eastern side of the island, such as Benlister Glen and the hillsides between Glen Cloy and Glen Shurig. Moderate forestry land includes sites capable of an average yield class between 16-18 $m^3ha^{-1}yr^{-1}$ and covers approximately 28% of the area. Poor forestry land has an average yield class of between 12 and 14 $m^3ha^{-1}yr^{-1}$. Windthrow risk is high and short rotation, no-thin harvesting schedules would prevail. Land in this category includes peat or peaty soils on the more exposed slopes and hills at elevations in excess of 250 m where Sitka spruce is often grown in mixture with lodgepole pine to overcome nutritional difficulties during establishment. Very Poor forestry land occurs on land capable of sustaining only low rates of growth (yield class less than 10 $m^3ha^{-1}yr^{-1}$) or which is technically unafforestable due to rockiness or hagged peat. This land generally occurs at the highest elevations within the study area.

Other factors - often site specific and not identified by the data in the investment model - have also to be taken into account when considering investment potential. For example the strip of land along the north east coast has Good forestry potential but is unlikely to be attractive to any investor due to poor access (no road) and operational difficulties on ploughing steep slopes adjacent to the sea. The narrow coastal strips along the east coast are also less attractive due to their awkward shape and terrain and the presence of large areas of natural scrubland.

Investment Potential

Poor and Very Poor land categories could not be purchased at any price for forestry on the basis of a 6% return since the Expectation Land Value (ELV) is negative. The average ELV for Moderate land is £260 per hectare and for Good forestry land £1400 per hectare. Most of the land within these categories is hill land and land price at the time of the study was around £75-200 per hectare depending on quality and maintenance. Land price is therefore unlikely to inhibit investment on better forestry land.

There is however no clear evidence of a reemergent demand for planting land on Arran by the private sector. In addition, the FC which was responsible for the majority of new planting on Arran in the past is now less active due to a cutback in their national planting target to around 5000 ha per year. The FC owns substantial areas of unplanted ground within the study area but this is generally of Poor or Very Poor performance and unlikely to be planted particularly since environmental issues relating to water quality and conservation would have to be addressed. Land acquisition for new planting on a small scale may however continue particularly if the property directly adjoins existing FC plantations.

Land use change to forestry will not necessarily occur even should a forestry investment give a satisfactory return to capital. Agricultural tenancy or partnership agreements and national or European Economic Community (EEC) agricultural programmes, for example, can present difficulties for land transfer to forestry as can environmental concerns and personal preference of the seller. Thirteen of the major landowners and farmers within the study area were interviewed to obtain information on land tenure, land ownership and the likelihood of land sale to forestry interests. The majority of the study area is tenanted to two principal landowners. Tenancy agreements prohibit afforestation by the tenant but permit the landlord to resume land subject to a set of legal procedures and financial compensation. Nearly all of the study area is also in the Scottish Islands Agriculture Development Programme (ADP). The programme, which is part EEC financed, aims to improve the agriculture of islands subject to structural or infrastructural handicap. It provides grant aid for farm development, environmental measures and livestock improvement. Its effect will likely be more long term however, since many farmers are using the finance available to improve the infrastructure of their farms to allow expansion of output after 1993, (intensification being prohibited during the life of the ADP). Resumption of tenanted land within the ADP by the owner for afforestation will therefore be less likely since the scheme will lead to fixed capital improvements and higher incomes and would necessarily involve the landlord in higher levels of compensation and the loss of increased rental income. Agricultural incomes are in many cases also supported by diversification into non-farming activities such as holiday accommodation and off-farm jobs and it is unlikely that the financial situation of most farmers will deteriorate sufficiently in the near future to cause a significant area of land to come on the market.

Land transfer to forestry in some locations within the study area is further complicated by an intensive distribution of archaeological sites including standing stones and burial chambers (cists). Grant approval would necessarily involve the prospective seller of the land in protracted negotiation to safeguard the archaeological sites and in all likelihood the loss of substantial plantable area.

DISCUSSION

Since the budget changes of 1988 investment activity in forestry has lost momentum and it seems unlikely that, regardless of the economic advantages of forestry in many areas over other land use activities, much new planting will occur on Arran or in the rest of Scotland in the near future. Government support for the industry is still strong however and should investment demand increase there are substantial areas of land with forestry potential. It is difficult to predict what the trigger for renewed investment activity might be but institutional investors such as pension funds may revive their interest if land price falls; the land itself seen as a good investment. A fall in agricultural land price may occur due to changes in support levels for hill ewes but the specific effects of adjustment of agricultural policy in the hills and uplands are difficult to predict. It is questionable whether raising grant support for forestry by the government is a feasible route to encourage external private investment since grant support already covers more than 50% of the total cost of establishment. Further increases would reduce the contribution of private capital to a relatively small proportion of the total cost and this could lead to considerable public concern over the use of public funds for private profit. The reduced net outlay of capital would also encourage institutional clients to invest in fairly large scale afforestation projects to ensure a satisfactorily large expenditure to optimise fund management efficiency (Taylor 1989). Large scale afforestation is however difficult in many areas of Scotland due to environmental and agricultural restrictions. Increased grants would, on the other hand, increase new planting among farmers and traditional estates with spare land available.

The decision to make an investment in forestry is often based on a complex range of factors which can be unrelated to crop performance and are often site specific in nature. The objectives of landowners, for example, are central to the question of future availability of land for forestry. The accurate prediction of where new forestry planting may occur in the future at regional or national levels is therefore complex. The approach to modelling forestry investment potential adopted in this paper goes a considerable way toward identifying where new planting might occur based on predicted crop performance and financial yield. Areas unlikely to be afforested on the basis of very low IRR or land use constraints can also be identified. The investment model can be applied at local, regional and national levels utilising physical information held within the Macaulay Institute's Land Use database and has obvious value to policy makers interested in forestry potential.

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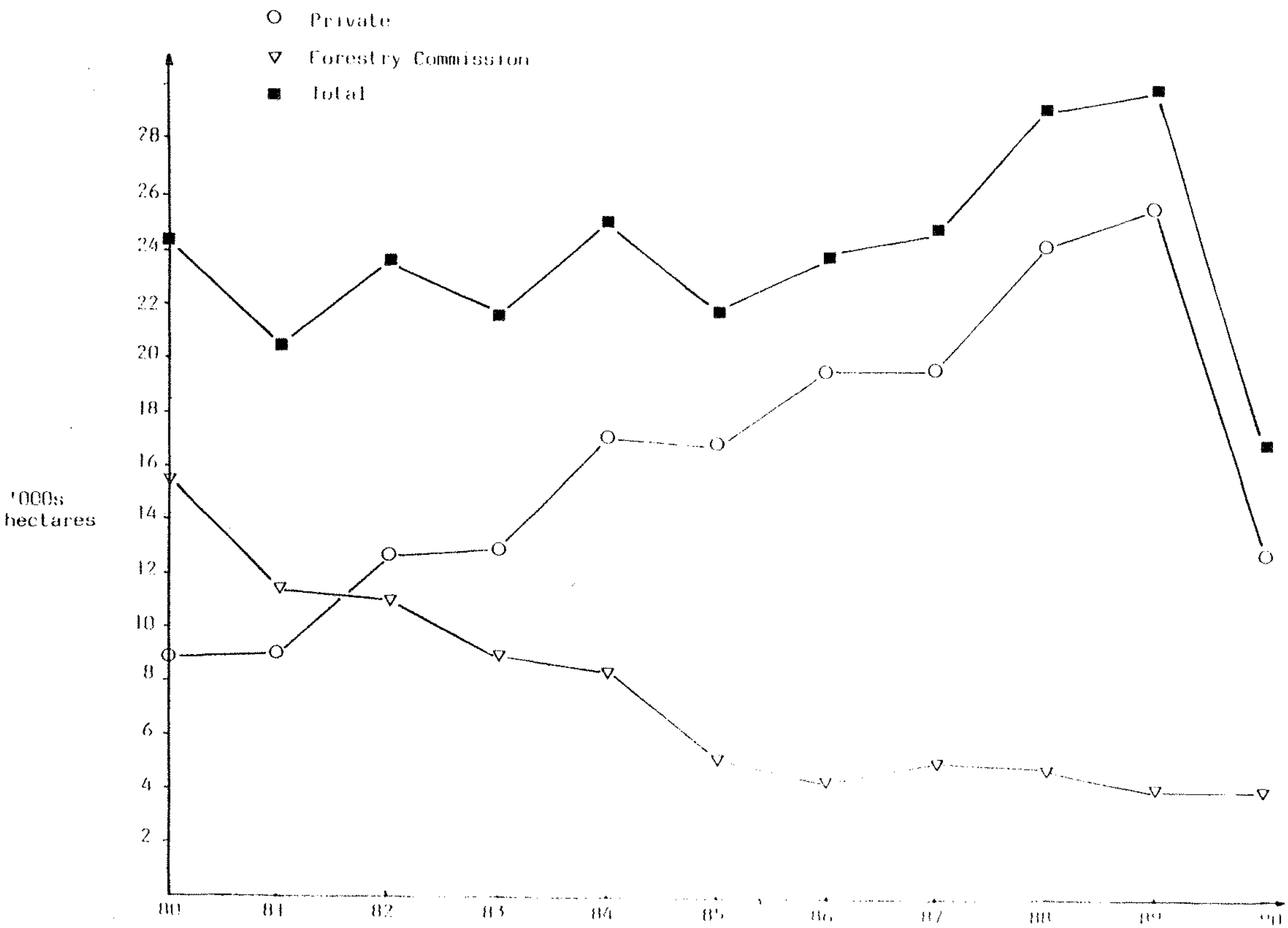
Figure 1. New planting 1980-90 : Forestry Commission and Private.



Legend

land not available for new forestry planting

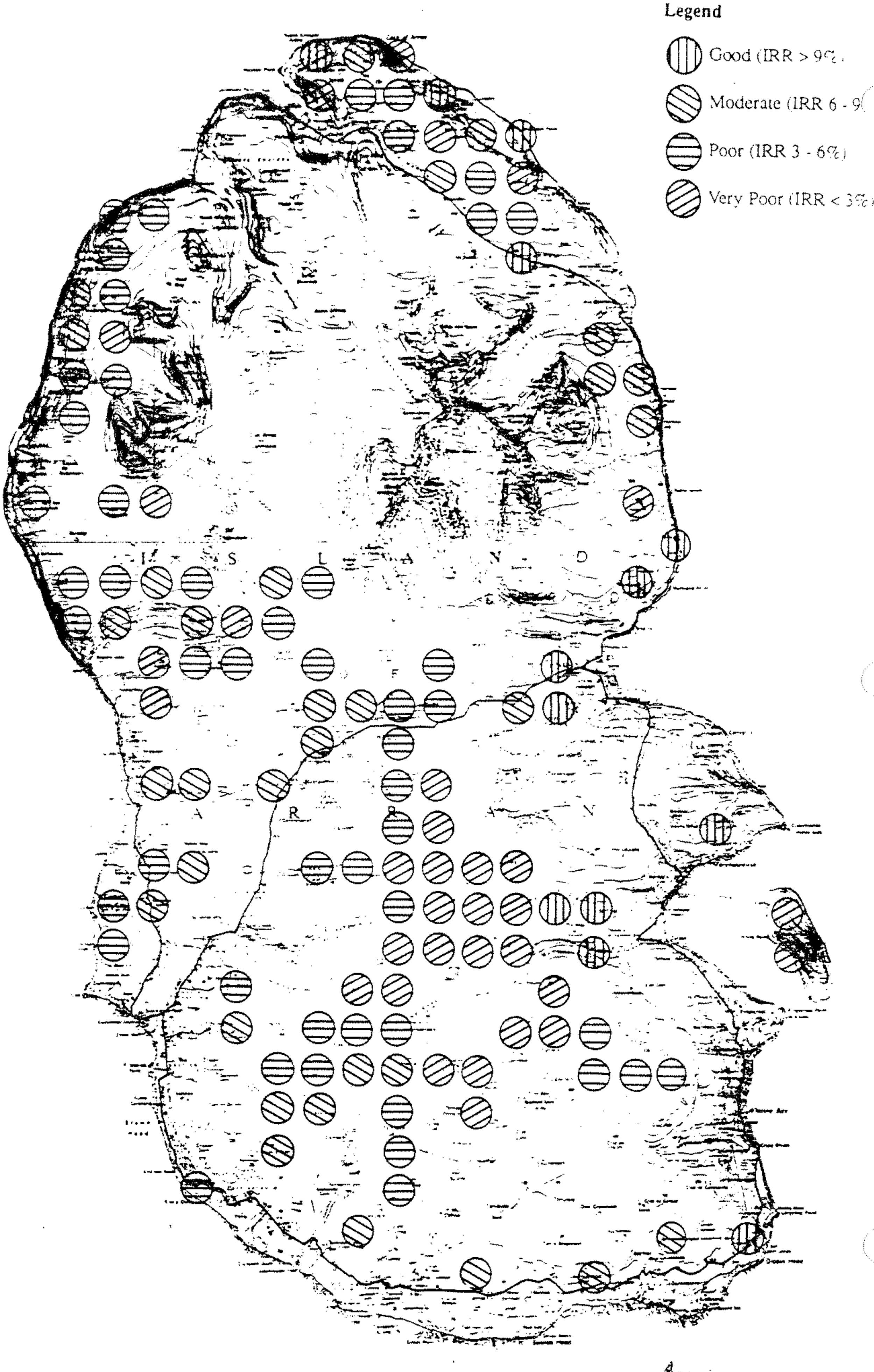


Figure 3: Forestry potential at 1 km intervals

Figure 4: Mapped forestry potential within study area

THE DYNAMIC TRANSITION MODEL

A tool for forestry planning and valuation

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INTRODUCTION

In economics models are of major theoretical and practical importance. They constitute the preliminary stage of theory formulation, serve as useful clarifying instruments and are an essential tool for establishing forecasts and assessments. In practical decision-making, the main purpose of models is to analyse and evaluate alternatives by means of anticipatory determination of possible consequences. Beside this, they are of major significance in teaching (thinking in terms of systems and interrelations).

Thinking of forest management from a business point of view, a model which includes the forest assets could be based on the following conception of a forest enterprise: factors of production, such as a forest (land and stands), labour and know how are invested, combined and transformed into products and services with the help of nature (see Table 1). The resultant output is either sold on the market or consumed by society free of charge (infrastructural functi-

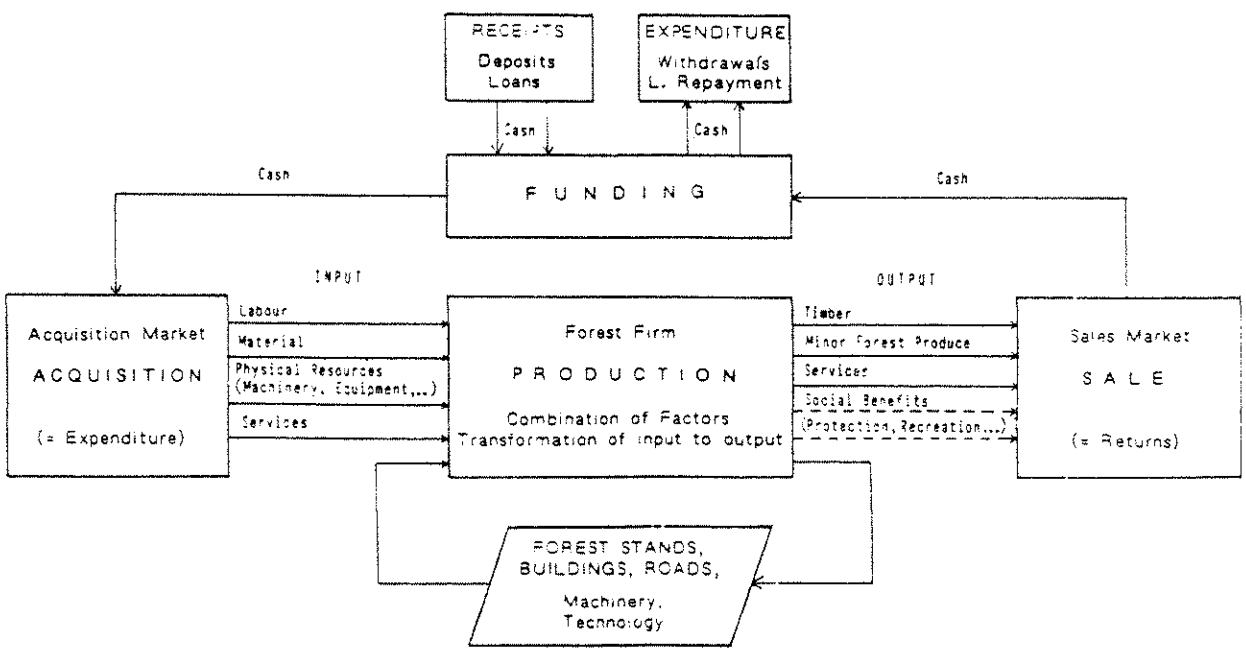


Table 1: *Transformation processes in a forest enterprise (Jöbstl, 1973)*

ons) *(external output)*, or reinvested as long-lived assets, such as growing stock, self-constructed buildings and roads, which in turn become an input for the following period *(internal output)*. Time is the most important dimension. All things have to be seen in the course of time. The time continuum can be divided into segments (periods: a year, a decade). Plans, reports on execution of activities, physical and financial statements of account and - at certain dates - inventories are prepared for these time segments: as business management plans mostly for one year; in forest management as medium-term and long-term plans mostly for a period of ten years. They are both closely interconnected like communicating vessels.

Forestry activities are goal-oriented. We may distinguish between *forest state objectives* and *output objectives* (the business management objectives in the narrower sense). The objectives are multiple and interlinking with regard to content and time. Output objectives have an impact on forest state objectives and vice versa. This is true for the short-, medium- and long-term perspective. Timber production involves a long time span between input and output. Traditional accounting methods take into account forest-related changes and actual-state parameters very inadequately.

The future performance (increment, yields, etc.) of a forest estate will mainly be determined by the forest structure as a key characteristic (age-class distribution, volume of timber growing, species, site class, degree of growing stock, state of health etc.) and by the future management activities.

Because of the long time span between input and resultant output any evaluation of a forest enterprise and of silvicultural measures and strategies must be seen in a long-term perspective. Input/output relations have to be considered explicitly.

ACTUAL STATE - TRANSITION - TARGET STATE

Table 2 outlines the actual state of a management unit, a distant target state and, in between, the transition period with its periodical results (output objectives). Analogously, one may define interim forest state targets for the end of each time segment. The *ACTUAL state* is determined by forest inventories, the *TARGET* is predetermined by establishing objectives and plans; *OUTPUT results* of the transition period must be ensured.

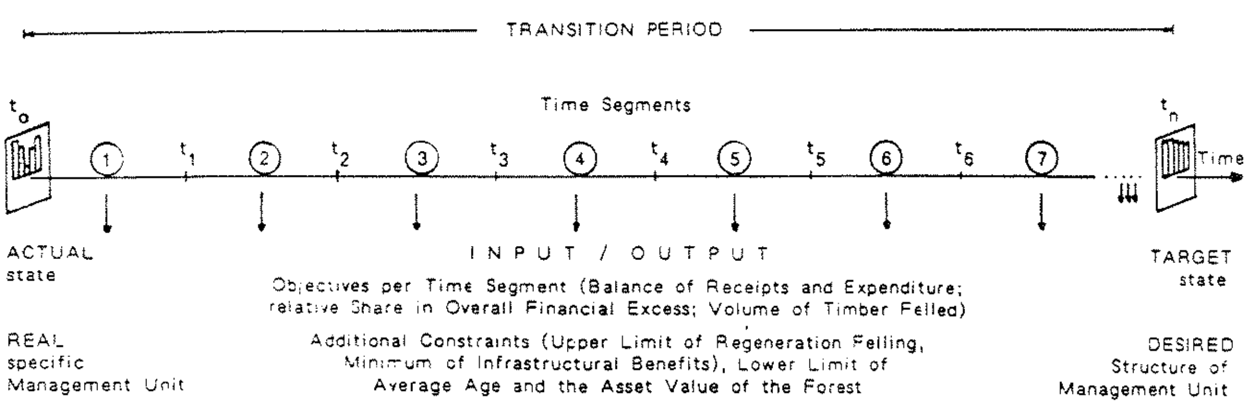


Table 2: *Scheme of a sustained yield model in forest management (Jöbstl 1973)*

This table illustrates a conceptual framework for developing the "forest estate" system over time. Instruments for its quantified computation (in a model) are LP-models and simulation. The so called "utilization plan" is of focal importance. Taken in the widest sense, it embraces the advance and final fellings in the course of time and all other production measures and is reflected in parameters such as size of area to be treated, volume of timber harvested, labour and machines requirement, returns, expenditure, and profit contribution.

MODELS AND CALCULATION EXPERIMENTS

Objectives are the guidelines which provide orientation. The means (strategies, measures) to arrive at this aim are to be sought. Conceptually, we are dealing with a question of "What happens, if..." (IF-THEN). There are basically two types of questions to be distinguished:

1.) given: actual state plus strategies/measures (IF)
wanted: target state plus external output (THEN)

2.) given: actual state plus target state (IF)
wanted: the means (measures and external output) to arrive at the aim (THEN).

The *target state* can be studied statically in its structure and future output by means of the normal forest model or its modified forms, which have been adapted to reality. This study will provide information on average values of growing stock, annual increment, fellings (yields), contribution margins, and net income per hectare. These parameters are *measures for the sustained output capacity* of a forest management unit (see Fig.1).

