YIELD AND ECONOMICS OF THINNING ALTERNATIVES

APPLIED TO *Pinus patula* STANDS

IN PUEBLA, MEXICO

By

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1. INTRODUCTION

Economic evaluation of forest management alternatives is essential to determine the most appropriate silvicultural management regimes to follow when managing a stand or a forest. This is particularly true when the forest owner's main goal is to maximize all future net revenues resulting from a forest production process. Such gains can be accounted in terms of utility, satisfaction, or in monetary units. Because some combinations of silvicultural practices applied to a stand may result in better economic gains that common practice forest management, any new management strategy must be evaluated under economic criteria (Solberg, 1991).

The history of forest activity demonstrates that new management practices are undertaken by forest managers only if an increase in wealth or gains is achieved when compared with existing practices. Borders *et al.* (1991) statement, "stand management decisions should be based on economic considerations for profit-oriented organizations and individuals", is a reflection of this view.

In Mexico, a lack of information regarding the most appropriate management strategies is the rule, rather than the exception. This can be explained, in part, by the limited accumulation of knowledge on basic quantitative information on the dynamics of growth of the species under management, as well as a lack of published information on costs and prices associated with management. For most species it is difficult to find growth and yield models that predict physical production at the stand level. When available, models are often too general to make accurate predictions at a regional level.

Current management strategies being carried out in the primary-production element of the forest sector, in most of the cases, are not subject to formal economic evaluations. It is also true that forest managers take into account their empirical knowledge about the economic implications when making decisions about the forest plans. However, no formal studies support the decisions they make. Consequently, mistakes made in the past are not necessarily avoided later because evidence from past decisions is not documented. The reverse is true when adequate decisions are made.

Even though most of the problems mentioned above apply to the present study, an effort was made to compile and generate the necessary minimum information required to use standard tools of economic analysis and utilize preliminary insights regarding the effects of thinning alternatives applied to natural stands.

An economic analysis of thinning alternatives for the region is justifiable for several reasons. First, most of the region's stumpage entering the market is in the form of sawlogs, which might be augmented in quantity and quality through proper thinning. Consequently, this would result in greater economic gains. Second, a growing industry that uses small logs to make pallets and boxes exists in the region. This creates a better price for small logs than the traditional use as fuelwood. Additionally, very small material up to 2.5 cm in diameter can be sold as fuelwood for domestic use, bakeries or public baths, which use a considerable amount of this wood product. The broad picture of the region, in addition to the fast growth of patula pine (*Pinus patula)* indicated that management alternatives that include thinning might be substantially better than the existing practice.

The purpose of this study is to analyze the economic implications of different thinning intensities applied to two natural even-aged stands of patula pine in the Chingnahuapan-Zacatlan , Pue., region of Mexico. The main question to be answered is whether financial returns are improved by thinning in natural stands of patula pine.

1.1. Objectives

- To fit growth and yield models to project the subsequent development of thinned and unthinned stands of *Pinus patula* as a prerequisite to carry out an economic evaluation.

- To evaluate the economic impact of different thinning alternatives in the production process of natural even-aged stands of *Pinus patula*, throughout the use of standard tools of forestry economics.

- To determine the economically optimal harvesting time for the stands under different thinning treatments considering the flow of timber products and costs incurred during one rotation.

2. LITERATURE REVIEW

2.1. Economic importance of thinning as a silvicultural practice and earlier findings from economic analysis

Thinning is considered one of the most important intermediate silvicultural practices in a silvicultural system, especially when the production's objective is sawtimber or veneer (De los Santos-Posadas *et al.*, 1995). Its direct main objective is to increase the overall yield of primary forest products per unit of area and to improve its quality (Dobie, 1978). Indirectly, and as a final goal, thinnings are applied to increase the net value of forest production at time of final harvest. This is accomplished by concentrating production on trees of greater value, by capturing mortality, reducing the rotation period, and by generating monetary returns early in the production process. These early gains lighten the financial burden of carrying costs on the stand's capital and compounded regeneration cost (Kellogg and Olsen, 1988). Under general economic principles, thinning should be applied to stands only if by doing so the output of such activity increases the level of wealth, net revenue, satisfaction, or of any other unit of account that allow forest owners to compare with the no-thinning alternative.

Past results from economic analysis of thinnings have shown both positive and negative, net gains. Earlier studies such as the one conducted by Worthington and Fedkiw (1964) in Western Washington (USA) observed an economic superiority of thinning over no-thinning alternatives. They found that managing 45 to 55-year-old Douglas-fir stands with thinning increased total net income after taxes by 3.6% when compared with unthinned stands. This increase was attributable to salvage of mortality through light, frequent thinnings applied to high quality stands (site index of 180 and 170 ft, no base age was reported) laying over gentle to medium sloped terrain. These authors also found that thinning promised a internal rate of return (IRR) of 5% assuming a gradual 50% increase in stumpage price, and a 3% IRR when constant prices were considered. The 5% IRR was clearly superior to the hurdle rate of 3.5% used in the analysis. They also mentioned that stands of more than 70 years of age did not respond efficiently to thinning. In a more extensive study, Chappelle and Nelson (1964) found both, economic advantages and disadvantages resulting from several thinning alternatives, given a set of economic conditions (prices, costs, and interest rate), stocking levels, and site indexes. Unfortunately, these authors did not mention the specific conditions under which the analysis was carried out.

In 1978, Dobie and Wright concluded from a combined thinning-pruning study that even though thinning did not increase tree rate growth, it did reduce mortality and increase merchantable volume growth over a 20 year period when compared with a control plot. Consequently, positive net gains resulted from the thinning.

Later, LeDoux and Brodie (1982) demonstrated that using the most efficient harvesting machinery available to carry out thinnings in Douglas fir on mountainous terrain, led to increments of 19.2% in cumulative soil expectation value and 3.2% in mean annual volume per acre at final harvest. They also reported that at final harvest, precommercial thinning resulted in increases of 2.2% in volume and 93% in soil expectation value over values for stands not precommercially thinned. These results were attributed to the increased gross value of products manufactured from larger trees and to increased efficiency of harvesting and processing larger logs. An interest rate of 3% was used to discount the cash flows in the study.

Kellog and Olsen (1988), analyzed the thinning impacts on the financial returns of two 32 year-old precommercially thinned western hemlock-sitka spruce stands in the Pacific Northwest of the United States. Their main finding was that the best management strategy for the species was to clearcut the stand at the rotation age (70 years) without an intermediate thinning. The conclusion was attributed to the expensive skyline logging systems required to carry out the thinning operations because the steep terrain and to environmental concerns, which produced a negative cash flow that was not offset by the harvest benefits. They noted that present net worth (PNW), calculated using a 4% discount rate, was negative at thinning age for all treatments but the control. They also observed that at the age of harvest the no-thinning alternative had the highest PNW. The best thinning treatment had a PNW value 27% lower than the control. A sensitivity analysis carried out by varying the base assumptions (harvest cost, price of logs, interest rate, and rotation age) did not change the outcome. These authors mentioned that if several thinning entries had been evaluated, harvesting costs would have been higher and that thinning in older stands often result in less favorable growth response. Therefore, they concluded that hemlock-sitka spruce stands develop adequately to rotation age without need of being thin, but by controlling the density with precommercial thinning. Site index for this study was 117 ft at base age of 50 years.

Franklin *et al.*, (1990) conducted a study to determine single thinning-harvest regimes that maximize net present value (NPV) of stumpage for yellow-poplar. Wide ranges of initial stand age (30 to 60), site quality (90 to 130 at base age 50), and stocking (100 to 200 ft^2) were evaluated at 5 and 10% discount rates. Using a computerized stand development model, they found that using a 5% discount rate net present value was maximized by thinning in most regimes. At a 10% discount rate thinning was optimal only at initial age of 30 years on the highest quality sites and initial stocking. They also found that "lower initial ages, high initial stocking, and higher site index favored thinning over clearcutting", and that high discount rates have the opposite effect. The major sensitivity was found in the discount rate and initial age.

More recently, Rollins *et al.* (1995) indicated that an experimental improvement cut applied to release understory white pine in Cartier Lake, Ontario (Canada), significantly increased the present value of net returns per hectare from treated stands when compared to control stands (without the release cut). Gains in increment were attributed, in part, to the fact that release costs occurred until the stand was 55 years old, which prevent them from substantially offsetting benefits at harvest age. The authors concluded that results from this type of studies are extremely sensitive to interest rate in an inverse way.

No reported experiences on the economics of thinning were found for patula pine in the Mexican literature. Morales (1991) reported the only source that included the financial component in an analysis of thinning. Such study was on the establishment of a thinning study for *Pinus arizonica*. Unfortunately no final results have been published.

The examples above presented are a good representation of the conclusions reached in past economic studies of thinning. It is not necessary to indicate other experiences to realize that the economic feasibility of applying thinnings can not be defined by extrapolating past results, or by following preestablished rules of thumb; but only by evaluating each and every case of interest. Thus, to identify thinning regimes of maximum financial yield, managers must consider not only the length of rotation, timing entries and volume removals, but also the proper harvest equipment, precommercial and commercial treatments, and economic factors. Readers interested in reviewing other study cases on this matter might refer to Stokes (1992) who presents an annotated bibliography concerning thinning studies. The following paragraphs briefly present the most important factors that define the profitability of thinning regimes

2.2. Factors that influence economic analysis outcomes

As mentioned above, the biological, technical, and economic assumptions held when carrying out the analysis, as well as the production objectives are the most important factors defining the outcomes (Sutherland, 1968; Dobie and Wright, 1978; Klemperer, 1996). Clutter *et al.* (1981) in their economic analysis to compare the outcomes of thinned versus unthinned old-field slash pine plantations, suggested that management recommendations regarding the use of thinning as a silvicultural practice are not definitive, but strongly tied and dependent to specific economic situations.

Klemperer (1996) give examples of several physical and economic factors that, if varied, will change the results of an evaluation of alternative regimes. As physical factors he mentions species and type of growth model used, site quality, original stand density and type of thinning. Among the economic factors the examples given are discount rate, current and projected stumpage values, and logging costs.

Broderick *et al.* (1982) carried out a study on the economic evaluation of old-field loblolly pine plantation management alternatives. In their report, they concluded that "changes in economic assumptions often cause large variations in present values but generally brought little change in the optimal management alternative". They also concluded, from a sensitivity analysis, that the optimal rotations were shortened as the real interest rate was increased from 4 to 10%, and that no changes in the optimal rotations were seen when a substantial increase in the price of all products was simulated. The same authors suggested that the results of this kind of studies are defined by the particular situations of the forest and time of analysis.

Chang (1983) developed a similar but more analytical study and concluded that the impacts of changes in management intensity and economic factors are "far from cut and dried". He stated that with the exception of site preparation cost, changes in any other parameter can always lead to the possibility of uncertain results. Later in 1990, Eng *et al.* reported that variation of soil expectation value was sensitive to interest rate and prices, but not to taxes.

According to Rose *et al.* (1988), the discount rate used has a "tremendous effect on the financial analysis results". It varies from one investor to another and is a function of his needs, wants and alternatives. Thuesen and Fabrycky (1989) argued that each investor must decide on the appropriate rate to discount cash flows of a project after taking into account his investment policy and profit related objectives, which depend on how he sees or foresees the business opportunities, associated risk, and his own financial situation. Thus, for example, investors that own a highly vertically integrated enterprise will apply a different discount rate than others that have an investment that is their only source of income or profit.

2.3. Information needed to evaluate thinning alternatives

In general, three types of information are indispensable to develop economic analysis of thinning: (1) Stand growth and yield responses to thinning alternatives, more specifically, estimates of merchantable timber volumes for each year through the stand's life. (2) Market prices and future demand for timber forest products resulting from the management course of action followed, and (3) Costs associated with thinning under various stand conditions and machinery used.

Growth and yield models are tools that help managers make management decisions for at least three reasons, (1) allow to forecast production and consequently to optimize forest harvest, (2) allow to evaluate alternative management regimes or treatments, and (3) can be used as a way to control yield (Aguirre-Bravo, 1985). Thus, adequate forest management of a given species can not be fully achieved without such important tools.

When making economic decisions it is necessary to take into account all the benefits and costs throughout the whole management rotation period in order to select the best management alternative. Generally speaking, the information needs fall into five broad categories: administrative costs, treatments or intermediate labor costs and revenues, harvest cost and benefits; stand growth and yield at different points in time, and financial parameters such as discount rate, risk premium, inflation rate, prices of wood and other goods produced, among others. Usually information on costs is known, but great deal of uncertainty surrounds future yields and benefits.

Despite this uncertainty, forest managers must attempt to estimate volume and value impacts of proposed silvicultural treatment methods. Commonly, researchers and managers use computer models to simulate stand growth and yield. Once the simulated physical yield (forest products) estimates are known, they are transformed into their monetary value in order to know their associated costs and benefits. When no available simulators exist, growth curves or equations are used instead.

2.4. Decision making process to select optimal management alternatives

The objective of this part of the literature review is to describe how the concepts of the basic decision making process have been applied to select the best management alternative for forest stands. Throughout its development, the steps of the decision making process will be briefly stated and comments will be made on the special case of choosing thinning alternatives for pine species. Most of the comments will be derived and supported in the literature reviewed.

When making decisions at least five basic steps must be sequentially identified and/or developed: definition of the problem, establishment of objectives, identification of possible solutions, selection of the best alternative, and finally its implementation (Rose *et al.*, 1988). Making silvicultural management decisions depends on the landowners' management objectives, the biologically possible management alternatives, and the economic costs and returns for the investment. One approach that can help forest managers to make better decisions is economic analysis, which is founded in economic models. A general description of this approach is presented in the subsequent paragraphs.

Defining the problem

Frequently, forest managers and landowners face the need to define the management regime to apply to a certain type of forest. To make such a decision is not easy because of the number of available and feasible alternatives. In a simple case, the problem faced could be to decide between using one of a reduced number of alternative management regimes (as is the case in the present study) to select the best thinning alternative. In a more general and difficult situation, alternatives within all the variety of possible regimes (several initial stocking densities, thinning intensities and timings, and time to final harvest) could be the case to solve. This latter situation is the one that provides better results and often occurs in the real world. A major disadvantage of this case is that complete and sophisticated physical growth and yield models are required, which often do not exist for some species. However, an effort must be made to collect all information and tools needed since a good application of the process of making decisions mandates that all options must be considered if the best alternative is going to be chosen (Willis and Affleck, 1990).

On this matter, Davis and Johnson (1987) mentioned that problem identification is an art that improves with experience and requires imagination. They also mentioned that by practicing and making consistent and careful use of procedures, concepts, and terminology skills and performance may be increased to achieve professional competence.

Specifying manager's objectives

The second step to consider when approaching a decision making problem is to define carefully the forest manager or landowner's objective(s). Clearly definition of the landowners objectives will help to simplify the decision making problem by establishing the link between objectives and the potential alternatives (Rose *et al.*, 1988). Suppose the objective is to manage the forest while minimizing costs or maximizing returns along the rotation period to produce timber, rather than to maximize aesthetic values to "produce" recreation opportunities. Then the management alternatives will differ and the number of alternatives will be less once the objective has been defined. Also, if the landowner wants to minimize risk during the forest production process, instead of minimizing costs, the feasible alternatives will decrease even more (Straka and Hotvedt, 1985).

For the case here reviewed it is assumed that the objective is to manage patula pine stands to maximize the net returns at the end of the rotation period, using ecologically sound management alternatives.

Because the selected management regime implies costs and benefits that will influence the output (return) at the end of the rotation period, its comparative analysis must be carried out with data from the establishment of the forest (regeneration) and until the stand is harvested. In other words, it is necessary to consider all the activities developed throughout the whole management regime to observe concluding results.

Identifying management alternatives

Once the problem has been defined and the objective(s) have been clearly stated, the next step is to construct and identify feasible management alternatives or solutions given the prevailing circumstances. In a first glance all biological and legally possible management regimes for the species and site conditions might appear adequate alternatives to the managers. However, some options can be easily eliminated due to their clear inapplicability. In fact, it is impractical to evaluate an extremely large number of alternatives individually, which makes necessary to narrow down the list to a manageable few (Rose *et al.*, 1988). For instance, less intensive management regimes could be better for non industrial private forest (NIPF) landowners because their willingness to spend money in this kind of activities is limited. More intensive regimes could be a better option for industrial landowners because of their need for management regimes that insure a constant supply of raw materials for their manufacturing facilities.

All alternatives considered up to this point in the decision-making process must be in complete agreement with the objectives initially defined. Each alternative must lead to choices and consequences later in the production cycle that are consistent with the over all objectives. To help forest managers to select appropriate options from the multiple choices, an analytical approach based on economic criteria may be used.

A schematic diagram displaying the optional paths from project initiation to completition may be helpful to the forest manager. It ensures that he/she pays attention to all stand treatments throughout the rotation and, at the same time, it assists in defining costs and benefits (returns), and to evaluate uncertainty through the use of probabilities (Willis and

Affleck, 1990). If all possible alternatives are considered, a very complex diagram (also called decision tree) will be built , which would be extremely difficult to analyze due the great amount of information required. The already discussed necessity of carefully defining the management objectives is an aid to help the manager to save a great deal of effort and unfruitful analysis.

Efficiency criteria to evaluate management alternatives

Making valid the assumption that forest managers treat stands (which represent a way of holding wealth or capital) in the same way they would treat any other productive capital, a rational criterion to guide economic efficiency should imply that no capital should remain in, or be added to the forest unless it earns at least as much as the owner's minimal acceptable rate of return (MAR) (Fedkiw and Yoho, 1960; Broderick *et al.*, 1982). This approach is adequate to evaluate silvicultural strategies due to the way trees grow. Experience indicates that trees grow physically, and consequently in value, at a higher rate in their early ages, after that, they steadily slow down their growth rate up to a point beyond which decay follows. Thus, at a certain point in tree's life, the capital they represent would grow better if invested in an alternative project (Klemperer, 1996).