Figure 1: *Normal forest management class (Rotation period = 110 years)*
Results of 2 variants: (with and without game damage)

Parameters	*(values per hectare)*	**Variants**	
		with DAMAGE [W]	**wo. DAMAGE [R]**
GROWING STOCK	cum u.b.	245	257
INCREMENT / year	cum u.b.	7,0	7,1
Final felling volume / year	cum u.b.	4,6	7,7
Advance felling volume / year	cum u.b.	2,4	2,4
TOTAL FELLING VOLUME / year	cum u.b.	7,0	7,1
Contribution margin final cut / year	AS	2.732	3.024
Contribution margin advance cut / year	AS	399	645
TOTAL CONTRIBUTION MARGIN / year	AS	3.131	3.669
NET INCOME / year	AS	1.131	1.669
VALUE (stumpage value)	AS	89.000	104.000
PRESENT VALUE of net returns (4%)	AS	28.275	41.725

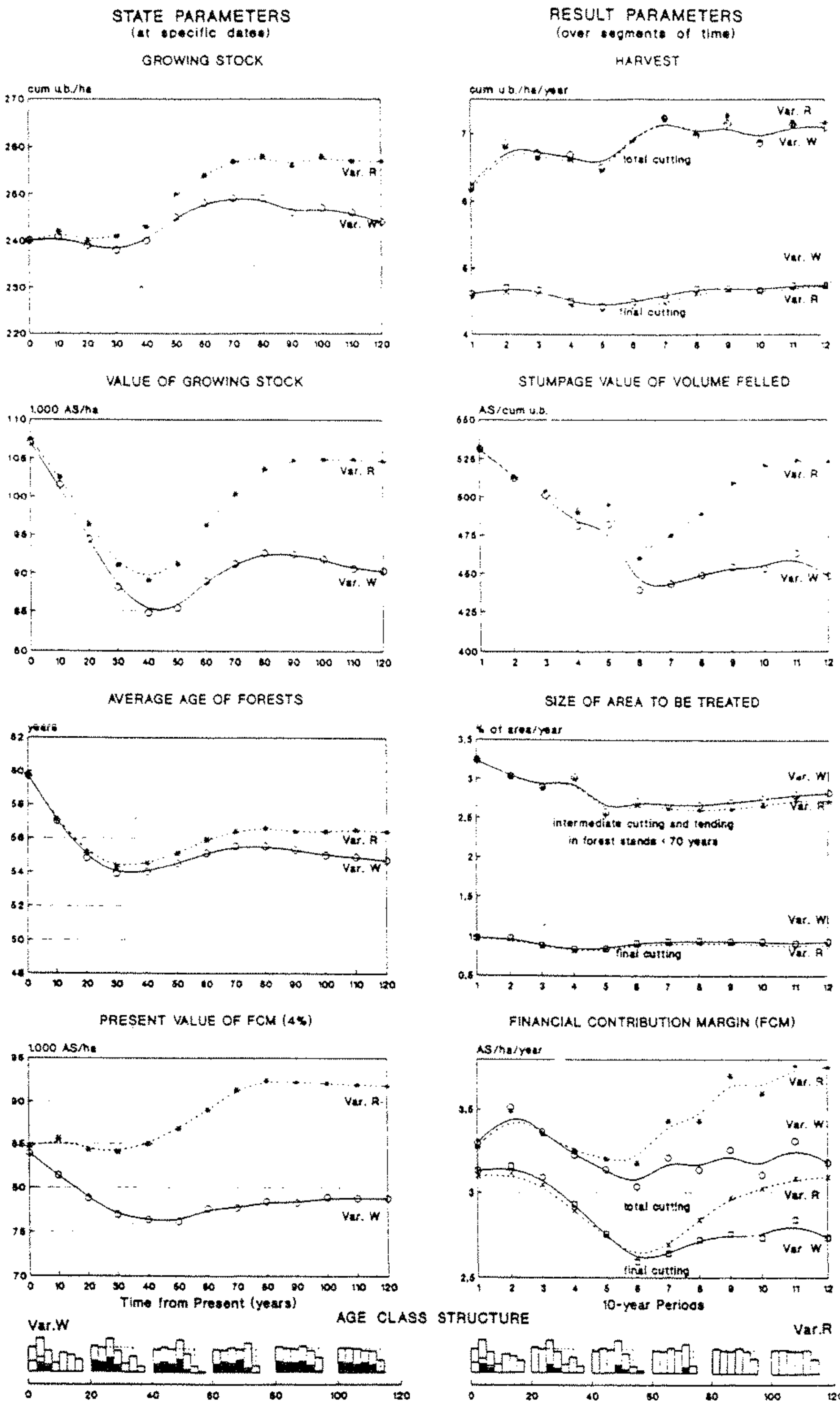
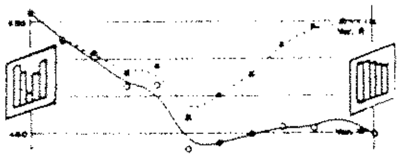


Table 3: *Results of two simulation variants created by Forest Management Class Simulation Model FOBSI (with continuing game damage (W) and after reduction (R)), Jöbstl 1978, 1987*

Figure 2: *Transition model - Results of 2 variants (Transition period = 120 y.)*



Parameters	*(values in AS per hectare)*		Variants: with DAMAGE [W]	Variants: wo. DAMAGE [R]
AVERAGE FINANCIAL CONTRIBUTION MARGIN (FCM)	TRANSITION PERIOD (T)	years 1- 40	3.347	3.337
		years 1-120	3.227	3.448
	after T (t=120)	normal forest	3.131	3.669
PRESENT VALUE OF FUTURE FCM (dynamic sum according to Krieger)	t_0	Interest rate *(IR)* 4%	83.874	84.684
		(time preference) 2%	164.300	171.200
	t_{120}	Interest rate *(IR)* 4%	78.275	91.725
		(time preference) 2%	156.550	183.450
COEFFICIENT of economic performance capacity		Interest rate *(IR)* 4%	3.355	3.387
		(time preference) 2%	3.286	3.424

In practice we are not managing a normal forest, but a real one, which is subjected to dynamic change (cf. *Gerold, Kiraly, Kouba, Kurth, Möhring, Suzuki*). Seen in terms of business management, we are therefore primarily interested in the transition period and its output. The *transition phase* from ACTUAL to TARGET is to be analysed over time (dynamically). It is characterized by an original state and different transitional situations (states, events, interferences) and the changes thereby effected. The results allow for a deduction of objectives and management patterns over time.

The results of both analyses together determine the output of a specific management unit. *The actual value of a management unit must be derived from the future results* during the period of transition on the one hand and from the normal forest model on the other. Depending on the course of the graphs of the relevant parameters and on the given time preferences (rate of interest) different forest values will result (see Fig.2).

Total output $O_{tot} = O(N) + O(T)$

O(N)...sustained output after end of simulation (derived from normal forest model)

O(T)...output of transition period (derived from dynamic transition model)

By means of a simulation model one may determine the values of the relevant (physical and monetary, actual-state and output) parameters in the transition period (Table 3). Their development curves over time are taken as the basis of valuation and assessment of alternatives. From the output parameters which have been evaluated in monetary terms [attributing monetary values (value ratios) to physical state and output variables is necessary in order to render different timber species, grades and qualities, costs etc. comparable and thereby addable] one may calculate net present values by way of discounting (interest rate as a measure of time preference). This discounted value represents the present worth of forest returns (assuming, of course, stability of price and costs over time). The curves of "financial contribution margin" and its discounted value show remarkable differences (see Tables 3, 4).

Table 4 gives examples for question type 2: different ways (represented by three different felling rate formulas) to attain a predetermined target. Note: Although the total results in the overall transition period are almost equal, the felling strategy variant No. 3 reaches only 77% of the discounted present value of forest return of variant No 1.

By using a computer models can be calculated in several variations. It is, for instance, possible to account for uncertainties and risks such as calamities, timber price variations, forest damage ... in the simulations. Calamity variables can be estimated on the basis of historical data, risks can be delineated by calculating optimistic, probable and pessimistic variants.

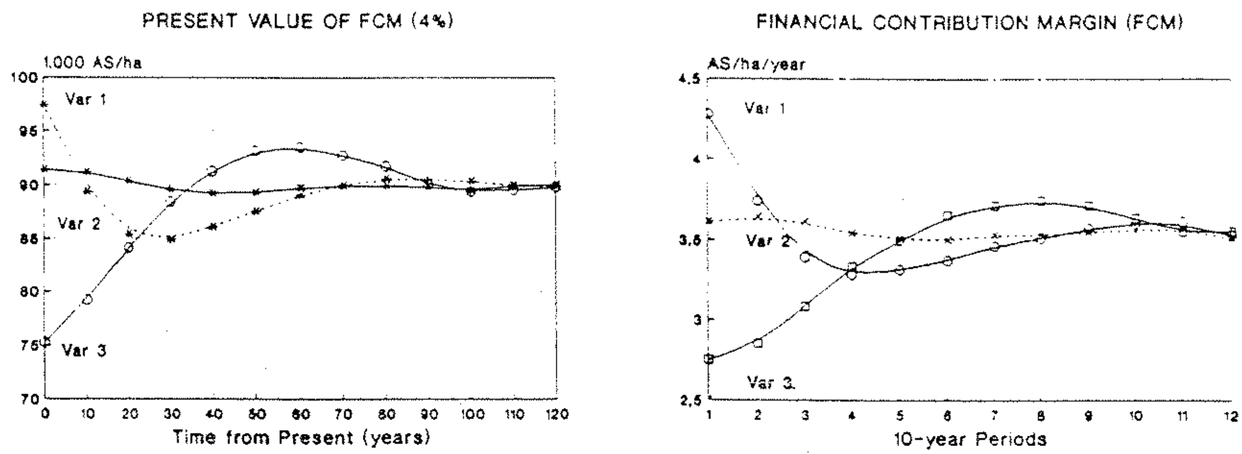


Table 4: *Comparison of three simulation variants created by FOBSI (different felling rate strategies, identical actual and target state)*

USEFULNESS OF THE MODEL

There is a wide range of applications for the results and the model, i.e.:

1. **Forest valuation:** Valuation of the actual forest state on the basis of future output (returns) (= discounting of the financial yield series plus additional evaluation of other target components against their long-term development).

2. **Evaluation of plans as a basis for decisions:** Design of alternative utilization plans and their evaluation as a basis of medium and long-term planning; analysis of long-term strategies; examination of plans as to sustained yield; complex regulation to ensure sustained yield, taking account of a variety of factors. Other management functions (purchase, funding) and forest social benefits can be - at least partly - included and evaluated, and accounted for as constraints (e.g. species distribution).

3. **Identification and specification of objectives:** Apart from evaluating plans and long-term strategies (e.g. game and peeling), identification and specification of objectives is facilita-

ted. Developments and correlations (cause-effect) are clearly depicted, which paves the way for a decision as to which aims and results to strive for (sustained financial yield, supply, reserves, growing stock etc.).

4. **Training of foresters in better understanding of the forest enterprise (thinking in terms of systems and long-term cause-effect relationships):** Models of this kind illustrate the relationship of forest management and business management in an enterprise and their relation to other management functions: e.g. the effects of different felling rate formulas (as felling strategies) on growing stock, increment, harvest, forest value; the problems of short-term budget-oriented thinking (implementation or omission of cultivation and tending measures; forest damage; over-cutting and under-cutting) and their long-term economic effects. Such illustrations promote long-term thinking in terms of sustained yield which is geared to the needs of a forest enterprise.

5. **Advancement of the theory of management class and normal forest:** This advancement is the result of the elaboration of individual "normal" management class models (with a positive skew) which are closer to reality (the target forest is an improved version of a normal forest model) and of the dynamic transition model. The latter illustrates transitions from the real to the target forest, the time dimension of all forest management actions and results, as well as the opportunities and problems to be expected for the individual enterprise.

6. **Medium-term performance analysis of the forest enterprise:** Determination of forest-state changes over the medium term by means of two forest state inventories; assessment of physical and monetary performance capacity. Comparison of target and actual forest state, identification of deviations and analysis of causes.

CONCLUSION

The presented *dynamic transition model* most clearly illustrates the relation of *forest management planning*, which is usually directed to physical parameters, and *forest business management*, whose criteria of evaluation are based on economic rationality and financial targets. This model is of equal importance for both disciplines. Business management considerations which fail to include the resultant changes in the structure of a forest do not make sense and will lead to misdirected judgements. The model helps to overcome the problem of inadequate accounting for the most important forest asset, i.e. forest stands, in bookkeeping. However, forest management can be only part of medium- and long-term economic planning in forestry. This ranking of subjects is not a question of delimiting disciplines and their representatives, it is a question of holistic thinking and global approaches from a system-oriented point of view. As subjects, both disciplines are equally legitimate and important; in practice, however, they must not be dealt with or implemented to independently of each other.

ABSTRACT

Forest management and business management perspectives meet in particular in medium and long-term targetting, planning and performance evaluation. Specifying objectives and en-

suring a sustained yield require a prospective analysis of possible future developments of an enterprise (long-term simulation of operations). Static and dynamic sustained-yield models for management classes are the key element.

The actual forest state is compared or conceptually related to the normal forest model or its sub-forms, which have been adapted to reality (positively skewed age-class distribution, varying stocking density, different species distribution and yield classes). By means of normal forest model calculations it is possible to analyse management alternatives (rotation cycles, cultivation measures, thinning intensities, game densities etc.), to establish yield forecasts and to perform evaluations. The transition phase from the current state to the normal or target forest state is to be illustrated and calculated in a second model - the dynamic transition model. (Note: It is appropriate to attribute monetary values to physical actual-state or output parameters, in order to correctly depict the economically relevant relationships between different objects relative to the objectives.) The results derived from the transition period are both the basis and measure for plan evaluations and management (class) valuations. Taken together, the "normal" and the "transition" model supply data for strategic decision-making (plan alternatives and forecasts of their impact) and evaluation (management, forest estates,etc.). In this paper the basic ideas underlying the concept of the transition model, the possibilities of formulation and implementation are presented, and illustrated by examples.

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SIMULATION MODEL OF ALLOWABLE CUT ESTIMATION

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Summary

In Czechoslovakia the cutting index for the management class is computed as the sum of products of individual volumes of age classes and corresponding cutting percentage which are tabelated according to duration of regeneration period.

The development of the age structure can be expressed as a stochastic process using Markov's chain characterized by a transition matrix.

The result of this solution is the simulation model of the cutting intensity in the age degree according to the probability theory, so as to reach the stationary vector "a" representing a normal proportion of age degree in the shortest possible time.
Keywords: Yield regulation, index of yield reg., allowable cut.

Problem and aim of work

The yield indexes are of great importance for the regulation of the allowable cut because they materialize data on the yield possibilities of forests from the viewpoint of permanence and evenness of yields. The indexes of final cutting are of decisive importance for the natural reproduction of the forest resource.

Most of the present indexes of the allowable cut follow from the classical theory of a normal forest which assumes a trouble-free development of stands and their populations. In reality the planned activity of forestry is interrupted by natural and antropogene factors which influence negatively the forest functions which results e.g. in salvage cuttings. Therefore, it is reasonable to consider the yield indexes derived in accordance with the calculus of probability.

The aim of the work is to investigate and evaluate the method of regulation of the allowable cut in the Czechoslovakia based on the volume indexes and the method of regulating the allowable cut according to the calculus of probability.

Basic material and selected processing methods

The selected experimental object was the School Forest Enterprise of the University of Forestry and Wood Technology in Zvolen, the category of commercial forests with the total area of 5, 805, 36 ha.

The evaluation of individual methods aims at two main conditions which are to be fulfilled by the methods of the regulation of the allowable cut:

- maximum utilization of the growing stock in mature stands,
- long-term evenness of yields.

Method of regulation of allowable cut in the Czechoslovakia

In the Czechoslovakia the areal framework of yield regulation is the forest estate in which the index of yield regulation is solved according to management classes and the evenness of of yields within the framework of the forest categories (commercial, protection and special-purpose forests).

The index of yield regulation for the management class represents the sum of multiples of the growing stock of separate age degrees and the corresponding yield percentage in dependence on the length of the regeneration period and of the rotation

$$U = V_i \cdot c_i \cdot 100^{-1} \qquad (1)$$

where U - index of final cutting

V_i - growing stock of separate age degrees

c_i - yield percentage of the corresponding age degree

The indexes of yield regulation U_1, U_2, U_3 are calculated for the three following decades from the growing stocks V_1, V_2 and V_3. The expected growing stocks for the 2nd and 3rd decades are calculated for the 5th and older age degrees according to the formula

$$V_{i+1} = V_i - C + I \quad \text{or} \quad V_{i+1} = (V_i - C) \ . \ k \qquad (2)$$

where k - coefficient of the expected growing stock.

The formulae for balancing the allowable cut

$$E_1 = v.U_1 + v_2U_2 + v_3U_3 + v_0E_0$$

$$E_2 = (U_1 + U_2 + U_3) : 3 \qquad (3)$$

$$E_3 = 2\ E_2 - E_1$$

vhere E_1, E_2, E_3 - allowable cut of the 1st, 2nd and 3rd decade,

v_1, v_2, v_3 - weights of indexes of yield regulation for the 1st, 2nd and 3rd decade

v_0 - weight of the allowable cut of the last decade.

Method of regulation of allowable cut based on the calculus of probability

The calculus of probability applied to the problem of a normal forest has been most widely elaborated abroad by Suzuki, T (1983 and the given literature), in Czechoslovakia by Kouba, J. (1983 and the given literature).

Because the age structure of the management class is dependent on planned and incidental (salvage) final cutting, its development as an incidental process may be expressed by means of Markov's chain characterized by the matrix of transition probability P.

Normal representation of age degres, is line vector with elements $a_1, a_2, \ldots a_n$

$$a = \lim_{t \to \infty} p^{(0)} P^t = a^P \qquad (4)$$

The decade allowable cut per 1 ha is calculated according to the formula:

$$E_v = p^{(0)} \, . \, P^{t-1} \, . \, P^{T(1)} \qquad (5)$$

and the normal one according to the formula:

$$E_n = a \, . \, V_{dg} \, . \, P^{T(1)} \qquad (6)$$

Normal clearing to the formula:

$$G_n = a^{Pt(1)} = a_1 \qquad (7)$$

where V_{dg} - diagonal matrix with elements of the vector V^T

$P^{T(1)}$ - first colour of matrix P

The solution of tasks may be carried out based on data which are found in the elaboration of forest management plans (area, growing stock according to age degrees) and from the evidence (realized planned and incidental cuttings), or by the adjustment of these data in dependence on age.

Sumarisation of the obtained results

a) The method of regulation of the allowable cut according to volume indexes determined by the utilization per cents aims at the maximal utilization of the growing stock of mature stands, at simultaneous ensuring of the continuous development of cuttings. Therefore, the allowable cut derived in accordance with volume indexes for individual management classes is balanced for the three following decades within the framework of the category of the forest and compared with the mean annual increment at the age of rotation (PRP) and the area of a normal clearing (B_u). Graphical illustration of values of indexes of yield regulation U_i, volume allowable cuts E_{vi}, as well as their comparison with final mean annual increment (PRP) and 1/30 volumes of last 3 age degres (1/30 V) is in Fig. 1.

The indexes of yield regulation U_1, U_2, U_3 show a great fluctuation in the following decades resulting from the age structure of the considered management class. On the other hand, the differences of the balanced volume and areal allowable final cuts E_1, E_2, E_3 are acceptable from the viewpoint of the balance of cuttings in the future periods.

An adequate balance of cuttings is considered to be the fluctuation of the differences not exceeding ±10 % in comparison with the preceding period.

b) Due to the effect of injurious agents a certain part of the pre-mature stands of separate age degrees decreases, this being expressed by the area percentage or by growing stock. Therefore, the planned and realized area of final cutting, as well as the part of the areas of incidental final cutting during the decennium are transferred into tohe first age degree. The probable share of these incidental cuttings may be differentiated based on experience and from evidence.

An important results is the calculation of vector "a" which represents normal relative representation of age degrees and its first member may be considered as the objective index of a normal clearing.

The results of the calculation of the allowable final cut within the three following decades show that the differences between separate decades are very large and that they exceed the given limit ±10 per cent of the deviations of the allowable cut during separate decades.

c) The elimination of differences of indexes of allowable final cut during the following periods is possible either by their balancing for several decades which is done in the method used in the CSFR or by the correction of the area of the regenerated stands by a quantity dependent on the age structure of the management class. Such a quantity is the stationary vector "a", its element a_i being the objective index of a normal clearing which is dependent not only on the planned final cutting in mature stands but also on the salvage final cutting from the younger age degrees.

The practical use of the normal clearing calculated in accordance with the calculus of probability consists in the fact that in the initial vector of areal representation of forest trees according to age degrees the yield shares are determined by means of utilization per cents, the sum of yield shares being compared with the element of vector a_i. Two cases may occur: a) if the element a_i is smaller than the sum of all yield shares, these are gradually summed up from the oldest age degree to the younger ones up to the age degree in which the sum (including yield shares of premature stands) exceeds the value a_i; the difference is transferred into the following decade; b) if the element a_i is larger than the sum of all yield shares, this difference is completed from the age degree which has the highest representation in the regenerated stands; the residue is transferred into the further decade. Graphical illustration of the course of the decennial final cutting according to the calculus of probability without and with the correction by the element of vector a_1 is given in Fig. 2.

Discussion

The method of regulation of the allowable cut based on volume indexes utilizes in a maximum way the growing stock of mature forests by means of the utilization per cent. The solution is based on the distribution of growing stocks according to age. On the other hand, the balancing of indexes for three decades ensures the requirement of an adequate balance. A shortage is the small weight being attributed to inductive allowable cut and its synchronization with the deductive method.

The method of yield regulation based on the calculus of probability makes possible the complex solution of the yield regulation, as well as the calculation of further quantities on mathematical basis. In comparison with the preceding methods it takes into consideration the influence of calamities in younger age degrees on the area of the first age degree. This method solves the long-term balance but in the far future (several production periods). The proposal for introducing an objective balancing quantity dependent on the age structure of the management class was investigated. Such a quantity is the stationary vector "a" whose first member a_1 is the limiting index of the area of planned and incidental regeneration of forests. Moreover, owing to the age unevenness of the management classes and complexes of stands and to the possible losses of stand production in the last age degrees the deviation from this index ±5 to 10 per cent may be considered as reasonable.