Under this concept, it is possible to know at any given point in time how efficient a certain management alternative (silvicultural practice or regime) is with respect to the manager's feasible best investment alternative with a similar risk to the one being evaluated (MAR).

The MAR, also called guiding or alternative rate of return, is crucial to the manager when making decisions. The fact that it represents the opportunity cost (marginal input cost) associated with sacrificed feasible investment opportunities, allows forest managers to find the point in time (if time is considered and input) where a given management alternative reaches its maximum return. Analyses of this type allow managers to improve their financial situation by shifting any capital with prospective rate of return less than the MAR into better ventures or investments (Fedkiw and Yoho, 1960). The point of maximum returns is identified by observing the point in time where marginal input cost (MIC) equals marginal revenue product (MRP). More specifically, for forest investments, by observing the condition where the MAR (the interest on the standing stock and forest land value) equals the rate of value growth of the stand given a management strategy. Identifying points where MIC equals MRP for all management strategies of interest allows the manager to select the overall best or optimal management alternative, in other words, the alternative that results in the maximum returns to the owner.

For a explanation regarding why MIC and MRP should be used, instead of the most commonly used terms of marginal cost and marginal revenue see Chang (1984). Briefly, Chang argues that by definition, marginal revenue refers to a change in total revenue given a unit change in total output, by contrast, marginal revenue product means a change in total revenue given a unitary change in input. Thus, he stated, because time is an input of the timber production process, rather than an output, it should be labeled as MRP.

As expressed above, an equivalent decision regarding the optimal regime can be made if the optimal management alternative is defined as the one that maximizes a measure of net present value of all costs and returns while using the MAR as the discount rate (Figure 1). This is true because net present value is maximized when all the opportunities for adding or maintaining capital that can earn more than the MAR have been considered (Borderick *et al.*, 1982; Klemperer, 1996).

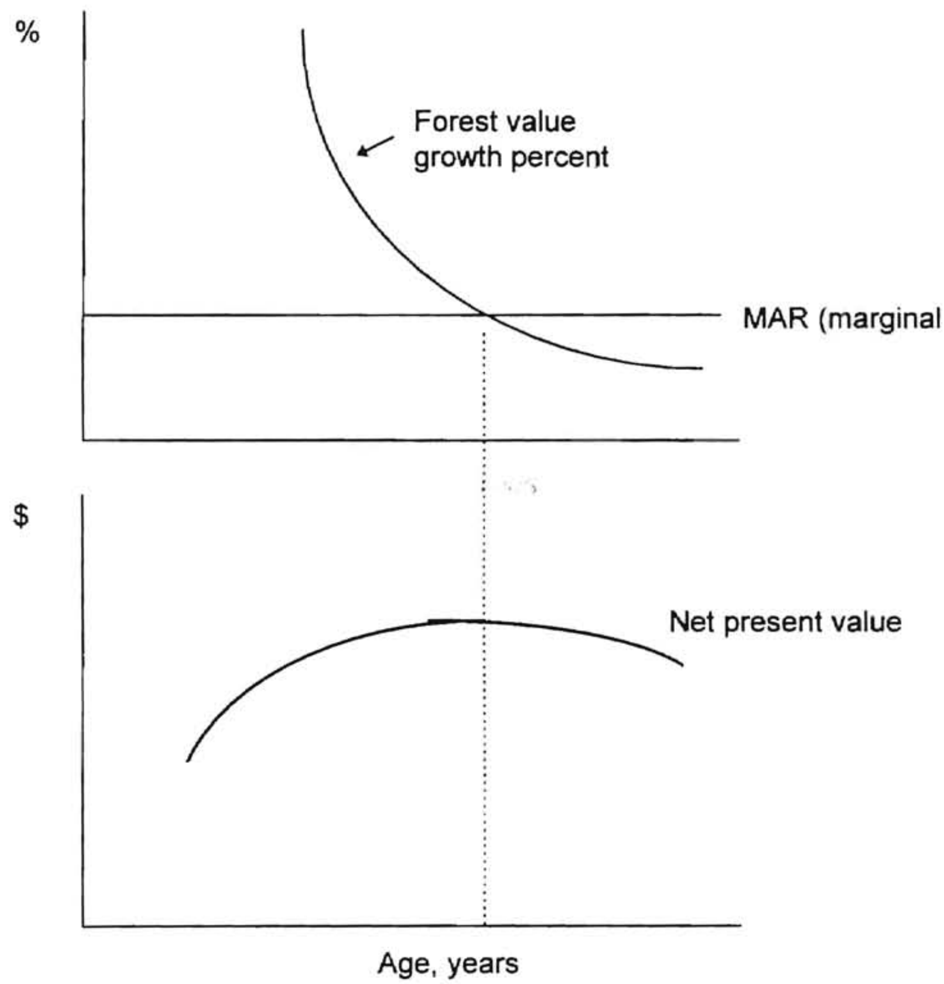

Figure 1. Equivalent criteria to define optimal management alternatives.

Summarizing, efficient or optimum management alternatives are those which maximize net present value, or any other desired unit of account, under a given set of biological and economical conditions. Indeed, the equivalent criteria mentioned above (although with many variants in the way net present values are calculated out) are the ones mostly used by forest managers to identify optimal regimes from management alternatives. The next section presents some of the models developed to help managers when making decisions.

2.5. Economic models to evaluate management alternatives

Before reviewing the economic models, general assumptions must be defined to clarify the conditions under which the models work. The first basic assumption, which has its roots in the theory of consumer behavior, is that rational individuals (common, "rational" people) always try to maximize their utility from a limited budget and/or wealth. Utility, in this sense, is measured in monetary terms, however, other units could be used such as "units of happiness", biodiversity conserved, satisfaction, etc.. The disadvantage of using alternative units rather than monetary ones is that the former are neither well understood nor accepted with equal value for all the people --their value is extremely subjective and varies greatly from one person to another. A second assumption is that the capital market is perfect, which means that any amount of money can be borrowed or lent at a preestablished interest rate. Third, the outcomes of management alternatives (physical and value growth and yield) can be predicted or known with certainty (Hirshleifer, 1970).

Economic analysis of intermediate silvicultural practices requires a considerable amount of economic and biological information. This complicates the analysis if compared, for instance, with the procedure followed to find the optimal rotation where regeneration and harvest are the only silvicultural practices. However, the concept and procedure is basically the same. As Bentley and Teeguarden (1965) argued, explicit introduction of preharvest costs and returns complicate the models (especially when presented graphically) without altering the conclusions. Thus, most papers that discuss forest optimal rotation definition highlight the importance of marginal principles (such as the efficiency criterion reviewed in the former section of this paper) when discussing the subject (Newman, 1988; Gong, 1991). At the same time they simplify the problem by stating the assumptions mentioned.

A considerable number of papers accumulated in the last century describe extensively both biological and economical models to evaluate management alternatives. Detailed discussions of various models can be found in Bentley and Teeguarden (1965), Duerr (1960), Lewis (1976), Chang (1984), Newman (1988), and Gong (1991). Simplified presentations are found in most forest management and forestry economics books such as Duerr (1993) and Klemperer (1996), therefore they are not presented in detail here. Only the models considered more relevant given the current economic conditions will be briefly presented. Net present value and land expectation value are first presented to pave the way for the willingness to pay for the bare land model. Later, models such as the internal rate of return (IRR), equivalent annual income (EAI), and present certainty equivalent of attained wealth and wealth gain, which account for the financial performance of investments are reviewed.

Net present value model.

The net present value or worth model (NPV) is also known as the Thunen-Wicksell rotation model when used to define the rotation (Duerr, 1960; Chang, 1984; and Gong, 1991). It defines the stand age at which its the net present value (NPV) is maximized. Such maximization occurs when the marginal value growth rate of the stand equals the MAR. Mathematically the model can be expressed as follows.

$$NPV = \sum_{y=0}^{t} \frac{R_y}{(1+r)^y} - \sum_{y=0}^{t} \frac{C_y}{(1+r)^y}$$

when R_y = revenue in year y, \$/ha
C_y = cost in year y, \$/ha
r = real interest rate, %/100
t = rotation or harvest age
y = index for years from 0 to t.

The main disadvantage of the PNV model is that it does not consider the cost associated with using the land in the production process. In other words, the opportunity cost of utilizing the land is neglected. Because both, the value of the stumpage and the value of the land under it have value, the opportunity cost of keeping the trees growing is not only the interest cost on the value of the stumpage value, but also on the land value.

Land expectation value model.

In 1849, Faustmann conceptualized the optimal decision rule that allows forest managers to identify the maximum discounted net returns from a given management strategy. The land expectation value (LEV), also known as the soil rent, soil expectation value, or Faustmann model is the most widely accepted model among foresters. Traditionally LEV has been used to select the optimal rotation age, but its usefulness do not end there, it can also be used to define optimal management alternatives by choosing the management strategy that maximizes its net value, or as the intent of the present study, to evaluate given management strategies.

Since its original proposal in 1849 the LEV model has been modified in several ways to make it more adequate and accurate to evaluate forest management alternatives under different assumptions or scenarios. Also, to make it more acceptable by forest practitioners. Thus, other models are simply special cases of the LEV model (Chang, 1984).

The reason of its better acceptance among foresters is because it overcomes the main disadvantage of the NPV model by treating land as a variable and assuming that it can be retained for its present use (grow trees), turned to a new stand, or sold for alternative uses. Mathematically LEV is defined as follows.

$$\mathrm{LEV} = \frac{\sum_{y=0}^{t} R_y (1+r)^{t-y} - \sum_{y=0}^{t} C_y (1+r)^{t-y}}{(1+r)^t - 1} + \frac{a-c}{r}$$

when R_y = revenue in year y, \$/ha
C_y = cost in year y, \$/ha
r = real interest rate, %/100
t = rotation or harvest age
y = index for years from 0 to t.
a = equal annual revenue or return, \$/ha
c = equal annual cost, \$/ha.

As indicated by the denominator of the right side of LEV equation, the model assumes that the forest activities in the stand being modeled will continue forever. Such an assumption appears to be desirable because it allows NPV to be defined and maximized for current and future production processes. However, even though it agrees with most current views regarding sustainable forestry and it is understandable for some public agencies, the dynamics that characterize investments and the evolution of forest management practices do not fit well under such a scheme of discounting cash flows. Capital movements among geographical places are becoming more feasible for forest investors, which makes it reasonable to believe that forest owners could change the land use or sell it before or after harvest. At least, it should be an alternative action to consider when making decisions under economic criteria. This way of thinking applies even to large well established forest firms, which are active buying and selling land nationally and internationally (Klemperer, 1996). Additionally forest management is constantly improving, which makes the scope of the yield models inadequate to model at infinity.

Willingness to pay for the bare land

As a response to current investment conditions, Klemperer (1996) combined the principles of the former models and presented and adaptation of the LEV model; the willingness to pay for the bare land (WPL). This model takes into account the possibility of selling the land after harvest and discounts the flow cash at only one production cycle (rotation). Klemperer renamed the LEV model as the willingness to pay for the bare land (WPL) to make it more descriptive, considering that the land can be sold, and to distinguish it from models that account for infinite production processes. Mathematically WPL is defined below.

$$WPL = \sum_{y=0}^{t} \frac{R_y}{(1+r)^y} - \sum_{y=0}^{t} \frac{C_y}{(1+r)^y} + \frac{L_t}{(1+r)^t} - C_0 + \frac{(a+c)[1-(1+r)^{-t}]}{r}$$

when R_y = revenue in year y, \$/ha
C_y = cost in year y, \$/ha
r = real interest rate, %/100
t = rotation or harvest age
y = index for years from 0 to t.
a = equal annual revenue or return, \$/ha
c = equal annual cost, \$/ha.
C_o = the regeneration cost
L_t = land value at year t.

As Klemperer (1996) emphasizes, the land value term is shown separately to emphasize the importance of including the land value.

In addition to the models presented above, others have been developed. For instance, Jonsson and Jonsson (1992) defined the optimal harvesting time for a given management strategy as the time when the net revenue on the stumpage value equals the cost of renting the land ("land use cost") minus the change in land value. The specific model to use depends upon the manager's goals and objectives, as well as upon the set of economical and political conditions prevailing in the economy or region.

Value growth rate

Value growth rate (VGR) is also called internal rate of return (IRR). It can be defined, in the particular case of evaluating thinning regimes, as the "interest rate at which the present value of future returns just balances the initial investment in growing stock" (Jiing-Shyang and Buongiorno, 1997). More commonly, VGR or IRR is defined as the interest rate that results in a zero net present value. It is a measure of the rate of growth of the capital invested in a project. Mathematically VGR is derived from a net present value equation (NPV_L) that represents the return to the land for a defined period of time.

$$NPV_L = 0$$

$$NPV_L = \frac{V_t}{(1+r)^t} + \frac{H_y}{(1+r)^y} - V_0 = 0$$

when r = **value growth rate**, which must be computed by trial and error procedures when NPV = 0
V_t = value of the stand at the end of the analysis period, year t
V_o = value of the stand at the beginning of the analysis period, year 0
H_y = harvest value at any year, y, between years 0 and t.

Under this criterion regimes with the highest VGR should be preferred. An apparent disadvantage of the VGR criterion is that it tells nothing about the efficiency of the growing stock per unit of area (stand), which makes it a poor indicator of financial performance (Jiing-Shyang and Buongiorno, 1997). The term "apparent" is used because contrary opinions exist on the matter. Klemperer (1996) argues that "annual growth rate per acre in volume or value is much less important that knowing this value as a percent of the total forest value per acre".

A simplified way of calculating the VGR of a stand is through the compounded annual rate of value change. This simplification is useful when no silvicultural labors or cash flows occur during the period between the beginning and final times of analysis (Gansner *et al.*, 1990; Klemperer, 1996). Thus,

$$VGR = \sqrt[t]{\frac{FV}{PV}} - 1$$

when FV = value of stand (no land) at year t
PV = value of stand at year 0
t = number of years since year 0.

Equivalent annual income

In a comparative study, Jiing-Shyang and Buongiorno (1997) stated that, "value growth rates [such as VGR] are useful for determining which trees or stands are growing too slow, relative to a guiding rate of return; but they can not decide the best levels and composition of the growing stock". They argued that a high rate of return does not mean much if it occurs, for instance, in an under-stocked stand. Through an example these authors demonstrated the disadvantages of using the VGR over the so called equivalent annual income (EAI) to evaluate the financial performance of stands with different stocking levels. EAI offsets the disadvantage of the VGR criterion. It can be defined as follows (Duerr, 1960).

$$EAI = NPV_L * \frac{r(1+r)^t}{(1+r)^t - 1}$$

when NPV_L = net present value obtained from a land unit between two periods of time. As defined above.
r = given discount rate
t = number of years since year 0.

EAI can be interpreted as the average annual rent a stand earns in a given period of time. It is equivalent to NPV_L, if computed for the same period times the number of years involved. If managers want to maximize returns, the regimes with the highest value of EAI must be selected.

A pointed drawback of the foregoing proposals to carry out economic efficiency analysis is that efficiency, as it is estimated, plays an important role in the decision making process only at harvesting age, and not along the whole production period, which inserts bias to the decision making process (Lewis, 1985). Additionally, models such as NPV, LEV, and WPL assume that positive cash flows that result from the application of intermediate silvicultural practices, such as thinning, are reinvested, which is not a true representation of the investment behavior of most forest investors in Mexico. Ejido members (which own 80% of the Mexican forest lands) are characterized by having a high time preference. They consume much of the gains that results from thinning Next, alternative criteria proposed by Lewis (1976) are presented.

Present certainty equivalent value of attained wealth and wealth gain

Lewis (1976) reviewed theoretical and empirical studies on the analysis of forest investments and concluded that "in general, the application of present value criteria as formulated [up to that date] in these studies can not be expected to define an optimum investment ensemble for timber production ...". He argued that economic criteria to evaluate stand treatments such as NPV, LEV, WPL, EAI, etc., which are all based in cash flows ignore the basic constraint related to investment: the stock of wealth; using instead an income constraint. Wealth is a measure of the individual's items or belongings that represent his/her consumption opportunities now or in the future.

Going further in his analysis, Lewis (1985) argued that if investment analysis are based only on criteria that discount cash flows biased decisions might be made due to the fact that growing stock efficiency (value growth rate) is not properly evaluated. He mentioned that such bias is introduced because cash flow based criteria do not recognize, properly, the value of wealth gains at the moment they are created. On the contrary, when this methods are used, wealth gains are recognized until harvest age.

This failure leads to underestimation of the real value of wealth gains when discounted or represented in units of current consumption.

Elaborating on this, Lewis (1985) mentioned that "the potential opportunity for consumption is created continuously during the period since investment". Therefore it could be implied that explicit consideration of investment efficiency along the whole life of the investment might lead to better decisions, at least to better informed ones.