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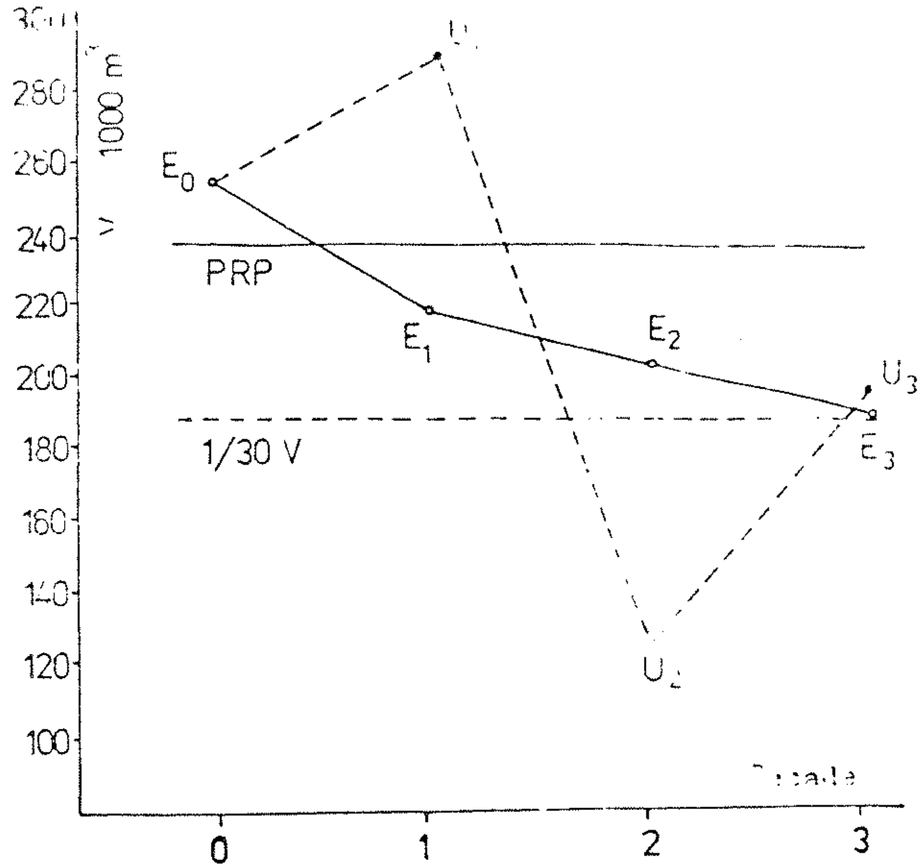

Fig. 1. The values of indexes of yield regulation U_1, U_2, U_3, volume allowable cut E_1, E_2, E_3, as well as their comparison with PRP and 1/30 V

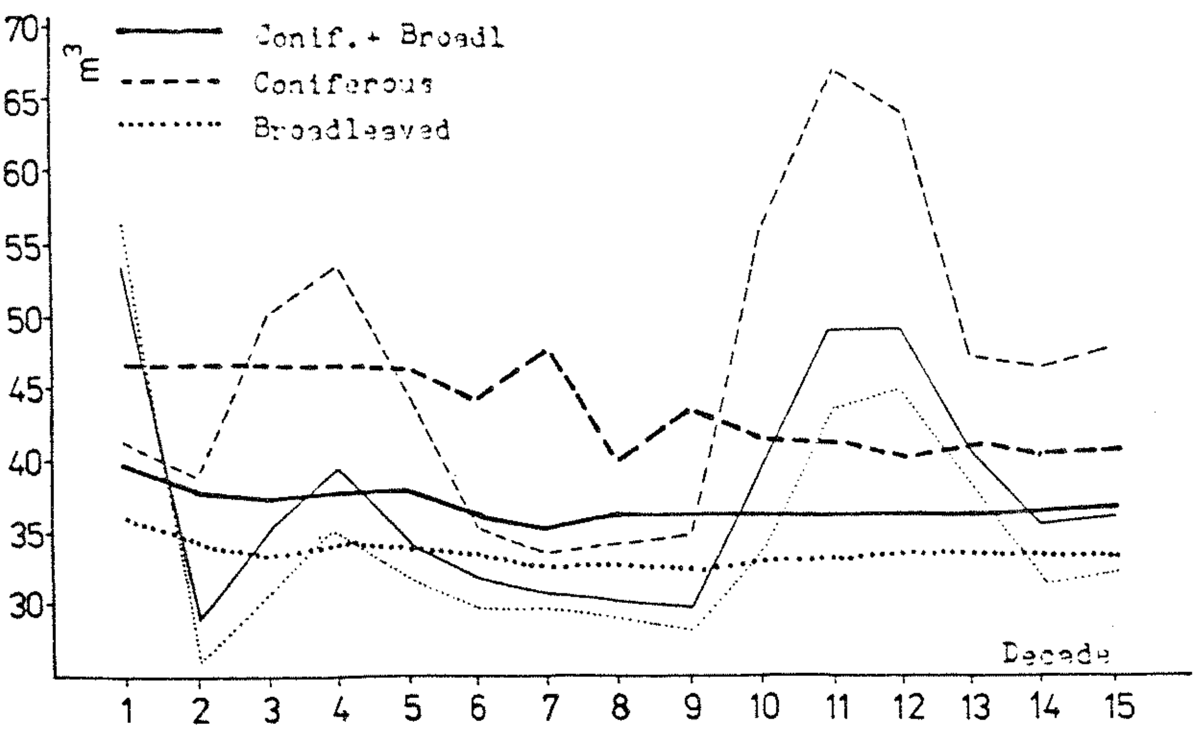

Fig. 2. The course of the decenial final cutting ($m^3.ha^{-1}$) according to the calculus of probability without (thin line) and with correction by the element of vector a_1 (thick line)

OPTIMAL CONTROL THEORY APPLIED TO JOINT PRODUCTION OF RENEWABLE RESOURCES

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SUMMARY

Renewable natural resource systems often represent examples of joint production. Optimal control theory (OCT) is employed using the linear variational method to derive the general solution to a two-output joint production problem with the objective of maximizing revenue. The general solution is applied to a timber-forage production problem. The results indicate that OCT can successfully solve such problems. The functional forms of the solution provide insight into how changes in parameters will influence the optimal joint production system.

Keywords: optimal control, linear variational method, renewable resources, joint production, timber-forage.

INTRODUCTION

Forest systems almost always generate multiple renewable outputs. Generally, this joint production involves competitive tradeoffs between the outputs. In a dynamic context, there are an infinitive number of joint production possibilities. Searching for optimum dynamic production systems has been the topic of numerous mathematical modeling efforts.

Several modeling techniques have been applied to dynamic renewable resource joint production problems. Multi-period linear or nonlinear programming are two of the most common approaches applied in forestry (Johnson and Scheurman 1979, Haight 1985) and to agriculture problems (Hazel and Norton 1986). Dynamic programming has been used extensively (Burt 1982, Brodie and Kao 1979). Optimal control theory (OCT) would appear to also have potential for application but has primarily been applied only to single resource problems such as timber (Sethi and Thompson 1981, Clark and Dupree 1979, Rapera 1980, Cawrse et al. 1984, Haight et al. 1985), fisheries (Clark and Monroe 1975), and water yield (Fontane et al. 1981).

The purpose of this study is to investigate the application of OCT to a two-output joint production renewable resource problem.

GENERAL OCT FORMULATION AND SOLUTION TO A TWO OUTPUT JOINT PRODUCTION PROBLEM

Formulation

Optimization of renewable resource joint production problems using economic criteria may involve either maximizing profits or revenues (Beattie and Taylor 1985). In the continuous (vs. discrete) formulation for a biologically constrained revenue maximization problem the general formulation is

$$J = \int_{t_0}^{T} \{p_1 h_1(t) + p_2 h_2(t)\} e^{-it} dt - b \qquad (1)$$

$$dy_1/dt = f_1(y_1, y_2, t) - h_1(t) \qquad (2)$$
$$dy_2/dt = f_2(y_1, y_2, t) - h_2(t) \qquad (3)$$
$$0 < h_1 < h_1 max,\ 0 < h_2 < h_2 max \qquad (4)$$
$$y_1(t_0) = A,\ y_1(T) = B,\ y_2(t_0) = a,\ y_2(T) = b \qquad (5)$$

where,

y_1, y_2 - size/amount of renewable resource
e^{-it} - discount factor with i the discount rate
h_1, h_2 - rate of harvest of y_1, y_2
p_1, p_2 - revenues for h_1, h_2
b - fixed production costs
f_1, f_2 - the growth function for y_1 and y_2 that indicates they are a function of their own size, the size of the other resource and time
t_0 - beginning of planning horizon
t_1 - time to begin harvesting a resource
t_2 - time to stop harvesting a resource
T - end of planning horizon.

The objective function is the time integral of the revenues from the harvest of the renewable resources less fixed production costs. The time values to t_1, t_2 ($t_o \le t_1, t_2 \le T$) and T are to be defined by the analyses. The rate of change (state) of the two renewable resources is determined by their growth and harvest rate. Equations 4 limits the size of the harvests of each resource and equations 5 indicate boundary conditions.

Solution

Several OCT techniques may be used to solve such problems including the Lagrange-Hamiltonian approach (Bryson and Ho 1975), calculus of variations (Gelfand and Fomin 1963) or the linear variational approach (Clark 1976). Clark (1976) suggests, for various reasons, the linear variational approach (LVA) be applied to these type problems. In linear problems such as these, the first variation does not explicitly include the control variable(s). The control is determined instead by solving the problem for the optimal path of the output called the singular path.

Using LVA the singular path for the joint products is determined by first solving for the control variables $h_1(t)$ and $h_2(t)$ in equations 2 and 3 and substituting these functions into 1 giving

$$J = \int_{t_0}^{T} \{p_1(f_1(y_1,y_2,t) - dy_1/dt) + p_2(f_2(y_1,y_2,t) - dy_2/dt)\}e^{-it}dt - b.$$

Then Eulers equation (Phaffenberger and Walker 1976), $F_y - \frac{d}{dt} F_{dy/dt} = 0$ where F is the integral, can be used to determine the singular paths. Eulers equation for y_1 is

$$e^{-it}[p_1 \partial f_1/\partial y_1 + p_2 \partial f_2/\partial y_1 - ip_1] = 0$$

and with respect to y_2,

$$e^{-it}[p_1 \partial f_1/\partial y_2 + p_2 \partial f_2/\partial y_2 - ip_2] = 0.$$

Equating and solving these two equations for y_1 and for y_2 give the two resource's singular paths, y_1^* and y_2^*.

Once the resource is on the singular path (i.e. $y_1 = y_1^*$ or $y_2 = y_2^*$), then the control or harvest is at the rate which keeps the output on the singular path or

$$h_1(t) = f_1(y_1,y_2,t) - dy_1/dt$$

$$h_2(t) = f_2(y_1,y_2,t) - dy_2/dt.$$

In application if y_1 or y_2 are not on the singular paths, then the fastest trajectory to the singular path is the optimal control. This is called the bang-bang singular policy (Clark 1976) and is expressed through the admissibility constraints (4). This policy in terms of $h_1(t)$ and $h_2(t)$ is represented by

$$h_1^*(t) = \begin{cases} 0 & \text{whenever } y_1 < y_1^* \\ \cdot & \\ h_1 max & \text{whenever } y_1 > y_1^* \end{cases}$$

and

$$h_2^*(t) = \begin{cases} 0 & \text{whenever } y_2 < y_2^* \\ h_2max & \text{whenever } y_2 > y_2^*. \end{cases}$$

For example, if y_1 is below its singular path, then the optimal policy is to let the resource grow until it reaches the singular path. The time that it reaches the singular path or the time to begin harvesting (t_1 here) is determined by finding the first time where $y_1 = y_1^*$. The same would apply to determine the time to begin harvest for y_2. If the resource level is above the singular path, the harvest is at largest level possible to bring the resource to the singular path in the fastest manner.

Through the harvest or control each resource is moved to the singular path. The time when the resource's singular path is reached depends on the actual resource condition. Both resources may not reach their respective singular paths at the same time.

The time for the end of the planning horizon, T, may be fixed or be free to take on different values (Pitchford and Turnovsky 1977). Where the renewable resource is not continuously being renewed (e.g. even-aged timber stands), the T may be viewed as the time for renewal or rotation age. As such it is free to take on different values and be part of determining the optimum. In any case, in OCT it is calculated after the singular path is identified.

Joint Production Theory

In static joint production theory, the optimal combination of products is where the slope of the isorevenue function is equal to the slope of the production possibilities function (Carlson 1939). The same condition applies here in a dynamic sense. That is, at each point in time the isorevenue and production function slopes must be equal.

In the two-output general formulation here this relationship of isorevenue slope to production possibilities function slope is expressed by

$$p_1/p_2 = dh_1/dh_2$$

or

$$p_1/p_2 = (\partial f_2/\partial y_1 - \partial f_2/\partial y_2 - i)(\partial f_1/\partial y_1 - \partial f_1/\partial y_2 - i) \quad (6)$$

The right hand side of equation 6 is the rate of product transformation or rate at which the two products may be substituted for one another. The rate of change of each resource (i.e. dh_1, dh_2) is a function of its own change, the change in the other resource and discount rate.

Equation 6 describes the necessary conditions for optimal two-output joint production as they exist through time. As the investment is changed (increased), this function can be used to derive the 'expansion path' for the two products in a dynamic sense.

APPLICATION - TIMBER-FORAGE JOINT PRODUCTION

Formulation

The simultaneous production of timber and forage represents a common example of joint production of renewable resources. In this application, the objective is to maximize the discounted revenue from timber and forage over an infinite series of rotations. Thus, Faustmann's (1849) formula's discount factor ($1-e^{-it}$) is used in the general formulation. The control variable is harvest via thinning. The time for clearcutting timber, T, is also a variable. Forage production is considered a function of timber volume, but timber volume is not considered to be influenced by forage.

In a manner similar to Clark (1976) and Cawrse et al. (1984), the logistic equation is used to model timber growth. A quadratic function suggested by Jameson (1967) (negative slope portion only) is used to model the relationship between forage production and timber volume/basal area.

The data used to fit the equations and estimate revenues was taken from Riitters et al. (1982) study of ponderosa pine-forage production. In this case, cattle consumed the forage and weight gain by cattle is used to derive a forage value. Their study involved using dynamic programming to determine the optimal joint production strategy. Thus, by using their data a comparison can be made between the OCT results and their work.

The OCT structure for this particular problem is

$$J = \frac{\int_0^T \{p_1h_1(t) + p_2y_2\}e^{-it}dt + p_3y_1(T)e^{-iT} - b}{1 - e^{-iT}} \tag{7}$$

$$dy_1/dt = ry_1(1 - y_1/k)at^{-s} - h_1(t) \tag{8}$$

$$y_2 = A - By_1 + Cy_1^2 \tag{9}$$

$$0 < h_1(t) < h_1max \tag{10}$$

$$y_1(0) = 0,\ y_2(0) = 0 \tag{11}$$

where y_1 - amount of timber ft^3/A

y_2 - amount of forage lbs/A

$\frac{dy_1}{dt}$ - timber growth per acre using the logistic equation less harvest rate via thinnings

y_2 - forage per acre as a function of amount of timber

p_1, p_2 - revenues per unit of timber (thin) and forage utilized respectively

p_3 - revenue per unit of timber (clearcut)

$h_1(t)$ - harvest rate of timber via thinning

$1 - e^{-iT}$ - perpetual series discount factor where i is the discount rate

r,k,a,s - coefficients in the logistic equation for timber
A,B,C - coefficients of the quadatric equation for forage
Others - as defined in the general formulation.

Solution

Using Eulers equation the singular path for timber is

$$y_1^* = \frac{p_1 r a t^{-s} - i p_1 - p_2 B}{2p_1(r/k)at^{-s} - 2p_2 C} \qquad (12)$$

and the singular path for forage is

$$y_2^* = A - By_1^* + Cy_1^{*2}.$$

The optimal time to begin thinning is found explicitly by equating y_1^* to y_1. The optimal harvest rate h_1^* (t) is determined by equating $dy_1/dt = dy_1^*/dt$ along the optimal path. The optimal values for t_2, time to stop thinning, and T, time to clearcut cannot be derived explicitly and must be found numerically via simulation. For brevity, the simulation is not shown here. The details of this phase of the solution are given in Steinkamp (1990). In essence, it involves solving the integral for different values of t_2 and T using Simpsons rule.

Figure 1, shows the singular paths for timber and forage joint production. Table 1, management scheme 1, list the times, production, and economic values associated with jointly producing timber and forage. Here, it is interesting to note that joint production occurs until year 38 (Figure 1) at which time timber volume becomes so large that forage production is minimal and cattle grazing stops. Soon thereafter, year (stand age) 46, t_1, thinning begins and continues until year 74, t_2. At that time thinning stops and the stand is allowed to grow until year 88, T, when it is clearcut. In this example thinning is discontinued 14 years before the clearcut because it is assumed there is greater revenues per unit volume clearcut than for thinned timber. If this was not the case, the clearcut would immediately follow the last thinning.

Would the situation be different without joint production? Management scheme 2, Table 1 shows the results if timber alone is the output. The optimal times for harvest are different and the revenues are reduced. If forage alone is produced (management scheme 3), total revenues are also reduced. Thus joint production is the preferable to producing either product alone.

Table 1. OCT and Dynamic Programming (Riitters 1982) Solutions

	Management Scheme	Time To Begin Thinning t_1 (Yr)	Time To Stop Thinning t_2 (Yr)	Time To Clearcut T (Yr)	Summation of Thinning Removals (ft^3/A)	Summation of Forage Utilized (lbs/A)	Clearcut Removal (ft^3/A)	Perpetual Series Discounted Revenue $/A
1	Timber Forage Joint Production	46	74	88	2838	18274	1723	954
2	Timber Only Production	49	69	81	2008	--	2290	599
3	Forage Only Production	--	--	--	--	670 lbs/A/yr	--	560
4	Ritters et al. (1982) Timber-Forage Joint Production	30	70[1/]	90	1474	14705	1611	867
5	Ritters et al. (1982) Timber Only Production	30	90[1/]	110	2718	--	1100	562

[1/]Thinnings occur at discrete intervals, every 20 years.

Certain of the OCT joint production results (Table 1, Management Scheme 1) are similar to Riitters et al. (1982) dynamic programming (DP) solution (Table 1, management scheme 4). Both approaches indicate about the same timber rotation age, T and time to stop thinning, t_2. Both approaches indicate a similar percentage drop in revenues if timber alone is produced. However, the optimal strategy for producing timber alone is different. The OCT solution shortens the rotation, decreases the thin volume and increases the clearcut volume. The DP strategy indicates the opposite should occur in each case. It's not clear what would cause these differences. It may be related to statistical variance in fitting the OCT growth/state equations or the continuous versus discrete treatment of the problem.

Sensitivity Analysis

The equation for the timber singular path (12) provides some insights into how the solution would change given sensitivity testing of the problem. The signs of the parameters and their magnitude indicate how, in general, the overall solution will change given a specific change in that parameter.

For example, the negative sign on p_2, revenue from forage means the singular path will always shift downward when forage is included with timber in joint production. Since B is greater than 2C, the numerator in equation 12 is reduced more than the denominator with an increase in p_2. Thus, increasing the forage revenue, p_2, will cause continuing shifts downward in the singular path resulting in earlier times to begin thinning and shorter rotations. With continuing increases in p_2, eventually thinning will not be done at all and clearcuts alone becomes the best alternative.

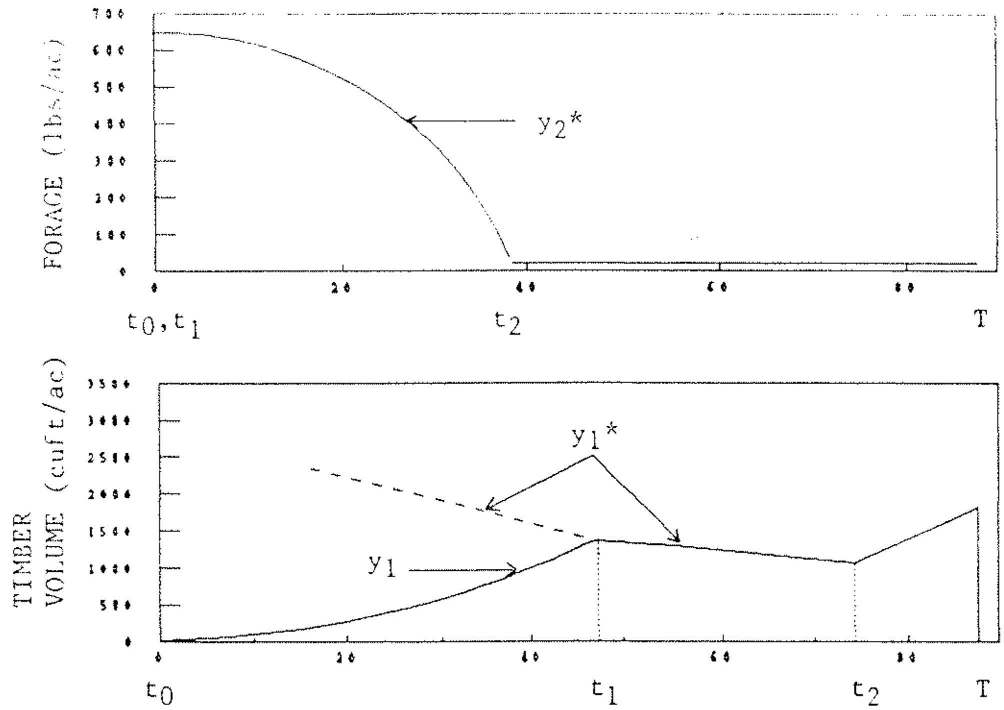

Figure 1. Singular paths and associated times for timber and forage joint production (Table 1, management scheme 1).