After stating other shortcomings of the way those criteria were applied, Lewis (1976) proposed "refined" criteria to carry out economic analysis of stand management alternatives, which, he argued, are more consistent with the fundamental economic principles of consumer choice. Among other equivalent criteria Lewis (1985) proposed present certainty equivalent of attained wealth (PAW) and wealth gain (PWG) as the criteria and their maximization as the decision rule to determine the best and or optimal management alternative. General formulas for these criteria are defined below:

$$PAW = \sum_{t=0}^{m} \sum_{i=1}^{n} \frac{P_{it} * Q_{it}}{(1+r)^{t}}$$

when PAW = present certainty equivalent of attained wealth
P = price of good i in period j
Q = amount of good i in period j
i = an index for goods; i = 1 to n
t = an index for years or periods; t = 0 to m
r = discount rate.

$$PWG = \sum_{t=0}^{m} \sum_{i=1}^{n} \frac{P_{it} * Q_{it}}{(1+r)^{t}} - W_0$$

where PWG = present certainty equivalent of wealth gain
P, Q, i, t, r, as defined above

$$W_0 = \text{initial wealth (endowment)} = \sum_{i=1}^{n} P_i * Q_i \text{ , in year zero.}$$

Maximum values of either PAW or PWG associated to specific management strategies might be used to define the economic harvest age for a particular stand type. Comparing maximum PAW values among all possible management strategies allows to define the over all best thinning regime, the one that maximizes attained wealth. For a detailed analysis of this criterion see Lewis (1976, 1985).

In this study PAW was selected to define the best thinning regime tested because it is well known that the main goal of the forest practice in Mexico is to maximize the wealth gains of all future net revenues resulting from pre-established management regimes. Goal that is unambiguously defined and consistent with the theory of investment choice when the alternative of maximum PAW value is chosen (Lewis, 1985). Besides, a maximum PAW value allows to define a parallel objective of this study: to approximate the optimal harvest age for patula pine stands. More details on the application of this model for the Mexican conditions are presented in the economic analysis chapter.

2.6. Risk in forest management

Risk is an intrinsic factor in most management decision problems. In general, two components account for the total risk involved when implementing a forest management project. According to Guttenberg (1950) these risk components are: production and marketing.

Production risk. It refers to the risk associated to not achieving the physical outcome desired --not producing the item of interest. For instance, when planting trees and /or tending a natural stand, there exists uncertainty of whether or not the trees will be harvested. Pests, diseases, fire, or other climatic phenomena could destroy the stands. Fortunately, in managed forests this type of risk is relatively low.

In recent years, a new source of risk affect forest resource projects: the implementation of environmentally oriented laws that prohibit harvesting operations in some areas.

Market risk. This component concerns market and price uncertainties. Thus, it is possible that once we get the desired product, it is not valuable in the market. Changes in consumers tastes and preferences, substitutes, or too much competition can make this situation occur. As Guttenberg (1950) mentioned, diversification of the production is a good way to reduce this type of risk.

The inability to estimate exact future outcomes from management strategies is the basic cause of risk in an investment (Clutter *et al.*, 1983). In response to that fact, since the second half of this century risk has been cause of concern among forest researchers (Flora, 1964; Thompson, 1968).

Recent works suggest that forestry, at least in some regions of the United States of America is not considered a high-risk investment (Klemperer *et al.*, 1994). Unlike this situation, the current economic and social Mexican conditions suggest that a higher investment risk exists in Mexico. This is supported by the current low rates of investment in the forest sector despite the major changes that have been made on the Agrarian and Forestry Mexican Laws since 1992 (SEMARNAP, 1997b).

For a review on how to account for risk in investment analysis refer to Klemperer *et al.* (1994), and Klemperer (1996). Below a brief synthesis of Klemperer's work is presented.

2.6.1. Methods for incorporation of risk into the decision making process

Present value probability distribution

In a first attempt to include risk when analyzing management alternatives, risk was associated to the probability of occurrence of one of the possible outcomes associated to a project. Mathematically,

$$\text{Expected revenue} = E(R) = \sum_{i=1}^{n} P_i * R_i$$

when $E(R)$ = expected value of a risky revenue
P_i = probability of occurrence of outcome i,
R_i = revenues associated to outcome i,
n = number of possible outcomes.

The problem with this model is that it does not reflect the variation around the mean value for a given outcome (R_i), which, besides the probability of occurrence, is an important factor to define the degree of risk of a project or investment. To overcome this problem, economists incorporated a variable to the model that allows to weight the outcomes considering a measure of variance. Thus, the risk associated to a given project is measured through its variance weighted by its probability of occurrence. Mathematically,

$$\text{Variance} = s^2 = \sum_{i=1}^{n} [R_i - E(R)]^2 * P_i$$

when $E(R)$ = expected value of a risky revenue
P_i = probability of occurrence of outcome i,
R_i = revenues associated to outcome i,
n = number of possible outcomes.

Because the units associated which express variance are squared, it is difficult to interpret, so risk is expressed in units of standard deviation.

$$\text{Std.Deviation} = s = \sqrt{\sum_{i=1}^{n} [R_i - E(R)]^2 * P_i}$$

The rule for this measure of risk is to select the project with the smaller standard deviation.

This modified criterion is restricted to comparisons of investment choices with similar or equal expected values for revenues (projects of similar size). If comparisons involve projects of varying scale, a measure of relative risk is required. The coefficient of variation (CV), which is defined below allows the comparison.

$$CV = \frac{s}{E(R)},$$

when s = standard deviation associated to the outcome
$E(R)$ = expected value of a risky revenue.

Here the rule is to select the project(s) with the lowest CV. The higher the CV, the higher the risk.

Discounting for risk (risk adjusted discount rate)

The most commonly used method to account for risk is the application of a risk adjusted discount rate (RADR), instead of a normal or risk-free rate of return to all cash flows when calculating an economic criterion of interest. An important condition for this approach is that investors are risk averse when evaluating future returns, in other words, they assign a lower present value to revenues with greater variance or risk.

To take account of the risk involved in a project, the interest rate (risk-free rate or return), has to be adjusted to reflect the risk. Mathematically, the net present value (PV) equation could seem unmodified as follows:

$$PV = \sum_{t=0}^{n} \frac{R_t}{(1+RADR)^t}$$

when R_t = revenues associated to outcome t,
RADR = risk-adjusted discount rate.

Here RADR is the risk-adjusted discount rate, which equals the sum of a given minimum acceptable risk-free rate of return and the risk premium required to compensate for the investor's level of risk. This RADR varies, theoretically from one investor to another due to the individuals' degree of risk aversion. It is important to know how it is estimated. The general procedure, as presented by Klemperer (1996) follows:

1. Ask the investor "what sure income -certainty equivalent (CE)- would give you the same level of satisfaction as the risky revenue?". For a risk averse investor CE < E(R), reflecting the reduced value due to risk.

2. Since a future CE is by definition risk-free, it should be discounted using the risk-free rate operating in the market to obtain the net present value (PV_{CE}). It is also possible to calculate the same NPV by discounting the E(R) with the RADR, thus,

$$PV_{CE} = \frac{E(R)}{(1+RADR_i)^n} = \frac{CE}{(1+i)^n}$$

under risk-aversion E(R) > CE and therefore RADR > r.

Rearranging the first two terms of the equation and solving for RADR we get:

$$RADR = \left[\frac{E(R)}{PV_{CE}}\right]^{1/n} - 1$$

Certainty equivalent coefficients or ratios

According with Clutter *et al.* (1983), a theoretically preferred method of adjusting for risk is the use of the so called certainty equivalent coefficients. This coefficients are defined as:

$$\alpha_t = \frac{CE}{E(R)}$$

when α_t = certainty equivalent coefficient for period t
CE = certainty equivalent. The monetary amount that if received with certainty would give an individual the same satisfaction as the risky amount E(R)
E(R) = expected value of a risky revenue
t = an index to represent periods of time.

If this method is followed, net present value (NPV) is calculated as follows:

$$NPV = \sum_{t=0}^{n} \frac{\alpha_t * C_t}{(1+r)^t}$$

when C_t = risky cash flow from period t
r = risk free discount rate.

Under this approach, management strategies as selected as usual, the ones with the maximum value of NPV.

Sensitivity analysis

According to Rose *et al.* (1988) this is usually the most appropriate procedure to use when analyzing the effect of uncertainty (no risk) in project cash flows on investment performance. Sensitivity analysis is also the most common approach to account for risk and uncertainty. It is done to test the effect of a specific change in any of the elements of the analysis (discount rate, costs of silvicultural treatments, price of products, etc.) on the project outcome.

Monte Carlo simulation

Under this approach the probability of achieving a specific outcome is estimated by recalculating the cash flows after drawing random observations from the probability distributions of all inputs and outputs. The Monte Carlo simulation approach requires computer programming to repeat the process many times until an empirical probability distribution for the desired output is created (Rose, 1988).

3. GROWTH AND YIELD MODELS

3.1. The species of interest: *Pinus patula* (patula pine)

Pinus patula, a native Mexican species, is the most intensively used conifer in the tropical and subtropical environments where it is widely planted as an exotic due to its fast-growth rate and adaptability. It was estimated that about one million hectares (ha) had been planted with *P. patula* in the world up to 1991, half of them in Southern and Eastern Africa (Wright *et al.*, 1995).

In its natural habitat, *P. patula* grows at altitudes between 1500 and 3100 meters (m), (4921 and 10170 ft), and latitudes from 17° N to 24° N. Figure 2 shows the geographic distribution of the species in Mexico. Most patula trees are straight and without branches for about 20 m (66 ft), which make the species highly desirable for commercial exploitation. Perry (1991) described patula pine's trees as "a very fine pine that attains heights of 30-35 meters (98 to 115 ft) and diameters at breast height of 50-90 centimeters" (20 to 35 in). The wood is used for construction (timber), pallets, posts, and as firewood. When the trees are harvested, they are distributed to supply several industries. Logs of 2.55 m (8.4 ft) in length and up to 20 cm (8 in) in diameter are sent to sawmills or to make veneer. Logs of diameter between 20 and 12 cm (8 to 5 in) are cut at 1.5 m (5 ft) in length and used to make pallets and/or wood containers (boxes). Raw material from the stem or branches that have a diameter between 12 and 2.5 cm (5 to1 in) used as fuelwood or for pulp. Fuelwood is the most common use of small

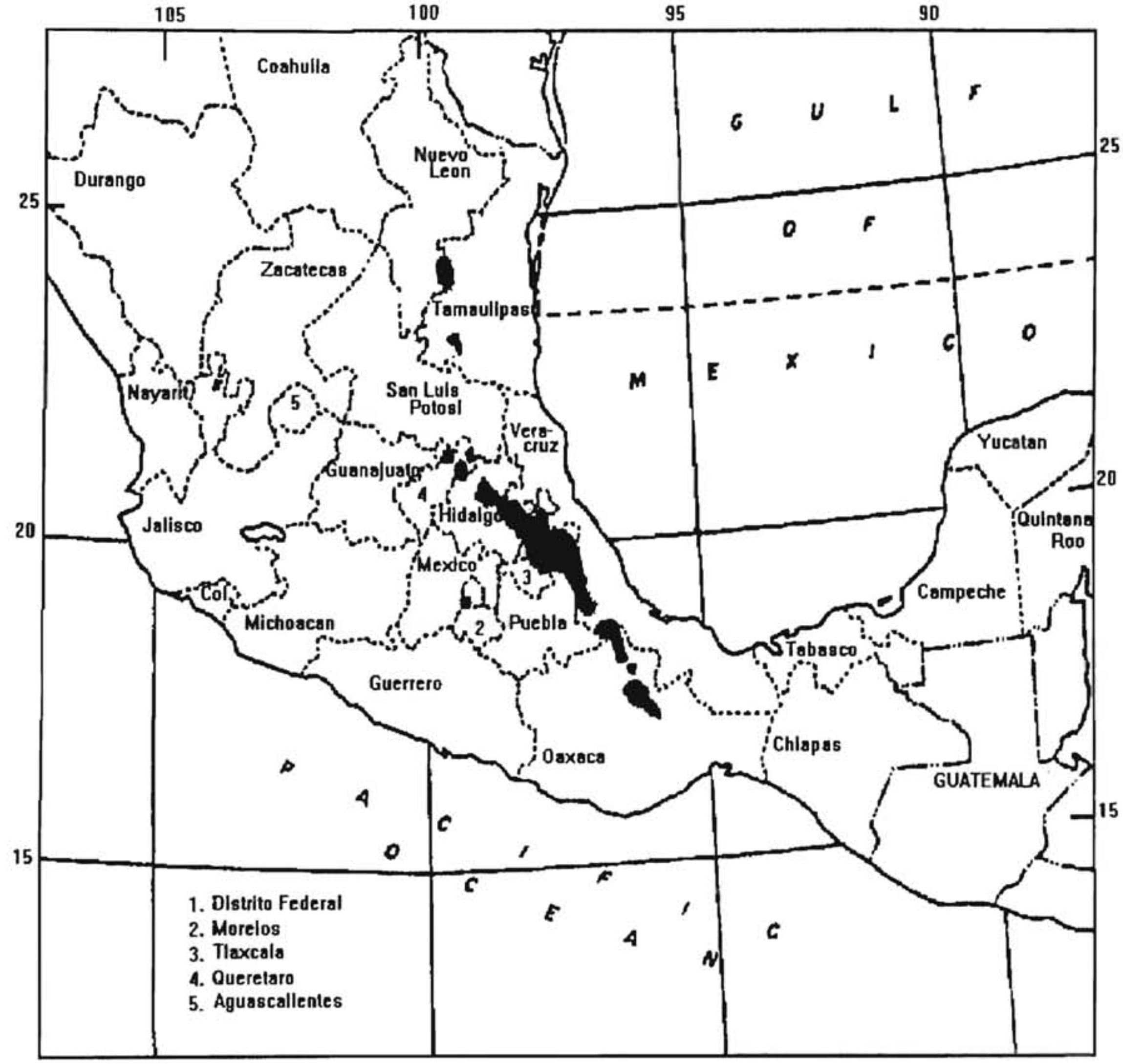

Figure 2. Natural Distribution of *Pinus patula*.

dimension material in the Chignahuapan region. Any remainder material is left in the forest as "waste". Detailed ecological information for patula pine in Mexico has been reviewed by Vela (1976).

3.2. Source of data and analysis pattern

Stimulus for this study arose from an earlier research project initially reported by Morales (1991), which compiled income and expenditures resulting from four levels of thinning applied to two patula pine stands of different ages located in the State of Puebla, Mexico (Figure 3). One of the stands, called Xopanac, had an average age of 19 years (with a range from 10 to 20 years) when the experiment was set up and the thinning was done in 1985. The other one, Atlamajac, had a average age of 23 years (ranging from 20 to 30) at the same date.

Originally, the experiment was planned as a complete randomized design composed of four treatments or thinning intensities with three replications for each of them. The nominal residual basal areas to leave in each treatment were 85, 75, and 60% of the basal area that existed in the control plots, which were considered to have 100% of basal area. An experiment was separately designed for each stand. Later, De los Santos (1993) found that mistakes were done when the experiment was set up in the field. After reviewing and comparing the residual basal areas left in each treatment, he noted that several treatments were not statistically different from each other, and that the nominal residual basal areas (planned) left in the plots did not correspond to the real (actual) basal areas in the field. In this study, the data from the experiment (measures obtained just after thinning and 7 years later) have been analyzed as a set of

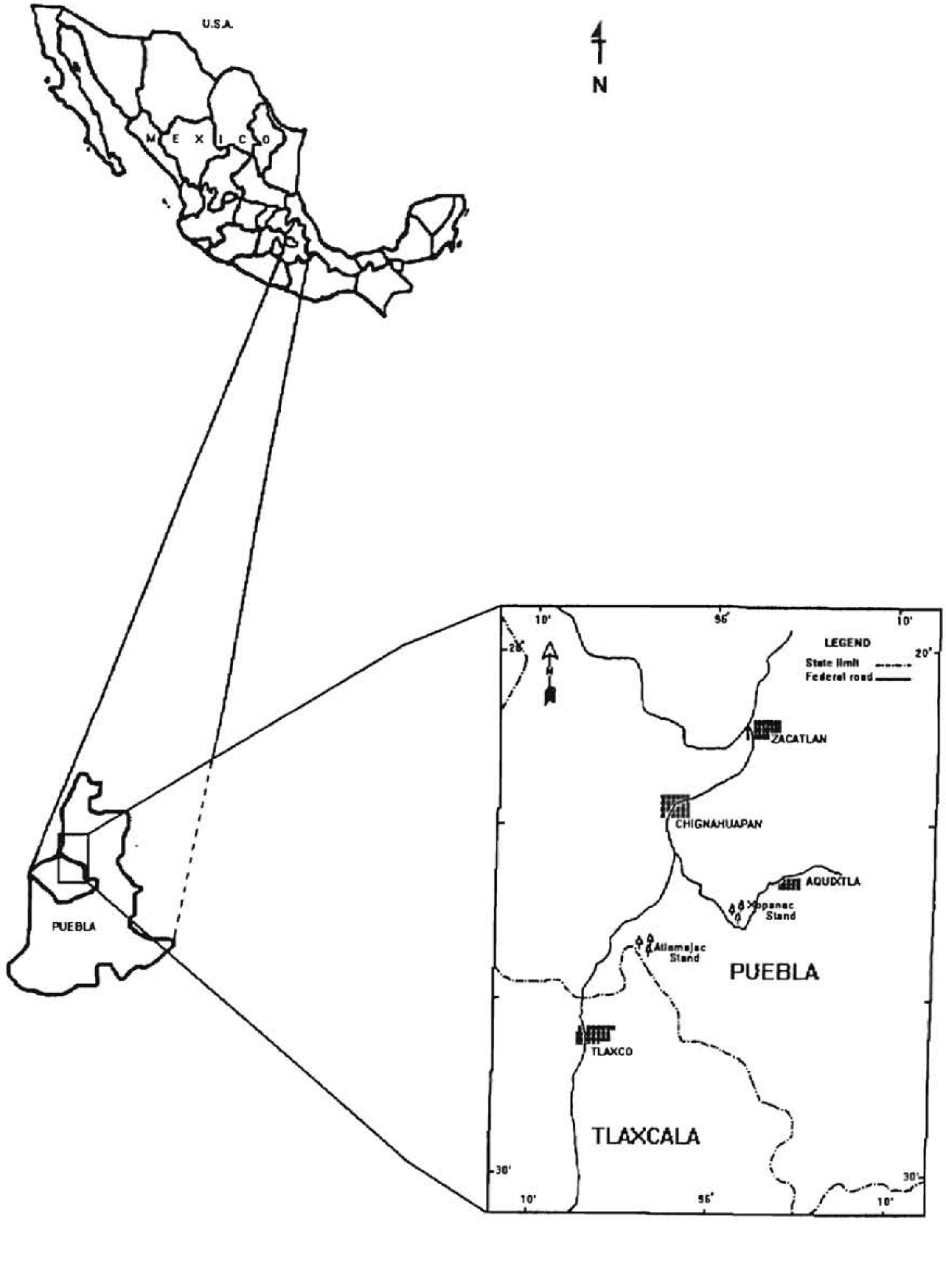

Figure 3. Location of stands under study.