On the other hand, no forage production (no p_2 in equation 12) will cause the singular path to shift upward and thinnings begin later. Since the earlier revenues from thins are eliminated, the rotation age tends to be shortened.

The $-ip_1$ component of equation 12 indicates that increases in the discount rate will shift the singular path downward. This results in earlier times to begin thinning and shorter rotations. Eventually the rate may become so high that timber production is eliminated, and in this case, production of forage alone becomes the best alternative.

Changes in p_1, $dy_1{}^*/dp_1$, is dependent on parameters of the timber growth function and the discount rate. Thus, the change in the singular path with respect to a change in timber price, p_1, will vary as a function of time.

If one assumes smaller revenues from thins vs clearcuts, the period for thinnings becomes shorter. Eventually, if differences in revenue become great (e.g., thin revenues are one-half of clearcut revenues), thinnings are eliminated altogether.

Equation 12 can be used to derive numerical results from specific parameter changes. Numerical results for such changes are shown by Steinkamp (1990).

CONCLUSIONS

OCT can be applied to joint production renewable resource problems to derive optimal harvest schedules. The general formulation was successfully applied to a timber-forage production problem. Similar problems, such as timber-water joint production might be modeled in a like manner.

The results indicate that continuous OCT can provide functional forms which help explain how changes in specific parameters directly affect the problem's solution and how the solution relates to joint production theory. The results also indicates a high degree of mathematical rigor is required, as opposed to LP or DP, making its application more difficult.

OCT would appear to have potential to solve dynamic joint production resource problems. Further research is needed in terms of problems that involve more complex interactions to determine its more widespread applicability.

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ERROR SOURCES AND PROPAGATION IN DECISION SUPPORT SYSTEMS FOR NATURAL RESOURCES MANAGEMENT

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SUMMARY

The next generation of management tools for natural resources promises to integrate spatial relationships from geographic information systems, projections of future conditions by simulation models, and management advice from expert systems and/or optimization algorithms into interactive, visually oriented, computer-based decision support systems. The impressive graphics and convenience of these systems may lead to overconfidence in their predictions. A simple decision support system is presented to illustrate error sources and possible error propagation techniques. Using representative values for initial errors, substantial amounts of uncertainty occur in timber yield estimates and in estimates of total area. When applied to fuzzy linear programming optimization, the overall effect is to considerably decrease the region of feasible solutions.

Keywords: Decision support system, propagation of error, growth and yield simulation, expert systems, geographic information systems, fuzzy linear programming, Bayesian statistics.

INTRODUCTION

Decision support systems integrate computer-based management tools, including simulation models, artificial intelligence, geographic information systems, and optimization algorithms. Instead of the resource manager accessing these management tools individually, a well designed graphically based access program provides convenient and simplified use (Buhyoff et al. 1988). A decision support system may thereby eliminate much of the need to master each of these tools individually. As a result, however, the user may not be fully aware of the individual estimation processes and accompanying sources of error in the final product.

The purpose of this paper is to explore these sources of error, propose methods for their integration, and trace their propagation through a simple decision support system. The system contains representative elements from the four types of management tools mentioned above: a Bayesian belief network from the area of expert systems in artificial intelligence, a computer growth and yield simulation model, area estimates from geographic information acquisition, and optimization using "fuzzy" linear programming.

Geographic information systems provide the spatial linkages for attributes within decision support systems, but can introduce substantial errors into area-based analyses. While predictive uncertainty has been estimated in expert systems and in deterministic simulation models, integration of the resulting errors has not previously been attempted. Since the cumulative uncertainty from these procedures affects optimality in linear programming algorithms, an approach based on fuzzy set theory has been used. The propagated error levels in the current analysis are not worst- or best-case scenarios, but have been selected to be representative of error levels that might reasonably be expected.

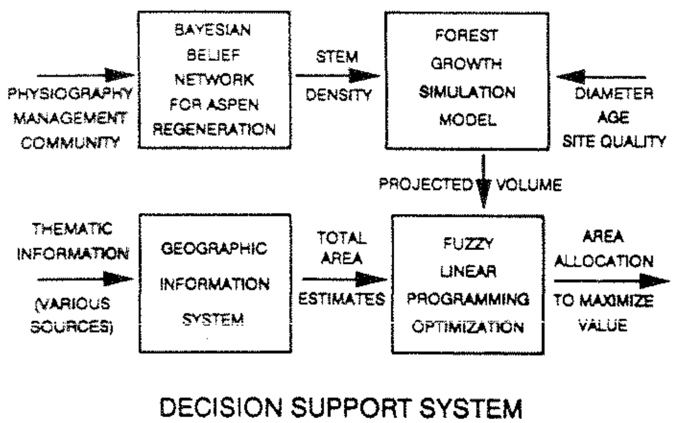

Figure 1. Schematic diagram of decision support system components and error paths.

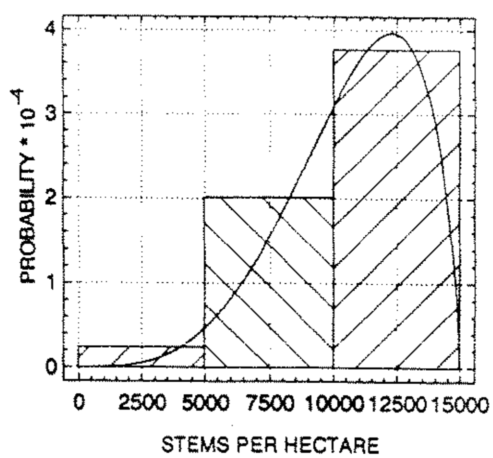

Figure 2. Approximation of Bayesian belief network probabilities by the beta probability distribution function.

METHODS

Figure 1 shows a schematic representation of the decision support system in the current analysis. The Bayesian belief network provides estimates of discrete probabilities of three levels of aspen regeneration density (Haas 1990). The mean of this probability distribution is used as the initial density value in the aspen growth and yield simulation model (Mowrer 1986). The corresponding variance is used to initialize the error associated with stem density. Errors are propagated through the simulation model using the technique developed by Mowrer and Frayer (1986). The resulting errors in yield are incorporated into an algorithm for fuzzy linear programming (Mendoza and Bare 1989). Representative errors in area estimates from geographic information systems were obtained from Walsh et al. (1987) and Green (1990). These error estimates are then used in the fuzzy linear programming algorithm to estimate upper and lower limits of fuzzy constraints. Wilson's timber-recreation model (Kent 1989) is used to visualize the effect of constraint uncertainties on a two-variable fuzzy linear programming optimization.

Bayesian belief network

The Bayesian belief network is an artificial intelligence technique that incorporates "expert" knowledge into a network of Bayesian conditional probabilities. The belief network approach has been used to estimate the amount of aspen regeneration for different site and management regimes (Haas 1990). While uncertainty calculation has been a component of expert systems since their inception, these have generally been of an ad hoc nature and not statistically rigorous. Ng and Abramson (1990) and Shafer and Pearl (1990) provide excellent overviews of uncertainty management methods in expert systems.

As with most expert system approaches, Bayesian belief networks represent the generic knowledge of one or more domain experts. Unlike the majority of uncertainty approaches, however, each proposition in the network is assigned a measure of belief consistent with the axioms of probability theory (Pearl 1986). These are propagated through a network of discrete conditional Bayesian probabilities. For aspen regeneration, Haas (1990) related the conditional probabilities to forest stand characteristics: physiographic variables (temperature range, soil moisture, and soil type), non-tree community variables (ungulate density and understory type), and tree community variables (crown cover of aspen and of competing species). Based on this approach, probabilities have been approximated for three levels of aspen regeneration density for the current study: 2500, 7500, and 12500 stems per hectare.

In order to obtain an estimate of the mean and variance associated with this distribution of probabilities, a beta distribution was fitted across the three probability classes (Figure 2). The beta distribution was selected because it is bounded and unimodal. Fully realizing the implications of ignoring higher order moments, the mean and variance from the beta distribution were used to approximate the normal distribution parameters and thereby provide an error estimate for propagation though the computer simulation model.

Growth and yield simulation

The simulation model (Mowrer 1986) provides a sequence of periodic growth and yield projections using linear and non-linear regression estimators. Total stems per unit area are apportioned into one-inch diameter classes using the normal probability distribution function. Heights and volumes from these classes are then aggregated to provide whole-stand estimates. Error propagation equations have been embedded in the calculation sequence of the model (Mowrer and Frayer 1986, Mowrer 1989, Mowrer 1990). First-order Taylor series variance estimation equations integrate errors in predictor variables with fixed contributions from estimated regressor coefficients. This sequence of error propagation equations provides estimates of the variances associated with each variable concurrent to each predictive step within the growth and yield simulation.

To start the error propagation procedure, errors in the variables necessary to initialize simulation model predictions must be obtained from external measurements. Since various sets of variables are interlinked within the sequence of simulation model calculations, these initial errors propagate throughout the sequence and are reflected to some degree in the propagated variance for subsequent variables. In addition, each time a variable is estimated (to project 10-year growth estimates, for example) the estimation errors for the regressor coefficients are also integrated into the errors propagated through that function. The result is a variance estimate corresponding to each variable in the model.

The Bayesian belief network provides an initial estimate of the stem density mean and variance, resulting in a coefficient of variation (standard deviation as a percent of the mean) of approximately 23 percent. The other four model initialization variables (mean breast height diameter, variance of diameter, age, and site index) were assigned a 25 percent coefficient of variation, a figure well within the range of inventory sampling error. Means for these four variables were assigned values commensurate with those of the physiographic variables in the Bayesian belief network. Five 10-year projections were made with the simulation model. Resulting propagated errors are shown in Figure 3.

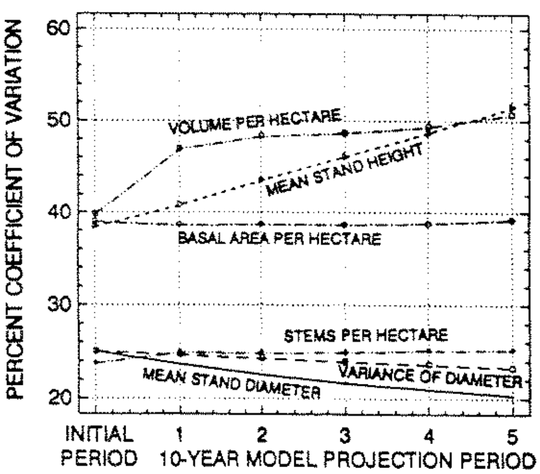

Figure 3. Error propagation results for a diameter distribution-based computer simulation of aspen growth and yield.

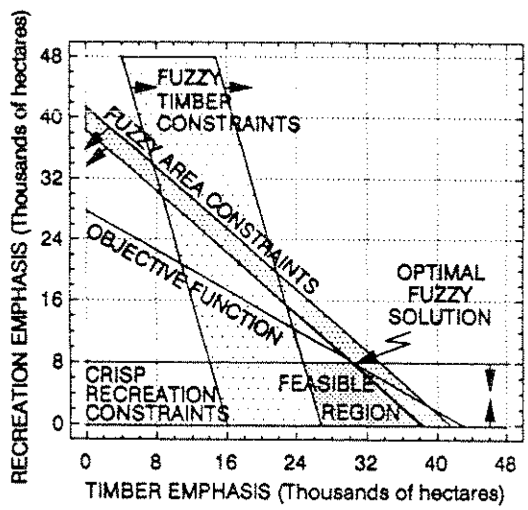

Figure 4. Fuzzy linear programming applied to Wilson's timber-recreation problem (adapted from Kent 1989).

The initial values for projected variables (mean stand breast height diameter, variance of diameter, and stems per hectare) were initialized as described above. Errors associated with derived variables (basal area per hectare, mean stand height, and total cubic volume per hectare) were not initially set, but were calculated within the model, as were subsequent values of the projected variables. The overall coefficient of variation for estimated volume was approximately 50 percent after five projection periods. This value was used to assign upper and lower limits to the yield coefficients in the fuzzy linear programming algorithm, as described below.

Geographic Information System

Geographic information systems incorporate spatial information from numerous sources into thematic layers representing various resource characteristics. The data sources for a thematic layer may include tabular data, graphic data (from manual digitization or scanning), digital summary data (from national mapping and census agencies), and remotely sensed data (from satellite and aircraft imagery).

Errors in these data can be described in three broad categories: obvious error sources, inherent variation and measurement errors, and processing errors (Burrough 1986). Obvious sources of error include out-of-date data, incomplete coverage, and differing map scales and observation densities. Inherent variation and measurement errors include positional errors, classification errors, data input/output errors, observer bias, and sub-resolution variation. Processing errors include the numerical precision of the computer, algorithmic and logic errors, and errors propagated through map overlay. While all these sources of error have been addressed to some extent, the best documented sources include classification errors and their propagation through the map overlay process. Classification error or bias occurs when a characteristic (from remote sensing imagery, for example) is misidentified. When this misclassification is systematic, i.e., another category (or sub-group) is consistently identified instead, classification bias results.

Walsh et al. (1987) conducted an unsupervised land-cover classification from satellite (LANDSAT) imagery, and compared the results to a random sample of ground plots. (This is somewhat the reverse of a supervised classification where training plots are used to improve initial classification accuracy.) They reported errors of 43 to 65 percent within individual data layers in the classification of land cover, aspect, and soil type. When two of these three data layers were overlaid, combined classification errors ranged from 71 to 83 percent. Three-layer error was 89 percent when grid cell classifications were compared to the randomly located ground plots. Green (1990) reported on a supervised classification of LANDSAT imagery utilizing training plots, expert opinion, orthophotos, inventory and research plots, and various other sources of existing information. Errors for single thematic layers were less than 10 percent for crown closure classification, and ranged from 20 to 30 percent for stem size classes. Since geographic information systems are traditionally used for area-based analyses, these reports indicated that an average error rate for area estimates for a given classification could reasonably be 20 percent. This figure was used in the fuzzy area constraint as described below.

Fuzzy linear programming

When assessing the effect of stochastic variation in linear programming coefficients, Pickens and Hof (1988) concluded that "land allocation linear programs with stochastic production estimates are very unlikely to find feasible solutions as they are typically solved." In an attempt to overcome this problem, Mendoza and Bare (1989) demonstrated the application of fuzzy linear programming with fuzzy coefficients. Under this approach, the original non-fuzzy or "crisp" constraints are reformulated. Additional fuzzy coefficients are introduced to represent upper and lower intervals of uncertainty and the decision maker's degree of confidence in these fuzzy coefficients. Thus, a minimum and maximum fuzzy constraint pair is generated in place of a single crisp constraint.

In order to visualize the effect of these uncertainties, the errors generated above were applied to a fuzzy linear programming approach to Wilson's timber-recreation model (Kent 1989). This simple two-dimensional problem optimizes the allocation of acreage between timber-intensive and recreation-intensive management alternatives in order to maximize net value. In the original crisp formulation, there were four constraints: timber, area, and minimum and maximum recreation constraints. In the fuzzy formulation shown in Figure 4, there are two fuzzy constraints each for timber and area. The two recreation constraints were unchanged since they were considered to remain crisp.

The error in gross cubic volume yield propagated through the simulation was used to calculate the upper and lower bounds on the fuzzy yield coefficients in Wilson's timber-recreation model. The coefficient of variation of 50 percent in timber yield was translated into a range of plus and minus one standard deviation (equal to 0.5 times the mean) about the mean volume estimate in Wilson's model. These were reflected in yield coefficients in the left-hand-side of the fuzzy timber constraints. Similarly, the 20 percent error in the total area estimate was translated into a range of plus and minus 0.2 times the total area in Wilson's model. This was reflected in minimum and maximum values for the right-hand-side of the fuzzy constraints for total acreage.

RESULTS AND CONCLUSIONS

Since the fuzzy boundaries were symmetric about the original "crisp" constraints, the effect on the feasible regions can be visualized in Figure 4. The optimal solution was only affected by the area constraints and not those for timber. The fuzzy optimum of 30,400 hectares for timber-intensive production represents only a five percent difference from the "crisp" optimum of 32,000 hectares. The larger errors propagated through the Bayesian belief network and the simulation model resulted in a wider range between the fuzzy constraints for timber. In the current formulation, this did not affect the optimal fuzzy solution. However, the two pairs of fuzzy constraints reduced the area of the feasible region by 36 percent.

This error analysis is itself subject to error. The use of the beta distribution to approximate the probability distribution for aspen regeneration density admittedly ignores higher order moments. While this is common practice in similar circumstances (Steele and Torrie 1980), other approaches are currently being explored. The error propagation through the simulation model is perhaps the best documented. Methods to improve error component estimation are also the subject of current research.

There is a great deal of literature in the field of remote sensing and geographic information systems on accuracy assessment and error sources. There appear to be no universally accepted or definitive techniques, however. Czaplewski and Catts (1990) have proposed a technique to use validation plots to statistically minimize misclassification bias. Additional work is needed to quantify the accuracy trade-off between additional information for training plots in supervised classification or using that additional information for classification recalibration.

The technique for integrating area and yield errors into the fuzzy linear programming algorithm is also subject to improvement, in part due to the different error estimation techniques employed. Fuzzy set theory has been applied to expert systems (Ng and Abramson 1990, Shafer and Pearl 1990), and has been recommended for simulation (Negoita and Ralescu 1987). Burrough (1986) also suggested the use of fuzzy set theory for Boolean manipulations in geographic information systems. Perhaps future error assessments may be united under a "fuzzy umbrella."

This analysis provides a first approximation of the effects of reasonable error levels when propagated through several decision support components. Though embryonic, it is a necessary preliminary to development of a more cohesive technique. While extreme-case error ranges were not presented, the results should encourage resource analysts to approach decision support system recommendations with care.

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APPROACH TO KNOWLEDGE OF ROTATION AGE FOR *Pinus sylvestris* L. STANDS IN CENTRAL SPAIN (*)

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SUMMARY

The percentage of timber suitable for veneer and the unit price index by diameter classes (d.b.h. classes), was determined from a sample of 18,192 trees, based on the actual timber market conditions for Scotch pine. Results were applied to a sample of 29 plots, inventoried in medium quality stands with ages between 80 and 160 years. These plots were placed into four age classes: 80-100, 100-120, 120-140 and 140-160 years.

The results show the evolution of the unit price index by diameter classes and distribution of timber production by diameter classes within each age class. As a consequence of the two foregoing results, the evolution of the average price index is obtained for stands of the four age classes mentioned. This information enables to limit Pinus sylvestris L.'s rotation to around 140 years under the ecological and silvicultural conditions in which their stands develop in the Central Mountain Chain.

O.- INTRODUCTION

Pinus sylvestris L. occupies an approximate area in Spain close to 1,000,000 hectares between natural and artificial stands, spread over four regions: Pyrenean Range, Iberian Range, Central Mountain Chain and Penibetic Range. The species lives between 800 and 2,000 m. above sea level. Its production and regeneration optimum is found between 1,200 and 1,600 m. Outside these heights, Pinus sylvestris L. has regeneration problems and its production drops considerably.

In the Central Mountain Chain, it forms even-aged, monospecific stands or mixed with Quercus pyrenaica Willd., but also with a predominance of Pinus sylvestris L.. Timber production varies with height above sea level and soil fertility (2 to 6 m3/ha./year). The management method traditionally being used is periodic compartments with silvicultural treatment by

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shelterwood systems and natural regeneration (although there are exceptions to this rule). Rotation varies between 100 and 120 years.

The I.N.I.A.'s FORESTRY SYSTEMS DEPARTMENT is carrying out an extensive survey in the Central Mountain Range on the growth and production of Pinus sylvestris L. which includes setting up a programme of thinnings (for which 5 test sites are available), drawing up variable silvicultural yield tables, study of natural and artificial regeneration and determining the species' optimum technological rotation.

This paper provides some data helping to define the rotation based on the production structure of Pinus sylvestris L. stands and the prices their timber reaches on the market.

Determining rotation is a subject which has given rise to great controversy both in the field of research and in that of practical application of forest management and forestry economics. Numerous methods have been developed, almost always based on mathematical, economic and financial criteria, which endeavour to optimize rotation from the point of view of the forest enterprise. These methods lay little importance on silvicultural reality which, in Spain, has many social and socio-economic implications (protection, grazing, firewood, recreation,...). This fact hinders the application of rigid management methods able to optimize a specific rotation, "a priori" defining a series of hypotheses on silvicultural management in time and space which have to be necessarily fulfilled in a period of over 100 years for Scotch pine stands.

The universally known fact of timber's unit price increasing with diameter and, consequently, with the stand's age, was used. If the unit price were constant with age, it is obvious that the optimum rotation would coincide with the rotation of highest income in species (product).

As the stand's age increases, the size of its trees and technological quality of its timber increases, and a unit price increase occurs, simultaneous to the growth in volume, which is usually called growth in quality (MACKAY, 1944). This paper endeavours to quantify the evolution of quality growth through the unit price index by diameter classes and the average price by ages for four age classes varying between 80 and 160 years.

1. MATERIAL AND METHODS

1.1. Determining the percentage of timber suited to veneer by diameter classes.

It is considered that a tree contains timber for veneer when at least a log of 2.5 m. long, 36-37 cm. in diameter without bark at its mid point in which no external knots can be seen can be obtained therefrom.

In order to determine the percentage of timber valid for veneer by diameter classes of a natural Pinus sylvestris L. stand in the river Lozoya's upper catchment area (Central Mountain Chain), 18,192 trees with a diameter breast height over 30 cms. were measured, pertaining to all the trees hauled from the forest for exploitation during a 5 year period (1986-1990). The d.b.h. of each tree was measured with bark at 1.3 m. height and its total volume and veneer timber volume were calculated.