independent plots of variable initial density (residual density) for the purposes of fitting yield models to project volumes at different points in time. For the thinning analysis itself, only one thinning treatment that represents, in average, 80% of residual basal area and the control (no-thinning) were taken as originally applied for the Xopanac stand. Residual densities representing 70 and 60% of the control treatment were simulated. For the Atlamajac stand, three thinning alternatives besides the control were considered as originally done (approximately 60, 70, 80, and 100% of residual basal area). As can be noticed, the percentages of residual basal area here considered do not match with the percentages originally reported by Morales (1991), which results from using the real residual basal area instead of its nominal values. Table 1 shows the thinning treatments applied to the stands.

Table 1. Thinning treatments and associated residual basal area left in the thinnings applied in 1985 to Xopanac and Atlamajac stands.

	Stand (year of thinning)			
Thinning Treatment (% Basal Area left)	**Xopanac (19 years)**		**Atlamajac (23 years)**	
	Residual Basal Area		**Residual Basal Area**	
	(m^2/ha)	(ft^2/ac)	(m^2/ha)	(ft^2/ac)
100	31.01	135.2	41.81	182.3
80	24.80	108.1	33.34	145.4
70	21.70	94.6	29.26	127.6
60	18.60	81.1	25.08	109.3

3.3. The data base

As mentioned, the data is from an experiment to examine four thinning intensity levels (roughly 100, 80, 70, and 60% of residual basal area), and their relation to the subsequent development and productivity of two stands by relating density variables such as basal area and number of trees per hectare and productivity at different points in time. Details of the experiment, which was established in 1985, have been published elsewhere (Morales, 1991; Velazquez *et al.*, 1992).

Data for this study came from twenty-four rectangular plots of 0.1 ha (0.24 ac), that were established in two pure natural stands of patula pine. The plots are located in the Chignahuapan-Zacatlan region of the Mexican state of Puebla (Figure 3). They have a measured site index of 31 m (101 ft) at the base age of 35 years (Arteaga, 1985). Geographically, the stands are located at latitudes of 19° 15' N to 20° 08' N and at longitudes 97° 45' W to 98° 13' W.

Three measurements have been made on the plots. The first one was used to define the structure and composition of the stands in order to assign the treatments or thinning intensities levels. A second measurement, was carried out the same year (1985), after the treatments were applied to define the structural characteristics of the plots after the thinning. A third measurement (first evaluation) was done in 1992. For the present study only second and third measurements were used. The variables of interest extracted from the original data base were DBH, total height (H), and average stand age for the plot. Site index values were estimated by iteratively solving the equation fitted by Arteaga (1985) to build site index curves for the specie and region. In each plot, DBH's were measured for all trees. However, height and age were measured only for randomly selected trees from all DBH classes.

3.4. Models development

3.4.1. Height models

As mentioned above, height was not measured for all trees in the plots, thus, an equation to estimate the height of such trees was necessary. A considerable number of equations have been developed and used in past studies to estimate height for trees of different forest species. The common denominator of many widely used equations to predict height is that they use only DBH as the independent variable (Hush *et al.*, 1982; Avery and Burkhart, 1994). For this study, a model was sought which could adequately express the height-DBH relationship in the data, while minimizing variation on the predictions. The following models were fitted to the data using ordinary linear and non-linear least square regression techniques.

$H = b_0 + DBH$	
$H = b_0DBH + b_1{*}DBH^2$	(Trorey, 1932)**
$H = b_0 + b_1{*}\ln DBH$	(Henricksen, 1950)**
$\mathbf{H = b_0{*}(1 - e^{-b1{*}DBH})}$	**(Meyer, 1940)**
$H = b_0{*}(DBH^{b1})$	(Stoffels and Van Soest, 1953)**
$\ln(H) = b_0 + b_1{*}DBH^{-1}$	(Avery and Burkhart, 1994)

** Original sources not reported here.

A separate equation was fitted for each thinning treatment in each stand, instead of pooling the data to fit only one equation (each treatment had three replications). This increased the predictive power (R^2) and reduce the variability (MSE) of the predictions. On this matter, Clutter *et al.* (1983) recommended fitting separate equations for different plots when stand conditions show variability. Data from this study showed no variability among plots of the same treatment due that the replications were established in the same stand (in the same physical place). However, due that different thinning levels were applied for each treatment, variability was present among treatments, particularly from the data collected 7 years after the thinning. Clutter *et al.* (1983) also recommended that "data from different stands should never be pooled to calculate a single regression equation of height as a function of DBH". Therefore, separate equations were fitted for each stand.

After the fitting and examining process was done, two equations (Meyer and Stoffels and Van Soest's -both non linear) were found to be the most precise and had the least bias for predicting height for the data under analysis. Meyer's equation fitted better to the data of 14 treatments (all treatments after the thinning -1985, and all but two in 1992). For the remaining two treatments, the Von Soest's equation was better. Thus, Meyer and Stoffels and Van Soest's type equations were used to estimate the height of trees not measured in the field.

Criteria such as mean square error (MSE) and fit index (FI) were used to define the most appropriate model. Fit index is defined as one minus the ratio of sum squares of error (SSE) to sum of squared total (SSTO) (FI = 1- SSE/SSTO). Also, analysis of residuals and "logic" properties of the models such as an asymptote height value for large DBHs, and height value close zero for trees with zero DBH were considered.

A comparison of the Meyer regression models for the different treatments was done using dummy variables. Unfortunately some models were not significantly different, while others were. Therefore, following Clutter *et al.*'s advice, a separate equation was used to predict height for each treatment in each stand.

Table 2 shows the parameter estimates b_0 and b_1, and the fit statistics for the regression models selected to estimate height for each treatment applied. Residual analysis for all equations showed no abnormal trends.

A good characteristic of the height equation chosen for most of the plots (Meyer's equation) is that it reaches an asymptotic height value equal to b_0 when the DBH becomes large (approaches infinite). The height equations here presented can be used to predict total tree height given DBH. However their applicability is local due that the data base used to fit them is restricted in range. Only one site index and two ages were represented in the data.

Table 2. Parameter values and associated statistics for selected height equations by treatment and site after thinning (1985) and at remeasurement age (1992). The model is $H= b_0(1-e^{-b1 *DBH})$, unless otherwise indicated.

		Stand							
		Xopanac				Atlamajac			
Year	Treat (%)**	b_0	b_1	R^2	Root MSE (m)	b_0	b_1	R^2	Root MSE (m)
	100	22.30915600	0.07701461	0.78	2.04	27.89688858	0.05617786	0.85	2.71
	85	21.28916819	0.08957843	0.76	2.00	27.18349610	0.06563060	0.76	2.46
1985	75	21.77972018	0.08522524	0.77	2.09	27.13142420	0.06034126	0.87	2.21
	60	20.64670045	0.09380336	0.80	1.81	26.29773829	0.07387446	0.76	1.99
	100	23.81579588	0.07229027	0.80	1.96	31.98617555	0.05039484	0.83	2.66
1992	85	22.99592145	0.07923253	0.59	2.40	31.98698317	0.05507353	0.76	2.28
	75*	5.293024586	0.40984797	0.66	1.98	31.19843501	0.05453539	0.86	2.23
	60*	5.409953928	0.39665204	0.65	1.98	31.33507789	0.05698931	0.73	2.23

* For Xopanac 1992, model different from the other: $H= b_0(DBH^{b1})$

** Residual basal area after thinning.

3.4.2. Stand volume and basal area models

Once the height models were fitted, it was possible to estimate individual tree total and merchantable volumes at different top limit diameters using the system of equations fitted for the species and region by Zepeda and Almonte (1994). These equations estimate volume inside bark for standing trees. They are defined as follows:

$$V = 0.000027601*(DBH^2*H)^{1.010769} \quad \text{--} \quad (1)$$
$$(R^2=0.97;\ MSE=0.0163905)$$

when V = total volume inside bark (m^3)
DBH = measured outside bark at 1.3 m above ground (cm)
H = total tree height (m).

$$MV = V*[1-0.863842*(TD^{3.1539822}/DBH^{3.0649789})] \quad \text{------------------------------} \quad (2)$$
$$(R^2=0.91;\ MSE=0.008279)$$

when MV = merchantable volume per tree at a given top diameter
TD = top diameter
V and DBH as above indicated. Notice that MV is a volume ratio equation type.