The data drawn up and placed in order by diameter classes are given in Table 1.

Based on the prices which timber reaches in the region's markets, the hypothesis was accepted that the price of logwood suitable for veneer is four times higher than logwood not apt for veneer. This proportion is conservative, but has been considered valid to give a greater margin of confidence to the results.

Columns (e) and (f) of Table 1 were calculated bearing the foregoing hypothesis in mind. Column (f) is an average price index per m3 with bark as reached by Pinus sylvestris L. on the market, depending on the percentage of veneer timber it contains (d).

By definition, 30-34 cm. d.b.h. trees cannot be exploited for veneer timber as they do not reach the diameter required by the industry.

Table 1's data shows the following results:

- The percentage of trees from which at least one veneer log can be obtained varies between 3.4% for the 35-39 cm. diameter class to 70.4% for the diameter class over 70 cm.

- The percentage of veneer timber in the timber as a whole varies between 1.5% for the 35-39 cm. diameter class and 28.8% for the 65-69 cms.

- The timber market's price index value (f) varies between 1.00/m3.c.c. for 30-34 cm. diameter timber not suited to veneer and 1.86/m3.c.c. for 65-69 cm. diameter timber (containing 28.8% of veneer timber) which means that the average price/m3.c.c. of 65-69 cm. diameter timber is 86% higher than the 30-34 cm. diameter timber price.

TABLE 1.- DISTRIBUTION OF TIMBER PRODUCTION IN m3 WITH BARK (m3cc) BY DIAMETER CLASSES

	Nº of trees			Volumes				Evaluation (*	
Diameter class (cm.)	Total nº trees	Nº trees with veneer timber	% trees with veneer timber	Total timber vol. (m3cc) (a)	Vol.veneer timber (m3cc) (b)	Vol.timber non veneer (m3cc) (c)	% veneer timber (d)	Total timber value (e)	Price index (f
30-34	3164	0	0	1289	0	1289	0	1289	1.00
35-39	3015	102	3.4	2021	3	1990	1.5	2114	1.05
40-44	3259	515	15.8	3173	333	2840	10.5	4172	1.32
45-49	2541	965	38.0	3327	544	2783	16.3	4959	1.49
50-54	2336	1042	44.6	3788	777	3011	20.5	6119	1.61
55-59	1576	864	54.8	3329	801	2528	24.1	5732	1.72
60-64	1128	678	60.0	2895	773	2122	26.7	5214	1.80
65-69	637	422	66.2	1943	560	1383	28.8	3623	1.86
>70	636	448	70.4	2698	728	1970	27.0	4882	1.81
Total	18192	5036		24463	4547	19916			

* (e) = 4x(b) + 1x(c)

* (f) = (e)/(a)

1.2.- Distribution of timber unsuited for veneer by qualities

Although thorough accounting in the region's sawmills is not available, it is accepted that, very approximately, timber not containing veneer but suitable for sawing (column(c),Table 1) is distributed by qualities and uses in the following way:

For every 100 m3 of logwood, the following is obtained:
- 16 m3 of logwood = 9.3 m3 of 1st quality plank.
- 17 m3 of logwood = 9.7 m3 of 2nd quality plank.
- 22 m3 of logwood = 12.8 m3 of 3rd quality plank.
- 45 m3 of logwood = 26.2 m3 of 4th quality plank.

These data refer to average figures estimated by professionals with long experience in this region ,and a 0.58% conversion factor is accepted.

Using the study on prices in force on the market, it was possible to see that by assigning a value of 1.00 for 4th quality timber, the proportional price variation for the remaining qualities is as follows:

- 1st quality timber: 3.7
- 2nd quality timber: 2.8
- 3rd quality timber: 1.9
- 4th quality timber: 1.0

This price ratio may be considered constant for any phase of product making, accepting that the conversion factor of the different phases and their costs per m3. do not depend on the timber quality.

Variation in quality with log diameter was not taken into account as it was considered that in the larger diameter trees, the percentage of veneer is higher and it is always found at the bottom of the trunk, with the top being for sawing as, naturally, it contains a greater proportion of knots and branches.

These figures, with all the inaccuracies they may have, demonstrate the importance which timber quality has in its price and the need to apply silviculture directed towards concentrating production on better quality trees.

1.3.- Distribution of production in stands of difference ages

In order to ascertain the production distribution by diametric classes and ages, 29 plots of a varying area between 1,000 and 2,000 m2 on which traditional silviculture has been applied, were measured. These plots form part of a more extensive survey which is being performed on the growth and production of Pinus sylvestris L.

Established in even-aged stands obtained by natural regeneration, the plots were placed into groups classes of 20 year intervals, as this is how long regeneration lasts (regeneration period). The plots were distributed by ages as follows:

Age	Nº. of plots
80-100 years	11
100-120 years	6
120-140 years	9
140-160 years	3

Average data per hectare and diameter classes relating to each age class are given in Table 2. The latter also includes the percentage of veneer timber (column (d)) and the price index (column (f)) which had been determined in Table 1.

2. RESULTS

It can be seen from the data given in Tables 1 and 2:

1.- That the percentage of veneer timber and average price index per m3 grow with the d.b.h in the following proportions:

Diameter class	Veneer timber	Price index/m3
20-24 cm.	0	1.00
25-29 cm.	0	1.00
30-34 cm.	0	1.00
35-39 cm.	1.5	1.05
40-44 cm.	10.5	1.32
45-49 cm.	16.3	1.49
50-54 cm.	20.5	1.61
55-59 cm.	24.1	1.72
60-64 cm.	26.7	1.80
65-69 cm.	28.8	1.86
>70 cm.	27.0	1.81

The percentage of veneer in trees of over 70 cms. diameter drops noticeably, and, therefore, the price index also falls. This may be due to there being naturally very old trees and fungi atacks causing woodrot are more frequent. The most common and aggressive for Pinus sylvestris L. is that known as Fomes pini Fr. and when it appears, it establishes a limit to the length of rotation.

TABLE 2.- DISTRIBUTION OF PRODUCTION IN m3 WITH BARK PER HECTARE (m3cc/ha) BY DIAMETER CLASSES FOR DIFFERENT STAND AGES

AGE CLASS 80-100 YEARS; Mean D.B.H. = 26.3 cm.

Diameter class (cm.)	Nº trees/ha.	Total timber volume (m3cc/ha.) (a)	% veneer timber (d)	Volume of veneer timber (m3cc/ha.) (b)	Volume of non veneer timber (m3cc/ha.) (c)	Total timber value (e)	Price index (f)
20-24	203	27.2	0	0	27.2	27.2	1.00
25-29	247	55.1	0	0	55.1	55.1	1.00
30-34	199	74.4	0	0	74.4	74.4	1.00
35-39	139	87.2	1.5	1.3	85.9	91.2	1.05
40-44	78	73.3	10.5	7.7	65.6	96.3	1.32
45-49	39	48.2	16.3	7.8	40.3	71.7	1.49
50-54	10	15.7	20.5	3.2	12.5	25.4	1.61
55-59	9	18.4	24.1	4.4	14.0	31.8	1.72
Total	924	399.5		24.5	375.0	473.1	
Average			6.14				1.18

AGE CLASS 100-120 YEARS; Mean D.B.H. = 34.5 cm.

Diameter class (cm.)	Nº trees/ha.	Total timber volume (m3cc/ha.) (a)	% veneer timber (d)	Volume of veneer timber (m3cc/ha.) (b)	Volume of non veneer timber (m3cc/ha.) (c)	Total timber value (e)	Price index (f)
20-24	91	13.1	0	0	13.1	13.1	1.00
25-29	129	28.6	0	0	28.6	28.6	1.00
30-34	160	61.5	0	0	61.5	61.5	1.00
35-39	160	103.8	1.5	1.6	102.2	108.6	1.05
40-44	100	90.9	10.5	9.5	81.3	119.5	1.32
45-49	63	76.7	16.3	12.5	64.2	114.2	1.49
50-54	32	49.8	20.5	10.2	39.6	80.5	1.61
55-59	14	27.2	24.1	6.6	20.7	46.9	1.72
Total	749	451.6		40.4	411.2	572.9	
Average			8.94				1.27

* (e) = 4x(b) + 1x(c)
* (f) = (e)/(a)

AGE CLASS 120-140 YEARS; Mean D.B.H. = 37.3 cm.

Diameter class (cm.)	Nº trees/ha.	Total timber volume (m3cc/ha.) (a)	% veneer timber (d)	Volume of veneer timber (m3cc/ha.) (b)	Volume of non veneer timber (m3cc/ha.) (c)	Total timber value (e)	Price index (f)
20-24	29	3.9	0	0	3.9	3.9	1.00
25-29	82	18.8	0	0	18.3	18.8	1.00
30-34	95	36.4	0	0	36.4	36.4	1.00
35-39	140	90.8	1.5	1.4	89.4	95.0	1.05
40-44	136	126.2	10.5	13.3	113.0	166.0	1.32
45-49	73	92.3	16.3	15.0	77.2	137.4	1.49
50-54	51	82.5	20.5	16.9	65.6	133.3	1.61
55-59	17	34.6	24.1	8.3	26.2	59.5	1.72
Total	623	485.5		54.9	430.6	650.3	
Average			11.31				1.34

AGE CLASS 140-160 YEARS; Mean D.B.H. = 45.5 cm.

Diameter class (cm.)	Nº trees/ha.	Total timber volume (m3cc/ha.) (a)	% veneer timber (d)	Volume of veneer timber (m3cc/ha.) (b)	Volume of non veneer timber (m3cc/ha.) (c)	Total timber value (e)	Price index (f)
25-29	8	1.9	0	0	1.9	1.9	1.00
30-34	32	13.7	0	0	13.7	13.7	1.00
35-39	38	25.4	1.5	0.4	25.0	26.6	1.05
40-44	87	83.2	10.5	8.7	74.5	109.4	1.32
45-49	107	138.9	16.3	22.7	116.2	206.8	1.49
50-54	88	144.2	20.5	29.6	114.6	232.9	1.61
55-59	58	118.6	24.1	28.6	90.0	204.3	1.72
60-64	20	48.0	26.7	12.8	35.1	86.4	1.80
65-69	13	38.0	28.8	10.9	27.1	70.9	1.86
Total	451	611.9		113.7	498.2	952.3	
Average			18.58				1.56

* (e) = 4x(b) + 1x(c)
* (f) = (e)/(a)

2.- The average percentage of veneer timber and average price index grow with the stand's age:

Age class (years)	Average % veneer timber	Average price index/m3.
80-100	6.14	1.18
100-120	8.94	1.27
120-140	11.31	1.34
140-160	18.58	1.56

It is interesting to recall that timber quality, in a broad sense, for a given species and silviculture system increases with the tree's thickness and with age, such that, with the same dimensions, older timber is better.

3.- Diameter distribution is excessively extensive in all age classes, which demonstrates that negligent silviculture directed towards intermediate productions (thinnings, improvement felling,. ..) has been used in these stands. This is the only way to explain the high number of trees less than 30 cm. in diameter existing in the four age classes. This excess of thin trees (dominated, compressed...) which should have been extracted by periodical thinning to concentrate production on better quality trees, has two harmful effects for the stand's production:

- They produce low quality, low priced timber, which has a negative repercussion on the average final price of the stand.

- They limit the growth of trees placed in the centre of the diameter classes, which are frequently those of the best quality.

4.- It can be seen that the timber's value grows significantly as from 40 cm. in diameter, which indicates that rotation will not have to be less than that necessary to obtain a high proportion of timber over those 40 cm. diameter. This aim can be achieved with a relatively short rotation (110-120 years) in stands with good site quality, by applying a rational thinning programme which gradually eliminates low quality trees and concentrates growth on trees with diameters in the centre of the classes.

If silviculture does not include a rational thinning programme and we wish to obtain a high proportion of timber over 40 cm. in diameter, rotation will have to be prolonged considerably. If we calculate the number of trees and the percentage of timber over 40 cm. for the four age classes contained in Table 2, we obtain the following results:

Age class (years)	% trees with d.b.h.>40cm.	% timber with d.b.h.>40cm.
80-100	14.7	38.9
100-120	27.9	54.2
120-140	44.5	69.1
140-160	82.7	93.3

Although it is difficult to decide the optimum rotation without taking other economic and financial aspects of the forest enterprise into account, it would seem from the data obtained and commented on in this paper, that at least for silviculture with natural regeneration not containing a rational thinning programme, which is that applied in these stands, the minimum rotation must be set around 140 years. This latter opinion must be stated in the following terms: For those stands of Pinus sylvestris L. which, for the low quality of their trees (branchiness, poor soils, ...) cannot produce quality timber in proportions minimally large, rotation of highest income in the species should be applied, provided there are no limits of an ecological and/or silvicultural nature.

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A COMPUTERIZED SYSTEM FOR DISTRICT FOREST PLANNING IN KOREAN PRIVATE FORESTS

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SUMMARY

The purpose of this paper is to illustrate the development of a computerized forest management information system including the labour requirements of silvicultural operations and cutting plans. A computerized district forest planning system based on Suzuki's long-term timber projection model is described. In Japan, a high proportion of forest owners are small-scale forest managers. Japanese studies of regional forest management, beginning in 1950's, resulted in the development and adoption of Suzuki's Gentan probability model. This paper suggests a computerized system to predict the timber production using a Weibull distribution, which is thought more reasonable in the estimation of the tree life than the Gamma distribution used by Suzuki. Results of a typical application of the system are discussed. Although the technique is oriented toward a specific cooperative forest in Kangweondo, Korea, the basic system concept should have a wide range of applications in both Japan and Korea.

The overall aim of the research is to produce long-term plans that are compatible with the Gentan probability model.

Keywords: Forest planning, Generalized normal forest

INTRODUCTION

Forest lands consist of about 6,499,000 hectares or 66 percent of the total territory of the Republic of Korea. The proportion of forested area is almost the same as that of Japan.

In Japan, a high proportion of forest owners are small-scale forest managers. Japanese studies of regional forest management, beginning in 1950's, resulted in the development and adoption of Suzuki's Gentan probability model.

The Korean ownership of forest is not conducive to productive management because of the many small private forests. Forest lands are owned by central government (national forests, 20%), local government (public forests, 8%), and individuals (private forests, 72%).

The private forests, representing more than two thirds of total forest lands, are divided among 1,979,056 owners. Ninety-five percent of the ownerships are less than 10 ha and 47% are less than 0.5 ha. Therefore, management of forest land must concentrate on the private forest estate, and development of private forest remains the main goal of the forest policy in the country.

When more than two forest owners adjacent to each other jointly organize a forest management unit, or work together, the basis of management is the co-operative forest management unit. The system described here is designed to provide forest management information for private owners to undertake co-operative forest management planning.

MODEL FOR THE GENERALIZED CONCEPT OF NORMAL FOREST

Suzuki (1959) proposed a new long-term timber projection model for timber production in district forests. His technique is an application of Markov Process theory to plantation forestry. It has found wide acceptance in the field of timber projections related to district forest plans in Japan.

The system presented here is based on a formula which is a kind of recursive equation , namely

$$\mathbf{a}_{k+1} = \mathbf{a}_k \mathbf{P}_k + \mathbf{b}_k - \mathbf{c}_k \qquad (I)$$

where

$\mathbf{a}_k$: forest age vector at the beginning of period k, each element of which represents the forest area belonging to the corresponding age class.

$\mathbf{P}_k$: forest age transition matrix associated with period k.

$\mathbf{b}_k$: conversion reforestation vector, each element of which describes a newly planted area through the conversion of a natural forest of broadleaved trees at the beginning of period k.

$\mathbf{c}_k$: conversion vector, each element of which represents the plantation converted to other land-use at the beginning of period k.

The variable $\mathbf{a}_k$ is uniquely defined by the above equation, and thus when the initial forest age vector $\mathbf{a}_0$, forest age transition matrix $\mathbf{P}_k$, conversion reforestation vector $\mathbf{b}_k$, and conversion vector $\mathbf{c}_k$ are given, all of the subsequent $\mathbf{a}_k$ can be obtained recursively. This computational procedure is facilitated greatly by the use of a large-scale computer.

Furthermore, by combining the above solutions with additional data such as local yield tables and the required labour per forest management treatment and operation, parameters such as the periodic harvest volume including clear cutting and thinning, the regeneration area including conversion reforestation, and the associated labour quantity required for the implementation of the planned forest practices can be determined. Therefore, the determination of the equation provides a basis for building a long term district forest plan.

The next concern is the determination of the forest age transition matrix P_k , resulting in the use of Gentan Probability. The distribution of cutting ages is the most important factor for projecting timber production in a district private forest where clear cutting is conducted over a wide range of cutting ages. In 1961, Suzuki proposed a model based on the Gamma distribution for the description of Gentan Probability and gave a technique of parameter estimation based on data taken from actual harvest activities. However, much work remains to be done on the choice of a statistical distribution for describing Gentan Probability in terms of better fit and practical application. In this paper, a first attempt is made to use the Weibull distribution with three parameters. The determination of the Weibull parameters requires data such as the mean value of the cutting ages, the associated coefficient of variation, and the specified minimum permissible cutting age. Such characteristics vary from district to district and also change over a period of time in a specific district. Therefore,it should be noted that attention has to be paid to the economic and environmental situations of the objective forest in fitting and choosing distributions.

The new stage is the determination of b_k , the vector of conversion reforestation. Reviewing the changes in the conversion reforestation percentage over ten years, and making a comparison between the present and target plantation percentage, leads to the determination of the subsequent b_k over a planning period. Finally, it was assumed that no plantation conversions to other land use are allowed in a district forest.

The above equations were suggested by Suzuki (1963) and Minowa and Nagumo (1981). Figure 1 summarizes the computational flow of the present system described above.

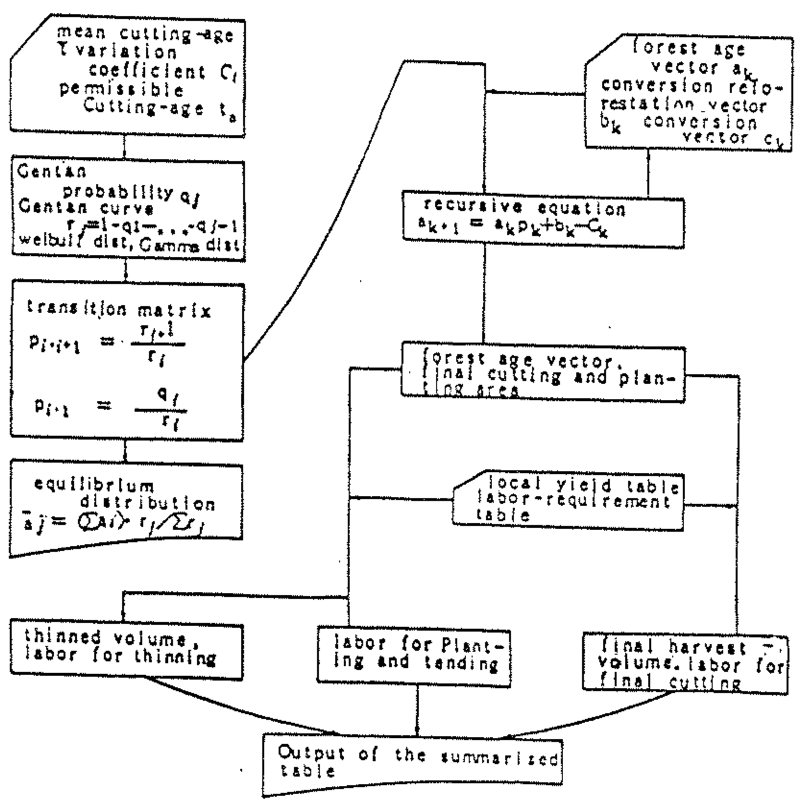

Figure 1. Flow Chart using Gentan Probability Model.

LONG-TERM LINEAR PROGRAMMING MODEL

Consider the problem of converting a forest of irregular aged compartments into a forest of some defined age class structure over a time of q periods in a suitably defined optimum way. If the forest's original total area is A hectares, consisting of p age classes of area a , it follows that $A=\sum a_i$. The target age structure consists of r age classes with areas b_i. it follows that $b_i=0$ for $i>r$.

Initial Age Class Areas	1	2	3	Conversion Period	q	Target Age Class Areas
						b_1
					$x_{1,q}$	b_2
				⋰	:	:
				⋰	:	:
				⋰	:	:
			$x_{1,3}$	.....	$x_{q-2,q}$	b_{q-1}
		$x_{1,2}$	$x_{2,3}$	.....	$x_{q-1,q}$	b_q
a_1	$x_{1,1}$	$x_{2,2}$	$x_{3,3}$	.....	$x_{q,q}$	b_{q+1}
a_2	$x_{2,1}$	$x_{3,2}$	$x_{4,3}$	.....	$x_{q+1,q}$	b_{q+2}
:	:	:	:		:	:
:	:	:	:		:	:
:	:	:	:		:	:
a_{r-q}	$x_{r-q,1}$	$x_{r-q+1,2}$	$x_{r-q+2,3}$	.....	$x_{r-1,q}$	b_r
a_{r-q+1}	$x_{r-q+1,1}$	$x_{r-q+2,2}$	$x_{r-q+3,3}$	.....	$x_{r,q}$	0
:	:	:	:		:	:
:	:	:	:		:	:
:	:	:	:		:	:
a_p	$x_{p,1}$	$x_{p+1,2}$	$x_{p+2,3}$	.....	$x_{p+q-1,q}$	0

Figure 2. Diagram of Yield Areas.

In such a situation two sets of constraints can be imposed. One set of constraints is purely logical or structural in nature and one set can be varied by management. The first set of structural constraints can be explained by reference to Fig. 2. In this figure $x_{i,j}$ represents the area felled in period j that is in age class i in that period. Areas b_i for i=1 to q can be defined by equations (II). Areas b_i for i=q+1 to p+q can be defined by equations(III).

$$
\left.
\begin{array}{lr}
\sum_{i=1}^{p+q-1} x_{i,q} = b_1 & (1) \\
\sum_{i=1}^{p+q-2} x_{i,q-1} - x_{1,q} = b_2 & (2) \\
\vdots & \vdots \\
\sum_{i=1}^{p+2} x_{i,3} - x_{1,4} - \cdots\cdots - x_{q-3,q} = b_{q-2} & (q-2) \\
\sum_{i=1}^{p+1} x_{i,2} - x_{1,3} - x_{2,4} - \cdots\cdots - x_{q-2,q} = b_{q-1} & (q-1) \\
\sum_{i=1}^{p} x_{i,1} - x_{1,2} - x_{2,3} - x_{3,4} - \cdots\cdots - x_{q-1,q} = b_q & (q)
\end{array}
\right\} \quad (II)
$$

$$
\left.
\begin{array}{lr}
a_1 - x_{1,1} - x_{2,2} - x_{3,3} - \cdots\cdots - x_{q,q} = b_{q+1} & (q+1) \\
a_2 - x_{2,1} - x_{3,2} - x_{4,3} - \cdots\cdots - x_{q+1,q} = b_{q+2} & (q+2) \\
\vdots & \vdots \\
a_{r-q} - x_{r-q,1} - x_{r-q+1,2} - x_{r-q+2,3} - \cdots\cdots - x_{r-1,q} = b_r & (r) \\
a_{r-q+1} - x_{r-q+1,1} - x_{r-q+2,2} - x_{r-q+3,3} - \cdots\cdots - x_{r,q} = 0 & (r+1) \\
\vdots & \vdots \\
a_p - x_{p,1} - x_{p+1,2} - x_{p+2,3} - \cdots\cdots - x_{p+q-1,q} = 0 & (p+q)
\end{array}
\right\} \quad (III)
$$

Areas in the final structure in age classes less than q+1 will represent areas felled and replanted at least once during the conversion period. Areas in age classes q+1 and greater will not have been felled.

The model in Fig. 2 implies that the total forest area A remains unchanged over the planning period. However, if area x_{01} is the area incorporated in the total forest by establishing a new plantation in period 1, then one of the equations in (II) must be rewritten as the equation below.

$$x_{o,1} + \sum_{i=1}^{p} x_{i,1} - x_{1,2} - x_{2,3} - \cdots\cdots - x_{q-1,q} = b_q \; (q) \qquad (IV)$$

The other equations must also be suitably redefined. Also equation (V) must be added to the constraint system. Here a_0 is the total area of forest incorporated during the conversion process.

$$a_0 + \sum_{i=1}^{p} a_i = \sum_{i=1}^{p+q} b_i \qquad (V)$$

The above equations represent the basic set of structural constraints, as suggested by Suzuki (1961, 1963) and Choi and Nagumo (1984). In addition to these constraints an additional set of management imposed constraints can be added to the model to match the problems faced by an individual manager. In this paper the constraints concerned manpower. In Japan, attracting labour into forestry has become difficult and can often constrain the range of feasible management options.

Therefore, the constraints chosen were as follows. First, the area felled in each time period had to lie within a set of boundaries in order to stabilise labour demand as labour demand can be taken to be very closely related to the area cut and subsequent tending operations. This constraint is shown in equation (VI) where S_j is the "ideal" felling area in period j that the manager imposes on the system from a consideration of manpower, and ΔS represents the limit of the range of acceptable areas.

$$S_j - \Delta S < \sum_{i=1}^{p+j-1} x_{ij} < S_j + \Delta S \qquad (VI)$$

To model a specific change in the areas felled in each period and the size of the labour force during the conversion period, constraints of the form in (VII) were used. If the left hand side of (VII) is greater than zero

$$\sum_{i=1}^{p+j-1} x_{ij} - \sum_{i=1}^{p+j} x_{ij+1} \lesseqgtr 0 \qquad (VII)$$

the area to be felled will gradually decrease and so will the size of the labour force required. If the reverse is true the size of the labour force will increase.

The objective function chosen is also open to management choice. Here the objective chosen was the maximisation of Z, the volume harvested over the conversion period. It is shown in equation (VIII) where v_i is the volume per unit area of forest of age class i.

$$Z = \sum_{j=1}^{q} \sum_{i=1}^{p+q-1} x_{ij} v_i \qquad (VIII)$$

Nautiyal and Pearse (1967) described a similar approach to that presented here, with a different objective function.

AN APPLICATION OF THE SYSTEM TO A DISTRICT FOREST

The models were applied to cooperative forests in Kangweondo, Republic of Korea. The total area of the forest under study was 2,216 ha of red pine (Pinus densiflora S. et Z.) stands in Kangweon region. The conversion period chosen was 50 years, comprising 10 periods of 5 years each. The size of the age class chosen was also 5 years. The local yield table for red pine and the local labour requirements for management activities were based on yield studies and empirical operational data (Choi, 1988). The equilibrium represents the basic data for the linear programming (LP) model.

The target age class distribution was Suzuki's "Generalized Normal Forest State" based on a distribution of cutting ages with an average of 35 and standard deviation of 8.75 years. The idea incorporated in such a distribution is that variations in site type will produce variations in cutting age. The minimum permissible cutting age was assumed to be 15 years to determine the location parameter of the Weibull distribution. It was found that the Weibull distribution was very useful because of its simplicity for mathematical manipulations and variety of curve shapes. Then it was easy to determine forest age transition matrix using the relationship between Gentan Probability and transition matrix, which is the key point of Suzuki's original model (1963).

In the LP model, in addition to the constraints described earlier, the following were added. No cutting was allowed in age classes 1 to 3. All timber in age classes above 12 was to be cut. The size of the area cut must not decline for the first 6 periods. Replanting is assumed to occur immediately after cutting.

RESULTS AND DISCUSSION

The models were run on a Cyber 170-720D computer system at the Kangweon National University. The conversion period chosen was 50 years made up of 10 periods of 5 years each. The size of the age class chosen was also 5 years. The target age class distribution was Suzuki's "Generalized Normal Forest State" based on a distribution of cutting age. The area to be felled in the first period of 5 years is 78.15 ha from age class 7, 98.40 ha from age class 8, 69.20 ha from age class 9, 52.20 ha from age class 10, 7.90 ha from age class 11 and 10.00 ha from age class 12 - a total of about 316 ha.

In general, the transition of age-class distribution depends on its initial distribution. The specific district forest consists mostly of young plantations, leading to a positively skewed initial age-class distribution. Such a skewed distribution is quite common all over Korea. Therefore, it is important to make a comprehensive forecast regarding the transition of age-class distribution under this skewed initial condition. These results give us a good basis for choosing harvest strategies. In recent years, there is an emotional tendency towards the choice of longer cutting-ages in discussing the future timber supply-demand situation in Korea. However, it should be noted that it is not always advisable to choose a longer cutting-age in establishing a district forest plan because of the large fluctuation between periodic harvests.

CONCLUSION

The system described here, intended as an adequate management plan for regional forests, is designed to provide forest management information for cooperative forest management planning for private forest owners. The overall aim of the research is to produce long-term plans that are compatible with the Gentan probability model.

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Semi-quantitative evaluation of multiple-use forest stands

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1. INTRODUCTION

All countries with a long forestry tradition have well documented techniques for the assessment of the economical, current or future value of forest-stands. For the last few decades, a world-wide interest for the multifunctional role of contemporary forests has been growing. This is specifically the case in regions with a low afforestation index.

In Flanders, the Dutch speaking part of Belgium, situated in the highly populated lowlands near the North-sea in Western Europe, the afforestation index is about 8%. This means only 0.02 ha forest is available per inhabitant. These forests are mainly private. As a consequence, the economical, recreational and ecological pressure on forests is considerable.

There is a need for a method to measure the way in which these real needs of society are fulfilled. Forest policy and forest management need to be based on an evaluation method which takes into account the multiple role of a forest stand. This means that other descriptive parameters have to be added to the traditional parameters like ;

- afforestation index;
- age;
- species composition;

- stocking density;
- productivity.

The aim of the presented research project is to make a guide-line for such an evaluation method in Flanders. All the relevant features of a forest stand are evaluated and are given scores. One global formula is build up with these scores.

Premisses are:

- a forest stand is the more worth, the more it is stable;
- the social (recreational, cultural ...), ecological and economical functions are of equivalent interest. However it should also be possible to extend the evaluation method to forests with more specific functions.

2. METHOD

2.1. General

The present evaluation method is based on scores for four basic parameters i.e.:

- tree species (A);
- stand structure (B);
- significance of the stand for the environment (C);
- stand potentials (D);.

If one wants to give a complete picture of a stand also other aspects, not appearing in this evaluation method should be considered e.g.:

- property structure;
- legal constraints;
- facilities for the management.

2.2. Tree species (A)

Although some species have no doubt a higher silvicultural value compared to others, it is difficult to make a real ranking. In the present evaluation method the classification for tree species is based on two sets of parameters. This ranking is only applicable however in the geographic region on which this study is based. Modifications can be necessary depending on the provenance of the seed. The first group contains *inherent constant features* of the species. The second group contains *inherent variable features* which means although these features are inherent to the species, the relevance or importance of them can vary depending on the management aims.

2.2.1. Inherent constant features

* native versus exotic species

In general, native species are more adapted to the local environmental circumstances, so native species score highest for this parameter.

* litter-quality

Differences in litter-decomposition have important consequences for the pedofauna and for the stability of the site as a whole. A classification based on data from different authors was made.

* stand building capacity

Some species are not able to form real forest-stands, at least not in our region. The so called *primary tree species* are capable to form impressive forest-stands (e.g. beech and oak in Flanders). Other species are called *secondary tree species* and can be of great importance as accompanying trees in stands (e.g. lime-tree, sycamore, ash in Flanders). The remaining species are not capable to be of any interest in our region or only play their role in the shrub-layer (e.g. bird cherry, hazel).

* vitality

Even native species can become very susceptible to a diversity of plagues, fungal attacks, insects, soil compacting, pollution ... Elm e.g. is a primary, native species in Flanders. However, because of the elm disease the species as a whole became of very small importance in Western Europe.

2.2.2. Inherent variable features

*** rotation**

Species with a long rotation time can be considered to be more stable because the vulnerable reforestation phase takes only a small percentage of the stand life. This means that the period in which the stand can fulfil its social and ecological most important role is not often disturbed with a reforestation phase which is less interesting.

If the management goal is to get a high financial revenue in a short period, species with a short rotation period get a very high score for this parameter. Stands with a more recreational or ecological vocation however are better served with trees which can be grown with long rotations.

*** temperament**

The crown-layer of so called *light species* is more light-transparant compared to stands based on *shade trees*. The light that passes through the crowns of the upper-story is available for the shrub-story, as a consequence of which the vertical architecture can become complex. This feature however is less relevant if the main goal of the manager is financial. Species with a low stand-building capacity often have to grow under shade conditions. So the evaluation of this feature depends on the species, the role it has to play in the forest-ecosystem and the management goal.

*** productivity**

This feature is defined here as the gain (money) per hectare and per year under favourable conditions on a suitable site.

Based on all these features, a classification for tree species in multifunctional forests is made in table 3.

Table 3: classification (scores between 1 and 10) of some tree species based on their suitability for multi-purpose stands in Flanders

Picea abies	1
Populus (not selected)	2
Prunus serotina	2
Sorbus aucuparia	2
Acer pseudoplatanus	3
Alnus glutinosa	3
Betula sp.	3
Pseudotsuga menziessii	3
Quercus rubra	3
Quercus palustris	3
Pinus nigra var Corsicana	3
Pinus sylvestris	4
Populus (selected)	4
Robinia pseudoacacia	4
Larix leptolepis	4
Larix decidua	4
Larix eurolepis	5
Fraxinus excelsior	7
Fagus sylvatica	7
Castanea sativa	7
Quercus robur	9

2.3. Stand structure (B)

Highly varied stands will get higher scores compared to monotonous ones because they are in general more stable.

* Stand composition (B1)

Stands with different strata or stories are considered to be the best, because of the more complex ecotope they consist of. The following classification is made. (-: not present, *: present):

type	1	2	3	4	5	6	7	8
upper-story	*	-	*	*	-	*	*	*
subsidiary story	-	-	-	-	-	-	*	*
under story	-	*	-	*	*	*	-	*
herb layer	-	-	*	-	*	*	*	*
evaluation of the vertical architecture	poor			average			good	very good
score	*4*				*6*		*8*	*10*

Deviations from the scores shown in this scheme are possible e.g. if one species (fern, nettle, black-berry) over-dominates the herb-layer a lower score can be given.

* Mixture of species (B2)

A stand can be mixed or build-up with only one tree species. Mixed stands, in general are considered to be better because of their favourable ecological and financial aspects. However, some mixtures can be a disaster e.g. poplar-larch because of sanitary aspects.

In young stands stem-by-stem mixtures are considered as a disadvantage compared to group-mixings.

Unfavourable mixtures get score 0.7, homogeneous stands get score 0.8 and good mixtures get score 1.

* **Density** (B3)

Low densities prevent natural branch-pruning and lead to inefficient use of the site. High densities however are considered to be even worse because of unfavourable sanitary conditions and the reduction of growing conditions for other organisms.

Possible scores are 0.7 for stands with less than 60% coverage or with a too high density. Score 0.8 is given if the crowns of the trees don't touch each other and the coverage is over 60%.

2.4. Stand potentials (C)

* **vitality** (C1)

The vitality of a stand can be evaluated on the field by an expert. Special attention must be given to:

- age of the oldest needles;
- colour and size of the leaves or needles;
- attacks by fungi or insects;
- suckers.

The actual observed vitality of a stand may differ considerably from the potential vitality of the species.

Unhealthy or dying stands get score 0.4, slightly unhealthy stands get score 1 and vigorous stands get score 1.2.

* **management** (C2)

Even stands composed of valuable species with different layers on an appropriate site can be of low value because of bad or no management.

Score 1 is given to well managed stands. Score 0.9 is given to stands with management problems. If even a renewed management can not save the forest from decline the score becomes 0.4.

*** suitability of the site** (C3)

It should be clear that this parameter is one of the most important. Most knowledge about the matching of species to sites in Flanders is based on the work of Baeyens or on field experience of the manager.

If the combination site-species is very good score 1.1 will be given, for good combinations this becomes 1 and for bad site suitability 0.8 will be the score.

2.5. **Significance for the environment** (D)

This parameter is based on:

- the afforestation index of the surroundings;
- specific ecological functions the forest might fulfil (reduction of erosion, sound insulation...);
- specific socio-cultural, historical or aesthetic features of the forest.

Possible scores for parameter D are 1 (normal stands) and 1.3 (stands of special interest.

3. A CASE STUDY

The presented evaluation study was used by LISEC to evaluate several hundreds forest stands.

The field observations were immediately transmitted to a form. A software package makes it possible to visualise the stand evaluation and to make several simulations.

The field work, the calculations and the reporting for a small scale, highly varied forest of 100 ha (150 stands) took about 20 days. No maps or inventories where available for this forest. If this data would have been available the study could have been accomplished in about 10 days.

In this case study the above described ideas where implemented in this formula:

$$\text{Total stand value } (W) = (A + B) * C * D * 0.3846$$

in which the characters A, B, C and D stand for the scores for:

- A = species
- B = stand-structure (B1 * B2 * B3)
- C = stand potentials (C1 * C2 * C3 * 7.576)
- D = significance for the environment
- 0.3846 and 7.576 are scale factors

The total stand value ranges from 0 to 100. With scores between 0 and 20 for forests which are of very poor interest and scores between 80 and 100 for the most valuable forests.

Although this formula and the way the different parameters were treated need to be improved, this experiment learned that this implementation leads to a classification which matches the subjective judgements of stands made by different experts. Perhaps even more important is the fact that this classification offers a base for fertile discussions.

In one case-study the evaluation method was used to compare different location alternatives for a 27 holes golf court in a private forest of about 160 ha. The information was used to make a map on which the stand value was shown in different colours. A picture of the implantation of the holes, according to the different alternatives was laid over this map.

To get a better idea of the importance of the effect the mean stand value before and after realisation of the golf project was calculated. This also facilitated the choice between these alternatives. It was possible to calculate the percentage of the stand value that disappears by a treatment or to calculate the effect on the entire forest.

In fact it is possible to calculate the decline in stand value caused by a certain treatment. This means the method can also be used in Environmental Impact Assessment studies.

4. RECOMMENDATIONS FOR FURTHER RESEARCH

The present list of parameters and features is based on the knowledge of forestry experts and biologists working at LISEC. It would be interesting to have a broader discussion about it.

The formula used in the case study should be studied in detail and different implementations are to be tried out.

Well documented with examples and pictures, tables and figures, a standard method for the evaluation of multiple forest stands could be the result of this exploratory study. Knowledge about the features which are most responsable for the value of a forest can also result in guidelines for the management.

The method could be adjusted to be used in forest-stands with more specific management goals.

This goal is very ambitious. However, as forests are becoming more and more important for the health of society it is necessary:

- to give an alternative for evaluation methods that are only based on productivity;
- to make explicit and systematic statements about the qualities of forest-stands and about their functions. This facilitates discussions between decision makers on the field and politicians or forest-users.

THE SEARCH FOR SUSTAINABLE NATURAL FOREST MANAGEMENT IN ASEAN: A CASE FOR SUSTAINABLE TIMBER PRODUCTION

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SUMMARY

The global concern over the issues of sustainable forest management of and timber production in tropical forests is gaining momentum. So much so that the terms "sustainable forest management" and "timber production and the rain forest" have attracted worldwide attention of the international media, research and funding organizations, timber consuming and producing countries, timber trade organizations, government and non-government organizations, etc. Scientists and forest managers have lost track of the essence of the issue. In ASEAN where the furor is kept in flames, this paper, in an effort to account for this global concern, defines and describes the concept of sustainability from the forests, sustainable timber production scenario, and some important strategies to promote sustainable forest management practices. This paper summarizes partly results from the study on "Sustainable Forest Management in ASEAN With Special Reference To Sustainable Timber Production in Malaysia".

Keywords: Sustainable forest management, sustainable timber production, ASEAN, tropical forests, biological sustainability

DEFINITION AND TERMINOLOGY

"Sustainable...", "Sustainable forest management", and "Biological sustainability" are terms and concepts which are difficult to define but are basic to what I will be discussing in this paper. Much confusion and misunderstanding can be, and has been, caused by the imprecise use of such terms. I wish to avoid this as far as possible. Even in this paper, the already over-used and over-cited word "sustainability of ...." is also being used. The following defines or explains or describes the key terms used in this document.

- "Sustainable" - as in "sustainable forest management" with the view to achieve "sustainable timber production" and "biological sustainability" of the forest.

* "Sustainable" or "Sustainability" implies the permanent maintenance of productivity (of something) on the site, with the costs of inputs (if any) not exceeding the commercial value of the outputs derived from such site.

* In the context of forestry (natural or plantation) and in the present paper, the site is a forest land; the sustained production of timber/logs+ (either at a uniform or non-uniform level) is the output in question; and the inputs are costs (indirect or direct) to produce the timber/logs, for example, management and silviculture costs, harvesting and transportation costs, etc.

  (+Note: the output can be extended to include non-timber forest products, such as rattan, bamboo, birds' nests, resin, etc. We may extend the definition of sustained production to timber/logs of commercial value only which will vary from time to time).

* Regarding the sustainability of tropical forests it is important the recognize that there are at least two fundamentally and distinctly different perspectives to the subject. These are:

  (a) the sustainability from the forests, i.e., the sustained production or outturn of timber/logs at either uniform (constant) or non-uniform level in each year of production. This is also referred to "sustainable timber production" or "sustainable yield harvest".

  (b) the "biological sustainability" of the forest. Tropical forests, as a wood production biological entity, can be sustained because the forests grow after they are harvested. Indeed, if harvest correctly and the residual stand are properly managed, they may very well grow at much higher rate (m^3/ha/yr., for example) than the undisturbed "natural" forests. For the forest to be biologically and economically sustainable, the growth rate or the growth in volume of commercial tree species (∂G) must be in the following order: ∂G in the ith cutting cycle >=∂G in the jth cutting cycle >=∂G in the kth cutting cycle >=....>=∂G in the nth cutting cycle, where i>j>k>....>n. Biological sustainability in tree growth is sometimes referred to as "annual sustained yield potential" or "annual harvestable increment".

* Truly enough, if the forest can be sustained in its timber/log production and in its biological growth, this implies that whatever silvicultural and management techniques used is suitable or applicable to such forest. Further, there may already be conditions, either technical or otherwise, that encourage the management for sustained timber production. All these constitute what is termed as "sustainable forest management".

SUSTAINABLE FOREST MANAGEMENT IN ASEAN

Ever since the forest management came into practice, the concept of sustained yield management has always been the guiding principle in managing the natural forests of the ASEAN countries. However, of late, this guiding principle becomes more critical than ever in some tropical countries, mainly as a result of:

1. **Diminishing forest resource base (mainly timber) due to:**

    * inadequate planning of natural forest harvesting.
    * inadequate harvesting regulations and/or insufficient attention to enforcement of logging rules.
    * extensive encroachment by shifting cultivators.
    * dependency on timber as an export commodity to provide revenue to a country.
    * unplanned conversion of forested land for agriculture and other development projects.
    * inadequate recognition of the existing forest policy and forest working plan and development.

2. **Inadequate resource replacement and development due to:**

    * insufficient effort to implement reforestation and to regenerate the logged-over forests.
    * insufficient trained manpower to carry out afforestation and reforestation activities.
    * existence of other resources (rubber, oilpalm, coconut, pepper, gases, petroleum, etc.) as revenue generator to a country.
    * lack of technical know-how such as inappropriate forest management systems and silviculture treatments of the forests.

While the above reasons may not be true to all tropical countries, they are generally seemed to occur in most parts of Southeast Asian countries. It is pertinent to see the extent of the forest areas within ASEAN in order to relate the concept of sustained yield management and the possibility of promoting the concept of sustainable forest management (see Table 1 for this purpose).

Most of the ASEAN member countries - Malaysia, Indonesia, Philippines, Thailand and Brunei - have explicitly stated in their legislation that their forests have been and will be managed on a sustained yield principle.

But there is a disparity between what "should be done" and "what has been done" to the forests in many parts of the region. It is not possible to give an accurate estimate of the area of natural forests which is genuinely managed under sustained yield basis in the region, but in the context of this paper sustained yield can only relate to the productive portion of the permanent forests (usually classified as Permanent Production Forests) of the ASEAN countries.

The timber yield from forests in the individual country of the ASEAN has fluctuated widely in the past, mainly because of a very large amount of the production had come from the initial standing stock of timber in primary forests and also from the forests allocated for other purposes. Log export from the region peaked at about 39 million m^3 in 1973 and declined to about 19 million m^3 in 1982. Available informations from the literature (Wan Razali et al. 1989) reveal that the annual harvestable increment of the forests in the region also varies, from about 1 to $1.5m^3$/ha/yr. for extensively logged but less intensively managed forests to about $2m^3$/ha/yr. for selectively logged and intensively managed forests.

In this regards there are two main types of natural tropical forest management systems in many parts of the world and particularly in ASEAN, namely Monocyclic System and Polycyclic or Selective System, both of which have its advantages and disadvantages (see Wan Razali 1990). The choice of one particular type of management depends on several factors, such as the types of forest, the requirements of the particular timber market and the forest policy of a country or forest owner.

Comparisons of long-term sustainable yield harvest (sustainable timber production) at the various annual harvestable increments with the most recent log out-turn figures are also given in Table 1. There are about 126 million hectares of forest managed for timber production in ASEAN. However, out of this only 57.20 million hectares (45.4%) are managed on the sustained yield basis . Overall, the sustained yield management area comprised only 31% of the total forested area (184.35 million hectares) and only 18.6% of the total land area (307.8 million hectares) in ASEAN.

From Table 1 it is obvious that Sabah was harvesting her timber by more than its yearly total growth harvestable increment of the sustained yield forests. Sarawak was in the similar position as Sabah. However, both of these states capitalize their log production from the initial standing stock of timber in primary forests and also from forests already allocated for other purposes. In the years to come they have to reduce their annual production of logs from the natural forests so that their harvest from the permanent production forests will not exceed their annual harvestable increment. Peninsular Malaysia is approaching a balance between the annual log production and the total annual harvestable increment.

Indonesia, based on the published information, is maintaining her annual log production consistent with the total harvestable increment of the permanent production forests. However, Indonesia has considerable scope to improve the sustainable log production capacity by practicing a more intensive management of the natural forests.

Philippines is having some difficulties to find enough forest areas to sustain the present annual log production, therefore the country has to reduce the annual log production accordingly. The Philippines' Senate Bills on Total Logging Ban and/or Selective Logging Ban of 1989 may help to ameliorate this situation but its effectiveness remains to be seen.

Table 1: A Comparison of Sustainable Production of Timber from Permanent Production Forests in ASEAN

Country	Total Forest Area (million ha)	Permanent Production Forests on Sustained Yield (million ha)	Sustainable Timber Production (million m^3) at the annual harvestable increment of 1.0m^3/ha/yr.	1.5m^3/ha/yr.	2.0m^3/ha/yr.	Annual Log Production (million m^3)
Pen. Malaysia	6.19	2.85	2.85	4.28	[5.70]	8.06
Sabah	4.44	3.00	3.00	[4.50]	6.00	11.50
Sarawak	8.45	3.77	3.77	5.66	[7.54]	13.66
Indonesia	143.96	39.20	[39.20]	58.80	78.40	35.77
Philippines	6.46	2.70	[2.70]	4.05	5.40	4.15
Thailand	14.38	5.50	[5.50]	8.25	11.00	2.07
Brunei	0.47	0.17	0.17	[0.26]	0.34	0.18

[ ] Indicates a most likely sustainable timber production scenario for each country.

Source: Wan Razali (1990).

The situation in Thailand is a little intricate. Although the annual log production is half the total annual harvestable increment from the sustained yield areas, apparently Forest Industry Organization of Thailand estimated that about 70 million m^3 of wood is removed annually and that land encroachment, shifting cultivation, illegal log poaching and illegal fuelwood collection are the major sources accountable for such a vast volume of wood. If this report is true (short of actual data) then the scope for sustainable timber production in Thailand will diminish. Even though Thailand has stopped all logging, and set apart as a leader in forest conservation among the many tropical countries, it will not help to sustain the timber supply from the natural forests unless the major sources of illegal activities mentioned above are solved.

Brunei, with about 80% still in forests and having an annual log production of only 180,000m^3 from the natural forests, is in a better position than any other countries in the region to sustain the log production over the next 30 to 40 years.

SOME IMPORTANT STRATEGIES TO PROMOTE SUSTAINABLE FOREST MANAGEMENT PRACTICES IN ASEAN

ASEAN, and many countries in Asia also, appear not to be lacking of development strategies and implementation plans in forestry, and of studies, reviews and meeting undertaken to assess its research needs. Some strategies that can be implemented to promote sustainable forest management practices include the following:

** **Related to Forest Policy and Administration**

- Increase the generally low awareness, support and commitment to carry out what have been formulated.

- Secure a sufficient area of natural forests, not less than 45% of the forested areas, in each country to be designated as permanent forest production area. Ensure that the land must remain in forest use after harvesting or logging.

- Curtail the harvesting level of natural forests to the level of long-term sustainable timber production based on the total annual harvestable increment.

- Agree among ASEAN, and perhaps among tropical hardwood producing countries on a price structure of hardwood timber and timber products that is equitable with its quality.

- Eliminate incentives, subsidies and other inappropriate policies and legislation that encourages economic inefficiency and over-harvesting of forest resources.

** **Related to Forest Management Practices and Silviculture Operations**

- Ensure and allocate sufficient government incomes, especially those obtained from logging, to finance inputs to silviculture and management of logged-over forests.

- Develop forest management systems that are more sensitive to ecological and environmental requirements and social needs of the people, especially to integrate forest dwellers and shifting cultivators into the systems.

** **Related to Forestry Research and Development**

- Develop innovative, economic and ecologically and environmentally sound management systems for natural, plantation and other forests within the PFE to enhance their productive potential.

- Increase forest resource base by improving the productivity of degraded and denuded land throughout a country.

- Develop appropriate technologies to achieve optimum efficiency in the economic recovery of harvestable timber and other resources with a minimum resource wastage and damage to the forest environment.

* Diversify the forest based industries by giving incentives to encourage local processing of secondary and tertiary products from timber and other related forest produce to enhance the manufacture and export of value-added and high quality products.

* Improve the utilization of wood and nonwood products from native and introduced tree species: improve and expand the use of minor forest products.

* Support in terms of fund, equipment and man power training in order to strengthen and increase research capabilities of national forestry institutions.

* Encourage networking to help the coordination of support, planning, execution and interpretation of results to maximize information yield and reduce unnecessary competition and duplication of research efforts.

CONCLUSION

o The annual harvestable increment of the natural forests in Brunei, Sabah, Indonesia, Philippines and Thailand are in the region of 1 - 1.5 m^3/ha/year.

o The annual harvestable increment of the natural forests in Peninsular Malaysia and Sarawak are about 2 m^3/ha/year.

o The long term sustainable supply of timber from Permanent Production (Natural) Forests of various countries in ASEAN is as follows:

*	**Peninsular Malaysia**	**5.70 million m^3/year**
*	**Sabah, Malaysia**	**4.50 million m^3/year**
*	**Sarawak, Malaysia**	**7.54 million m^3/year**
*	**Indonesia**	**39.20 million m^3/year**
*	**Philippines**	**2.70 million m^3/year**
*	**Thailand**	**5.50 million m^3/year**
*	**Brunei**	**0.26 million m^3/year**

o It is recommended that the annual level of log production from the natural forests in each of the ASEAN country should not exceed the annual sustainable timber production capacity of such forests.

o A major obstacle to the practice of sustainable natural forest management is not only the availability of little or sparse ecological and silvicultural information on most tropical forests but more important is to solidify and concentrate on the efforts to put the already known natural forest practices on the ground.

ACKNOWLEDGMENTS

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REVENUE SYSTEMS, RENT CAPTURE, AND LOGGING BEHAVIOR IN PENINSULAR MALAYSIA

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SUMMARY

The structure of forest revenue systems in tropical countries affects concessionaires' logging behavior and influences the allocation of resource rent (stumpage value) among alternative components: government revenue, windfall profits, high-grading, logging damage, etc. Malaysia provides a unique opportunity for studying these issues, because revenue systems differ widely among the thirteen states in the nation. We have established study sites in forests logged in 1989 in three states: Kelantan, Pahang, and Terengganu. Post-felling inventories will be compared to pre-felling inventories to develop quantitative estimates of the various rent components. We will use these estimates to study whether the effects of revenue systems are predictable and to suggest feasible means to increase government rent capture and to decrease high-grading and logging damage.

Key words: Tropical timber, forest revenue systems, rent capture

FOREST REVENUE SYSTEMS AND RENT CAPTURE

Forests in most tropical countries are government-owned. Timber from these forests is sold to concessionaires--individuals or firms holding harvesting rights--at charges established by government agencies, not by markets. These charges fail to capture the stumpage value, or resource rent, of harvested forests. Repetto and Gillis (1988) estimated that the percentage of rent captured by governments during 1979-1983 ranged from 11.4 percent in the Philippines and 33.2 percent in Indonesia to 82.8 percent in the Malaysian state of Sabah.

Exploitation of tropical forests has thus been characterized by a tremendous transfer of wealth from the public to the private sector. Revenue that might have been used to support public-sector investments is instead captured by concessionaires, at rates far exceeding average industrial profit margins. This implicit subsidization of timber extraction attracts resources that could be used more efficiently elsewhere in the economy, leading to excessive forest harvesting and unsustainable expansion of timber-based industries. The low returns to the government foster the misperception that forest management is not feasible (Vincent 1990).

The tendency of timber charges to be assessed on extracted logs, rather than on standing trees, and to be virtually undifferentiated by species or extraction difficulty creates additional problems, such as high-grading (including discrimination against lesser-known species) and logging damage (Gillis 1980, 1988; Vincent 1990). Figure 1 displays how an undifferentiated royalty (r) assessed on extracted logs causes potential rent to be split among three basic components: government revenue (GR), windfall profits (WF), and high-grading (HG). For simplicity, the diagram assumes that variation in log prices (p) can be ignored, which implies that differences in stumpage value result only from differences in extraction costs. The horizontal axis gives harvest volume. Increases in harvest volume are associated with higher marginal extraction costs (MC_i) in the short run. A profit-maximizing concessionaire would not harvest trees for which marginal cost exceeds marginal revenue. Marginal revenue is equal to the net log price ($p - r$). Rather than harvest all commercial timber on the site (V^*), the concessionaire harvests only up to the point where $MC_i = p - r$ (i.e., up to V').

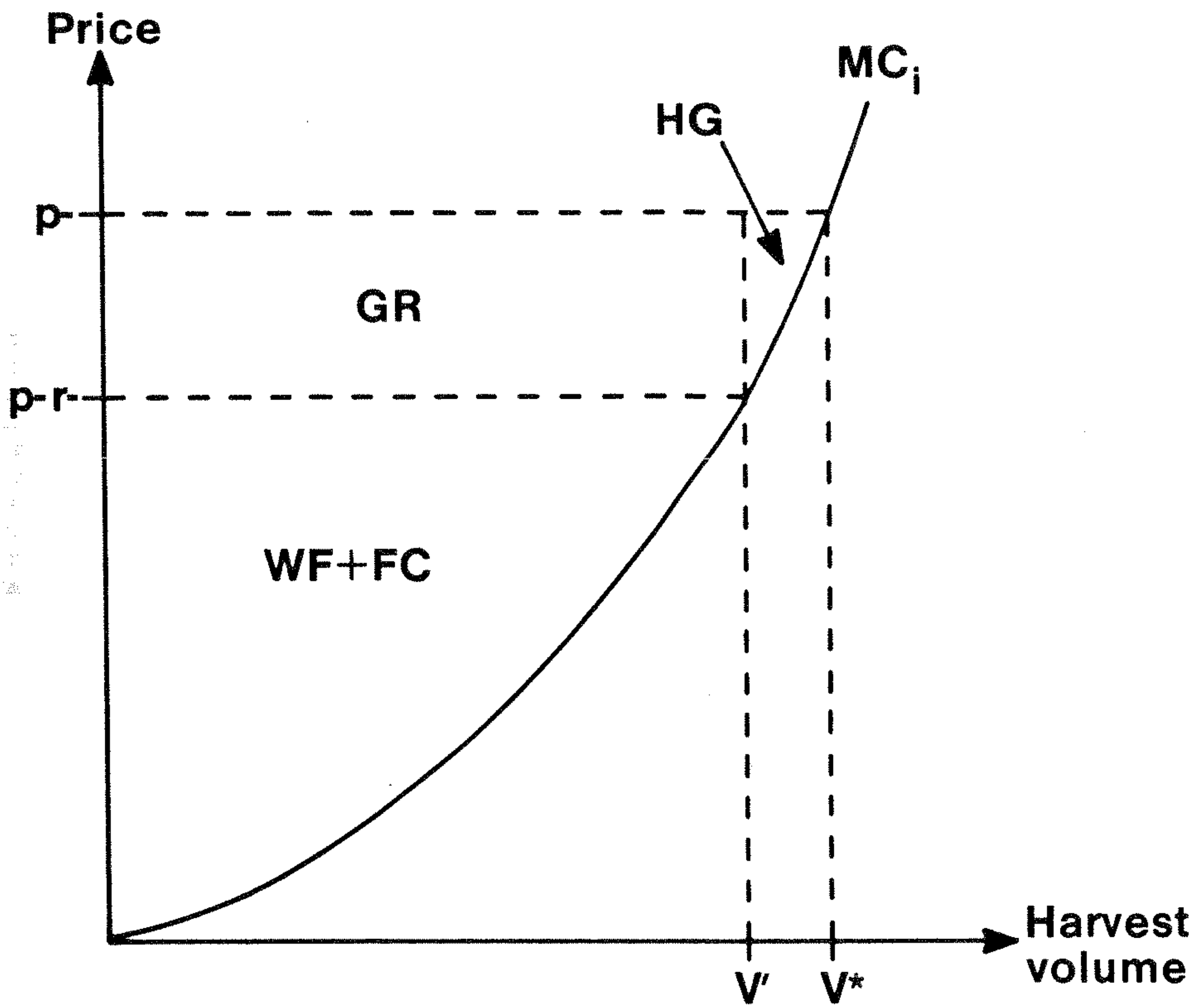
The area between the marginal cost curve and the price line represents the sum of potential rent plus fixed costs. The government collects revenue, GR, only on V', since royalties are assessed on extracted logs. The volume that is not extracted ($V^* - V'$) has rent value equal to HG, the high-grading component. This can be a deadweight loss: since they are not charged for unextracted trees or logs, concessionaires might fell these trees (for example, during road-building) and leave them in the forest to rot, or they might damage them during logging, resulting in reduced growth or even mortality. The size of the concessionaire's windfall, WF, depends on the size of its fixed costs (FC). Note that an undifferentiated royalty causes an unavoidable trade-off between WF and HG: as r increases, HG increases, and as r decreases, WF increases.

REVENUE SYSTEMS IN MALAYSIA

The failure of revenue systems in Malaysia to capture resource rent was alluded to in the 1960s by Chong (1966) and in the 1970s by Sulaiman (1977), and documented more recently by Gillis (1988) and Vincent (1990). Vincent (1990) estimated that during 1966-85, the percentage of rent captured by forest revenue systems in the three regions of Malaysia was only 18.4 percent in Sarawak, 21.8 percent in Peninsular Malaysia, and 46.2 percent in Sabah.

A broad array of forest revenue systems is employed in Malaysia, due to the autonomy over forestry matters exercised by the nation's thirteen states (Salleh 1983, Vincent 1988). The systems are typically comprised of a mix of charges based on extracted logs ("royalties," "cesses") and charges based on the area of the concession ("premiums"). In some states royalties are proportional to log prices and thus exhibit a degree of market responsiveness, while in others they are fixed at levels that have remained essentially constant since the early 1970s. Differences in revenue systems among the

Figure 1--Undifferentiated royalty and rent capture. p = price of log delivered to mill, r = royalty, V' = actual harvest volume, V^* = total merchantable timber volume, MC_i = marginal extraction cost for logs from tree i, GR = government revenue, HG = high-grading loss, WF = windfall profit, FC = fixed costs of extraction.



states have increased recently, with some states having enacted significant increases in royalties or begun determining premiums by sealed bids ("closed tenders"). Royalties for a given species can differ between states by a factor of 2 or more, and premiums can differ by an order of magnitude.

Its diversity of revenue systems makes Malaysia ideal for a comparative study aimed at generating pragmatic proposals for more efficient systems. Resource economics theory is unambiguous on how to price tropical timber: price should be based on stumpage value, which is the residual value of a tree after total logging costs (extraction and delivery costs, taxes, normal profit margins) are deducted from the log price paid by a mill. Strict implementation of a system based on stumpage value might not be feasible in Malaysia, however, due to constraints on forestry departments' staff and funding. Revenue systems must be sought that maximize rent capture and minimize such deleterious forest impacts as high-grading and logging damage, subject to the constraints imposed by existing administrative resources.

The remainder of this paper describes a study that aims to identify such systems for Peninsular Malaysia. The study is funded by the Osborn Center for Economic Development (part of the World Wildlife Fund and The Conservation Foundation). It is being carried out in cooperation with the Forestry Department of Peninsular Malaysia and State Forestry Offices in three states.

STUDY SITES

We have selected a set of study sites that:

1) are matched as closely as possible in terms of initial (pre-felling) forest characteristics, management systems, logging methods, and dates of logging, but

2) differ as much as possible in terms of the revenue systems faced by concessionaires.

By holding constant the traits listed in #1, we hope to isolate the effects of the differences in #2 upon rent capture and logging behavior. We will search for these effects by comparing pre-felling inventories of the sites to special post-felling inventories that we are carrying out during July-September 1990.

We conducted field visits and used pre-felling inventories to select study sites in three states: Kelantan, Pahang, and Terengganu. We chose these three states due to their importance as log producers (their combined harvest represents more than half of Peninsular Malaysia's), their similar forests, their proximity to each other, and their divergent forest revenue systems. The forest revenue systems in each state may be characterized as follows:

Kelantan--low royalty, low premium, royalty comprises larger share of forest revenue than does premium;

Terengganu--moderate royalty, low premium, royalty comprises much larger share than does premium;

Pahang--high royalty, high premium, royalty and premium comprise comparable shares.

Premiums are sometimes determined by sealed bids in Pahang.

Each site consists of a 50-hectare block of previously undisturbed (virgin) hill forest in a Forest Reserve (lands gazetted as part of the Permanent Forest Estate). Each was logged in 1989. The concessionaire in each case is a state-owned, integrated timber complex. Two sites were chosen in both Kelantan and Terengganu, and four in Pahang. An extra two sites were included for Pahang because of the additional opportunity in that state to study sites with auctioned premiums.

DATA COLLECTION

Data collection is in progress at the time of writing. Pre- and post-felling inventories comprise the most basic sources of information. Under the Selective Management System used in Malaysian hill forests, The Peninsular Malaysia Forestry Department carries out pre-felling inventories 1-2 years before harvest. The inventories record stocking (number of trees) per diameter class (12 classes, in 5-15 cm increments) by species group (the same groups as used in recording data on revenue and log prices). Estimates of standing timber volumes are made as well. Pre-felling inventory data for our sites have been provided by State Forestry Offices. In addition, the Offices have provided data from tree-marking inventories, which are carried out just before logging and provide a check for the volume estimates in the pre-felling inventories.

The Forestry Department also carries out post-felling inventories 2-5 years after harvest. This is too long a delay for our study. Instead, we have hired a private forestry contractor to carry out post-felling inventories specifically for this study. These inventories will collect information corresponding to that in pre-felling inventories and will include estimates of the timber volume in damaged, standing-dead, and felled trees left on site.

Data on prices and costs must be collected to supplement the data on timber volumes in the pre- and post-felling inventories. Monthly data on log prices at mills are available from regional offices of the Malaysian Timber Industry Board. Data on logging costs will be provided by the integrated timber complexes. These complexes, which use both their own logging crews and independent contractors, have proven to be the most reliable source of data on logging operations in previous research supervised by Abd. Ghani and Hadi. Data on volume harvested and revenue collected from each site, by species group, will be provided by State Forestry Offices. These data are based on records of checking stations, which scale logs and assess royalties.

ANALYSIS OF RENT DISTRIBUTION

A taxonomy of rent components is displayed in Figure 2. *Potential* rent refers to the total financial value attainable if 100 percent of the commercial timber volume on a site were sold at true stumpage value. An inefficient revenue system causes only a portion of potential rent to be *realized* through the actual extraction and sale of logs. This extraction may be *recorded* or may elude checking stations and be *unrecorded*. Recorded extraction rent is captured either by the government as *forest revenue* or by concessionaires as *windfall profits*. *Unrealized* rent consists of *residual* rent and *logging damage*. Residual rent refers to living trees left standing in the forest due to management prescriptions (*silvicultural* rent) or *high-grading* (failure to extract marketable trees). Logging damage refers to felled or standing-dead trees.

These rent components will be estimated as follows:

1. Pre-felling inventory data will allow estimation of potential harvest volume. The sales value (based on log prices) of this volume minus logging costs and profit margins will provide an estimate of *potential* rent.

2. The sales value of recorded harvest minus logging costs will provide an estimate of *recorded extraction* rent.

3. *Forest revenue* will be given directly by data on royalty and premium collections, and *windfall profits* will be given by the difference between this and recorded extraction rent.

4. *Silvicultural* rent and *high-grading* (together, *residual* rent) will be determined by comparing pre- and post-felling inventories on the basis of management prescriptions and harvest plans.

5. *Logging damage* will be based on post-felling information on dead or damaged trees of marketable size and species.

6. *Unrecorded extraction* rent will be the residual left after subtracting recorded extraction rent, residual rent, and logging damage from potential rent.

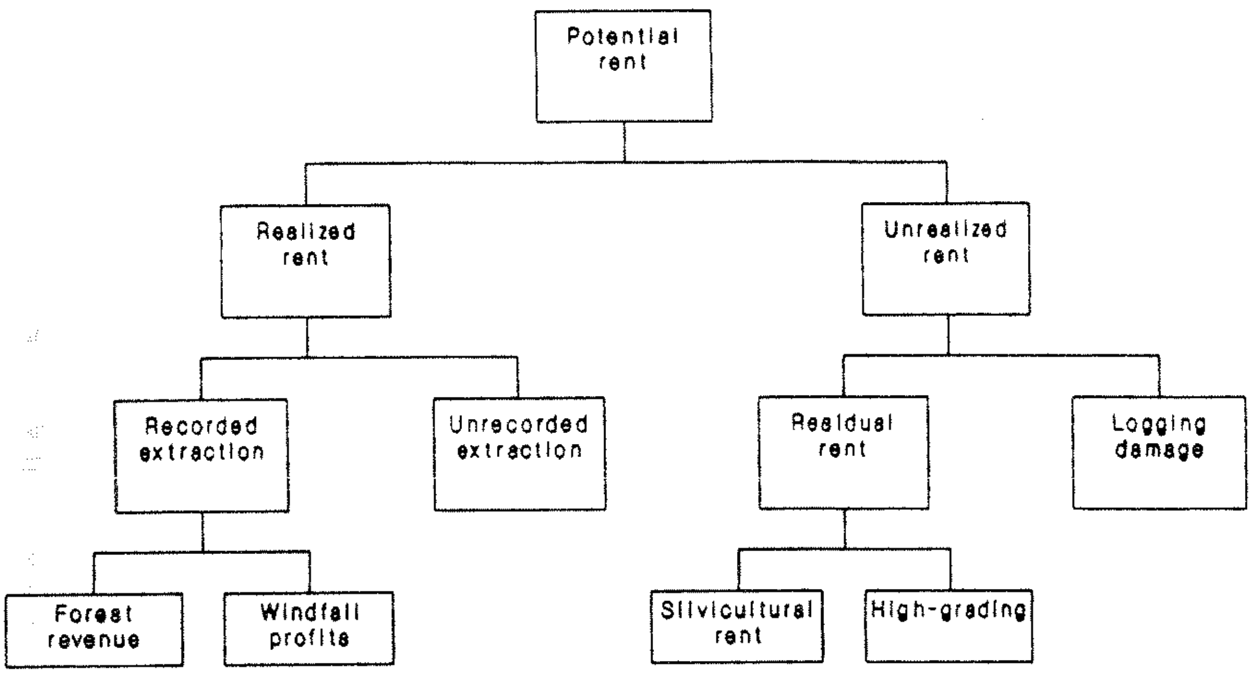
These estimates will allow direct comparison of revenue systems on the basis of not only the individual rent components, but also:

1. Economic efficiency: forest revenue relative to potential rent (net of silvicultural rent);

2. Transfers to the private sector: windfall profits plus unrecorded extraction;

3. Discrimination against lesser-known species: high-grading rent for species in well- and lesser-known categories, relative to each category's realized rent.

Figure 2--Rent distribution under an inefficient forest revenue system.



POLICY SIGNIFICANCE

The present time is an opportune moment for discussion leading to improvement of forest revenue systems in Malaysia. The need for revision of current systems is accepted by Malaysian forestry administrators and policy makers. Recent changes implemented by the states indicate a willingness to try new approaches. A comparative assessment of the various systems now in use would provide useful feedback to the states on the strengths and weaknesses of the systems they have begun experimenting with.

The policy significance of the study will depend in large measure on whether parties involved in the forest sector perceive their objectives as being furthered by revenue systems that increase the government's rent capture. We would argue that all parties will benefit in the long run. States will receive increased forest revenue. Industry will enjoy increased supplies of timber, due to decreased rates of logging damage and high-grading, and due to more intensive forest management made possible by increased forest revenue. The Peninsular Malaysia Forestry Department and the State Forestry Offices will see their goal of sustained management of Malaysia's forests advanced. These benefits will only materialize, of course, if government revenue is used efficiently.

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INDICATOR INCREMENT METHOD AND FUNCTIONAL FOREST MANAGEMENT

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ZUSAMMENFASSUNG

Der Beitrag beschreibt die Forsteinrichtungsmethode des Weiserzuwachses, die seit mehr als 2o Jahren auf den gleichaltrigen Hochwald in Rumänien angewendet wird; indem sie bezüglich der Garantierung der Nachhaltigkeit der Ernten für eine Zeitspanne über 4o Jahre verbessert wurde und die funktionelle Betriebsführung der Wälder unmittelbar beeinflusst wurde.

Die Ermittlungsweise des Waldhiebssatzes spezifisch für die Methode des Weiserzuwachses, unabhängig von der vorausgehenden Zuteilung der Bestände auf periodische Flächen, schafft die Bedingungen zur Staffelung des Schlagbetriebes gemäss der inneren Verhältnisse der Bestände und der Regenerations- und Zusammensetzungsverhältnisse jedes Bestandes.

Der ermittelte Hiebssatz stellt die freie, nichtlokalisierte Holzmasse dar, die nicht einer im voraus bestimmten periodischen Fläche entspricht, woraus sie in einer bestimmten Zeitspanne geschlagen werden sollte. Theoretischerweise konnte sie wo auch immer in dem Wald geschlagen werden, wenn alle Bestände hiebsreif sind. In diesem Fall würden die Eingriffe in jedem Bestand der Plenterform sich annähern. Durch diese mannigfaltige Reihe von Eingriffen trägt die Methode des Weiserzuwachses zur wesentlichen Erweiterung der Voraussetzungen für eine funktionelle Betriebsführung der Wälder.

Before the development of the indicator increment method for the Romanian even-aged high forest we applied management methods based on distribution: originally various alternatives of the methods in accordance with working sections (as to volume, to area, permanent, revocable, unique, mixed) and later an alternative of the age class method which still preserved - even in its most advanced form - a number of elements specific for the working sections [5].

The disadvantage of these methods lies in the fact that the determination of the allowable cut and the felling sequence condition each other, forest culture being thus closely connected with regulations specific for the management plan. Even the age class method in the form recommended in the management instructions of 1959 [7] determined the annual allowable cut by dividing the stand volume by the number of years corresponding to the periods under consideration. After regeneration the respective stands would form the first age class. Therefore they had to be cut and regenerated within a certain time period, which was called for by the determination method for the allowable cut. The allowable cut therefore depended on the preliminary distribution of stands on periodical areas and - once determined - implied in its turn the obligation to observe these distributions, thus directly influencing both the felling location and the duration of the regeneration process. But it is known that the general outline and the fixed regeneration periods convenient from the management point of view because they give the possibility to organize the forest on the whole depending on age classes show significant disadvantages from the point of view of the growth conditions. The rather rigid disposition of the periodical areas has been the object of a dispute between forest management and sylviculture [5] since the first methods according to working sections developed. In numberless cases this disposition hindered the differentiation of the management steps according to the stand requirements, the actual regeneration conditions and the structure aims established for each stand. This disadvantage gradually became more prominent, as the stands diversified from the functional point of view, when even on fairly small areas corresponding to a working section or subsection the structures must differ from one stand to another.

Taking into account the above mentioned facts the development of the indicator increment method represents a turning point in the management of even-aged high forests. As a matter of fact, the main premise of the indicator increment method aims at providing a flexible management frame by means of the management plan, corresponding to the implementation of an intensive and differentiated culture according to the established targets. In this respect the method met a requirement which was expressed in the literature long ago [6]: the separation of the allowable cut determination method from the felling sequence in time and space by means of the symultaneous use of the structure according to age and increment. The main idea consists in the fact that the allowable cut determination method - based on the taking into account of the indicator increment and of the actual structure conditions in the forest to be managed - should by no means infringe upon the stand regeneration and tending by strict regulations.

According to the method the allowable cut is determined by means of the formula

$$P = m\, C_i \qquad (1)$$

where:

C_i is the indicator increment defined by CARCEA as being "the current increment of a forest made of stands with the same composition, the same site indices and the same densities as the real ones ,but the age class areas are equal and

m - is a modifying factor which varies from one case to another depending on the structure of the growing stock, whose determination method represents an essential characteristic of the allowable cut determination method specific for the indicator increment method. In principle, its determination is based on the ratio between the actual stand volume that can be cut in certain time intervals and the volume these stands should have, so that the wood continuously harvested each year should equal the indicator increment. In order to simplify the calculations, instead of the volume ratio we used initially the area ratio, which proved to be inadequate in most of the cases [4] . In order to determine this modifying factor the indicator increment method provides different calculation possibilities depending on the forest (with or without fellable stand excess) [2] .

In the case of working blocks without fellable stand excess the following formula is applied in order to determine the allowable cut.

$$P = \rho + \frac{\rho}{V_d} \cdot \frac{\Delta}{2} \qquad (1)$$

where: ρ is the lowest of the ratios V_d : lo, V_1 :2o, V2 :4o; Δ , the difference between total yield increase and main yield increase in the next lo years, for the stands fellable during the first decade, and Vd, V1 and V2 stand for the wood volume that can be harvested during the first decade, during the first 2o years, during the first two 2o year periods.

In the case of working blocks with stands having equal age class areas or an area excess in certain age classes (the ratios V_d : lo C_i; V_1 :2o C_i; V_2 : 4o C_i are either higher or equal to 1) the allowable cut may be either higher or at least equal to the indicator increment (C_i), m being higher or at least equal to 1 (Fig.1).

CARCEA (1986) drew up a new variant of the indicator increment method with changes favourable to an intensive sylviculture that takes into consideration the necessity to extend the period of sustained yield from 4o to 6o years, adapting the allowable cut calculation the requirements of sylvicultural systems with long regeneration period and to the forest functional management [3,9] .

The determination of the forest allowable cut irrespective of the previous distribution of stands on periodical areas offers conditions for regeneration fellings to be carried out only in accordance with internal requirements, with the regeneration and structure conditions characteristic of each stands.The drawing up of a general felling plan is no longer necessary as yield sustention and growing stock normal condition are ensured by the use of the indicator increment itself as a basic element for the determination of the allowable cut. The allowable cut determined represents a free , unlocated volume. This does not mean that harvesting may be done at random, but the lo-year plan of regeneration fellings stipulated in the management plan is drawn up irrespective of the allowable cut determination method. The selection of the stands where the allowable cut of principal yield is to be carried out in the next ten years is done on the basis of their mapping according to felling and regeneration immediacies; the felling rate for each stand is no longer conditioned upon a fixed regeneration period as in the case of age class distribution methods. It is determined differently from stand to stand, according to the regeneration conditions and the final structures adopted, in view of stands performing their functions under optimum conditions. In accordance with these functions and the corresponding optimum structures, both the regeneration periods and the number and nature of interventions may largely differ from stand to stand, from unique clear fellings to fellings typical for the most intensive sylvicultural systems. In this case, the allowable cut need not be harvested from a previously established periodical area in a certain time interval. Practically, the allowable cut can be harvested in any stand where an intervention is necessary, and not only on 1/5 or 1/6 of the forest area. In case of necessity it might be harvested on the whole forest area provided all stands are ripe for felling and special reasons do not call for essential changes in the structure of a certain part of the stands during the first decade. Obviously this example is far-fetched, for in such a case the interventionns in each stand would be quite moderate, similar to selection system . The example was given only to underline the fact that the method leads to a flexible framework, appropriate for a wide range of structures, according to the functions each of the stands should perform. This is exactly how the method of indicator increment contributes to the essential broadening of the premises for the application of a functional forest management ,even when the drawing up of working blocks and sections based on functional criteria is not possible.

Mention should be made of the fact that so far the advantages of the indicator increment method-pointed out both in the chapter on allowable cut determination and in that concerning the sequence of principal yield felling-has not been turned to good account on a large scale in forest management practice [1,5].This advantage should be taken into consideration more and more in the drawing up of plantation plans comprised in the forest management,aiming at a marked differentiation of management steps in accordance with stand functions.

This is called for especially now,under the present conditions of the Romanian economic forestry,when an important intensification of the forest management approach is planned. Suffice it to mention a series of sylvicultural systems with long regeneration periods which promote natural regeneration, the avoidance of soil denudation as a result of felling and subsequently, a small number of clear fellings which are to be applied under special conditions; a 3-7 year period of the cutting area drawing near in order to prevent focusing the felling on slopes.

By eliminating the interdependence between the allowable cut determination method and the felling sequence, the indicator increment method provides the conditions for an adequate solution of these problems. Obviously, in the cases in which the volume of fellable stands under the conditions of intensifying the forest management system becomes a limiting factor, it is necessary to correlate the determined allowable cut and the provisions of the ten year felling plan by means of the management plan in an adequate way.

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A NEW DETERMINATION MODEL FOR THE ALLOWABLE CUT BY MEANS OF THE INDICATOR GROWTH

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In the frame of the indicator growth method, developed for even-aged forests (Carcea 1969a) the allowable cut is determined by means of the formula

$$P = m\,CI,$$

where: CI is the indicator growth and m a modifying factor inferred in relation with the fellable wood volume in the first part of the rotation period.

Some previous IUFRO reports (Carcea 1969b; Carcea, Milescu, Dissescu, 1986) underlined the reference value of the indicator growth, namely the fact that this growth always equals the volume of a normal size cutting area consisting of fellable stands characterized by production conditions equivalent to the average real ones in the elementary unit (stand). This is explained by the fact that CI is determined - for the main stand - in relation with the real compositions, site classes and densities, but taking into account a normal stand distribution according to age class.

The reference value of the indicator growth builds up the premises for the application of numerous calculation variants for the allowable cut, namely premises for the optimization of solutions in relation with any sylvicultural or socio-economic goal. The respective optimization can be achieved by means of the modifying factor m, for whose determination any requirements or restrictions implied by the mentioned goals can and must be taken into account.

Such an adaption of the allowable cut determination method has been lately induced by the application in the Romanian sylviculture of sylvicultural systems with longer regeneration periods and diversified from stand to stand according to their ecological characteristics and to the socio-economic functions they should meet.

Up to now for the determination of the modifying factor in the allowable cut formula, the following retios have been taken into consideration: v_d : 1o C_i; v_1 : 2o C_i; v_2 : 4o C_i, v_d , v_1 and v_2 represent the fellable stand volume in the first 1o, 2o and 4o years respectively (Carcea,1978). In case of some relatively short periods this solution was adequate both from the view point of ensuring a sustained yield and of regeneration.

The application of sylvicultural systems with long regeneration periods (15 - 3o years) brought about the fact that, for the determination of the modifying factor , not the full volume of the fellable stands in the following 1o, 2o, 4o years is taken into calculation, but only the wood volume which could be cut at the respective intervals taking into account the sylvicultural systems to be applied and the duration of the regeneration periods in view (Carcea,1986).

In the sense of the above-mentioned considerations, the mathematical model of the calculation of the allowable cut for the main yield of a production fund in the even-aged forest system is synthetically shown in the relations (1) - (21).

The symbols used in the model have the following significations:

P - volume of the allowable cut for the main yield;

CI - indicator growth of the production fund;

"i" - index of the elementary unit (stand), which is included in the production fund; i = 1 - n; n = number of elementary units included in the production fund;

j - index of the species (stand element); j = 1 - r_i; r_i - number of species which make up the stand in the unit "i";

a - differentiated calculation coefficient in relation with the rotation period (Table 1).

Table 1.

rotation period years	8o	9o	1oo	11o	12o	13o	14o	15o	16o
a	o.651	o.756	o.825	o.867	o.895	o.916	o.931	o.942	o.951

V^c_{ij} - unitary volume of the stand element (species) "j" in the unit, calculated for the ratation age;

c - duration of the adopted period;

s_i - surface of the unit "i";

k_i - closeness of stand index (density) inthe unit "i";

pij - partiapation ratio of the stand element "j" in the unit "i";

VD - wood volume which can be cut in the first decade, taking into account the total fellable stand volume in the respective decade, the adopted sylvicultural system characteristics and the duration of the regeneration period left;

VE - wood volume which can be cut in the first 2o years, taking into account the total fellable stand volume in the respective period, the adopted sylvicultural system characteristics and the duration of the regeneration period left;

VF - wood volume which can be cut in the first 4o years, taking into account the total fellable stand volume in the respective period, the adopted sylvicultural system characteristics and the duration of the regeneration period left;

VG - total fellable stand volume in the first 6o years;

VD1, VD2, VD3, VD4 - fellable stand volume in the first decade, which according to stand condition, sylvicultural system to be applied and duration of the regeneration periods left, could be cut completely, during the following 1o, 2o, 3o and 4o years respectively;

K1, K2, K3, K4 - fellable stand set in the first 1o years, whose wood volume can be cut according to the sylvicultural system characteristics and duration of the regeneration period left, in 1o, 2o, 3o and 4o years respectively;

$\overline{K1}, \overline{K2}, \overline{K3}, \overline{K4}$ - cardinal of the sets K1, K2, K3, K4 ;

V_{ij} - the present volume of the stand element "j" in the unit "i";

V_{ij}^{TA} - volume at the present age (TA) of the stand element "j" in the unit, calculated according to yield tables at the present age (TA);

V_{ij}^{TA+X} - volume at the age (TA+X); (X = 1o,2o,3o,4o,6o years) of the stand element; in the unit "i2 calculated according to the yield tables at the age (TA+X);

E1, E2, E3 - fellable stand set in the first 2o years, whose wood volume can be cut in relation with the sylvicultural system characteristics and the duration of the regeneration period left in 2o , 3o and 4o years respectively;

$\overline{E1}, \overline{E2}, \overline{E3}$ - cardinal of the sets E1, E2, E3;

VE1,VE2,VE3 - fellable stand volume in the first 2o years which, according to stand condition and duration of the regeneration periods left,could be cut in 2o, 3o and 4o years respectively;

F1 - fellable stand set in the first 4o years, whose volumes can be cut in the respective period;

G1 - fellable stand set in the first 6o years, whose volumes could be cut in the respective period;

F1,G1 - cardinal of the sets F1, G1;

C_{ij} - total yield increase in 1o years of the stand element "j" in the unit "i";

C'_{ij} - main yield increase in 1o years of the stand element "j" in the unit "i".

The mathematical formalization of the model are shown in the relations mentioned below:

1) $$P \begin{cases} R \cdot CI \left(1 + \frac{\Delta}{2\,VD}\right) & \text{if } Q < 1 \\ [a + (1 - a)\,Q]\ CI & \text{if } Q \geq 1 \end{cases}$$

2) $$Q = \frac{20 \cdot CI + DM}{20 \cdot CI}$$

3) $$CI = \sum_{i=1}^{n} \sum_{j=1}^{ri} \frac{V_{ij}^{c}\, S_i\, k_i}{c \cdot pij}$$

4) $$DM = \min. \{DD1, DD2, DD3, DD4\}$$

5) $$DD1 = 2 \cdot VD - 20\,CI$$

6) $$DD2 = VE - 20\,CI$$

7) $$DD3 = VF - 40\,CI$$

8) $$DD4 = VG - 60\,CI$$

9) $$R = \min \left\{ \frac{VD}{10\,CI} ; \frac{VE}{20\,CI} ; \frac{VF}{40\,CI} ; \frac{VG}{60\,CI} \right\}$$

10) $$\Delta = \sum_{i=1}^{\overline{k}} \sum_{j=1}^{ri} \left(C_{ij} - C'_{ij}\right)$$

11) $$VD = 10 \left(\frac{VD1}{10} + \frac{VD2}{20} + \frac{VD3}{30} + \frac{VD4}{40} \right)$$

12) $$VD1 = \sum_{i=1}^{\overline{k1}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+10} - V_{ij}^{TA}}{2} \right)$$

13) $$VD2 = \sum_{i=1}^{\overline{k2}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+20} - V_{ij}^{TA}}{2} \right)$$

14) $$VD3 = \sum_{i=1}^{\overline{k3}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+30} - V_{ij}^{TA}}{2} \right)$$

15) $$VD4 = \sum_{i=1}^{K4} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+40} - V_{ij}^{TA}}{2} \right)$$

16) $$VE = 20 \left(\frac{VE1}{20} + \frac{VE2}{30} + \frac{VE3}{40} \right)$$

17) $$VE1 = \sum_{i=1}^{\overline{E1}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+20} - V_{ij}^{TA}}{2} \right)$$

18) $$VE2 = \sum_{i=1}^{\overline{E2}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+30} - V_{ij}^{TA}}{2} \right)$$

19) $$VE3 = \sum_{i=1}^{\overline{E3}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+40} - V_{ij}^{TA}}{2} \right)$$

20) $$VF = \sum_{i=1}^{\overline{F1}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+40} - V_{ij}^{TA}}{2} \right)$$

21) $$VG = \sum_{i=1}^{\overline{G1}} \sum_{j=1}^{ri} \left(V_{ij} + \frac{V_{ij}^{TA+60} - V_{ij}^{TA}}{2} \right)$$

Based on this model calculation programmes were elaborated and widely applied in the forest managemant in Romania. In order to compare the results the official technical regulations allow the parallel utilization of other calculation methods, as for example those based on age classes. Of course, the comparison is useful mainly if in the case of the respective calculation methods the necessity to ensure sustained wood crops as well as other ecological and sylvicultural requirements are similarly taken into account.

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