Considering that the interest was to develop a whole stand yield model, volumes up to a certain top limit diameter from all trees in each plot were added. They provided part of the information (volume/ha) to fit the yield models for different products --sawtimber, pallets, and fuelwood, which are the main uses of the raw material in the region. The next step was to create a data base containing the following variables on a per ha basis: basal area (m^2), total, sawtimber, pallets, and fuelwood volumes (m^3), site index (meters at base age 35), and average stand age (years). All data were recorded for the initial age (thinning date) and for the age when the remeasurement took place (seven years later). Table 3 below contains some descriptive statistics of the data used to fit the volume and basal area yield models.

Table 3. Descriptive statistics of the data used to fit the basal area yield models. Volume units are m^3/ha; basal area in m^2/ha.

Statistic	Basal area	Total Volume	Pallet Volume	Fuel volume	Sawtimber Volume	Age (years)
Mean	32.459[1]	272.660	231.817[2]	272.057	145.999	24.3
Standard Dev.	6.621	89.441	95.279	89.658	92.439	4.3
Range	29.369	366.800	383.312	367.029	333.351	15.5
Minimum	18.968	122.313	71.016	121.820	18.931	16.6
Maximum	48.337	489.113	454.328	488.849	352.282	32.1

[1] Multiply by 4.3548 to obtain $ft^2/acre$

[2] Multiply by 14.2913 to obtain $ft^3/acre$. Same applies to other volume types.

Models considered to estimate growth and yield.

Several models reported in the literature were fitted to this data base. Initially, an adaptation of the Chapman-Richards model (Murphy *et al.*, 1992) was tested to develop yield relationships:

$$Y_2 = [b_1 - (b_1 - Y_1^{b2})*(A_2/A_1)^{b2*b3}]^{1/b2} \quad \text{---} \quad (3)$$

when Y_i = standing volume or basal area at time i,
A_i = stand age at time i, and
b_i = parameters to be determined.

Unfortunately convergence problems were encountered when trying to fit the data to this equation. Later, another non-linear equation also developed by Murphy *et al.* (1992) from the Champman-Richard model was fitted to the data to predict total volume and merchantable volume yield:

$$Y_2 = [b_1*\ln(A_1/A_2) + Y_1^{b2}]^{1/b2} \quad \text{---} \quad (4)$$

when Y_i, A_i and b_i as above defined.

Even though the data fitted well to this equation for basal area, total volume and fuelwood volume, they did not fit well for the remaining equations of interest. Thus, it was left as a second choice system of yield equations. Also, the fact that it does not consider site index as an independent variable, which is considered to be relevant (by definition) for comparing yield among different sites motivated consideration of other alternatives.

Also the well-known mathematically compatible system of equations developed by Clutter in 1963 (Clutter, 1963; Clutter *et al.* 1983) were fitted to the data. These equations include the stand volume equation known in the biometrics literature as Schumacher-type yield equation, which, together with a basal area projection equation can be used to predict net yield (volume and basal area) as a function of age, site index, and basal area. The system of equations is presented below:

$$\ln(V_i) = b_0 + b_1{*}S + b_2{*}A^{-1} + b_3{*}\ln(B) \qquad \text{----------------------------------} \ (5)$$

when V_i = total or merchantable volume per hectare (m^3)
S = site index (m)
A = stand age
B = basal area (m^2/ha)
b_i = parameters to be estimated.

Properties of the Schumacher-type yield models have been stated in detail by several authors such as Schumacher himself (1939) and Clutter (1963). However, it is important to emphasize that for this equation-type yield equation, yield approaches to an asymptotic value, defined by $\mathrm{EXP}[b_0 + b_1S + b_2 \lim_{A\to\infty} \ln(B)]$, as age increases without limit. This limit value depends on the site index.

The volume equation presented above suggests that a basal area prediction equation is necessary to predict volume. Clutter (1963) derived the following basal area projection equation as part of his compatible growth and yield system:

$$\ln(B_2) = (A_1/A_2)*\ln(B_1) + \propto_0*(1 - A_1/A_2) + \propto_1*S*(1 - A_1/A_2) \quad \text{---------------} \ (6)$$

when $\propto_i$ = parameters to be estimated, and
S = site index (m)
A_i = stand age at time i, and
B_i = basal area at time **i** (m^2/ha)
ln = natural logarithm

As a last step the Schumacher and Hall volume equation, which has been widely used to predict individual tree volume, was fitted to the data to obtain a comparable stand volume equation. Details concerning the analogous use of this equation type can be found in Lynch *et al.* (1991).

$$V_i = b_0*B^{b1}*H^{b2} \quad \text{---} \ (7)$$

when V_i = total, sawtimber or other merchantable volume per hectare (m^3)
H = average total height of dominants and codominants (m)
B = basal area (m^2/ha)
b_i = parameters to be estimated.

Average height of dominants and codominants was estimated with the equation fitted by Arteaga (1985) to develop site index curves. This equation follows:

$$H = 3.01939343 * S^{0.73011143} * (1 - e^{-0.07280574*A})^{8.67357572*S^{-0.3444947}} \quad \text{---------------} \ (8)$$

$R^2 = 0.98$
Root MSE = 1.96

when H = average total height of dominants and codominants (m)
S = calculated plot site index
A = average plot age
e = base of natural logarithms.

Selected models or equations.

Of all the equations tested, the one developed by Schumacher and Hall in 1933, equation (7), provided a better fit to the data and was used to predict total and merchantable volume up to several top limit diameters on a per hectare basis. Table 4 shows the parameter estimates and fit statistics for the total volume (V), volume for fuelwood (V_F), volume for pallets (V_P), and volume for sawtimber (V_S) Schumacher-Hall type prediction equations. No trends were observed in the residuals.

Table 4. Parameter values and associated statistics for yield volume equations.

Variable	Parameter			R^2	Root MSE
	b_0	b_1	b_2		
Total (V)	-0.177310	1.174511	0.544705	0.90	0.10320
Fuelwood (V_F)	-0.195405	1.176242	0.547811	0.90	0.10439
Pallets (V_P)	-2.041976	1.363396	0.875258	0.84	0.17464
Sawtimber (V_S)	-2.344479	1.213404	1.123535	0.87	0.26759

Note: *V, V_F, and V_P, can be estimated after projecting basal area with equation (9) and average height with equation (8). Differently, V_S must be estimated after projecting basal area with equation (10).*

The exact form of the equation to predict total volume yield is presented below as an example:

$$V = e^{(-0.1777310)}*B^{1.174511}*H^{0.544705}$$

$$V = 0.459640783* B^{1.174511}*H^{0.544705}$$

when B = basal area/ha
H = average height of dominant and codominant trees (m).
V = total volume

This and the other equations implied in Table 4 can be used to estimate volume per hectare, in m^3, for different products given total and sawtimber basal areas and average height of dominants and codominants. However, any estimation should be done between the ranges of data used to fit them (see Table 3). As Lynch, *et al.* (1991) mentioned, "equations fitted by least squares [which is the case here] perform best within the ranges of data used in estimating the coefficients". If desired, yield could be approximated for a few years outside the range (3-5) considered, but careful interpretation must be given to such extrapolations. In fact, if the equation to estimate fuelwood volume (V_F) if used to predict volumes more than 6 years outside the range of data used to fit it, will result in unreasonable estimations. Fortunately it was not of major importance for the purposes of the economic analysis developed in the second part of this research.

To project any of the different volumes per ha here considered (total, sawtimber, fuelwood, or pallets), first future basal areas and future average height of dominants and codominants must be projected at the age of interest. Therefore, total and sawtimber basal area equations were fitted to the data. Equation (6) fitted data better and was used to predict total basal area. However, site index was not significant. Thus, the final total basal area prediction equation is of the form:

$$\ln(B_2) = (A_1/A_2)*\ln(B_1) + 4.144173*(1 - A_1/A_2) \text{ ----------------------------------(9)}$$

$R^2 = 0.99$
Root MSE = 0.0427
when A_1 = the younger of ages A_1 and A_2
A_2 = the older of ages A_1 and A_2
B_2 = total basal area at age A_2
B_1 = total basal area at age A_1

Even though the site index variable was not significant for predicting total basal area, the percentage of variation "explained" (R^2) by the remaining variables is excellent. No trends were observed in the residual plots for the equation.

Equation (8) was used to estimate average height for dominant and codominant trees. This equation was fitted by Arteaga (1985). A spreadsheet was used to predict basal area at different ages. Later, in the same environment all volumes of interest where projected. Figure 4a and 4b exemplify the curves obtained from the equations fitted for the no-thinning regime and for the regime prescribing 80 % of residual basal area, respectively.

A different equation was fitted to project basal area yield for sawtimber products. This improved the percentage of variation explained by the variables (R^2) when predicting sawtimber volumes. The equation type selected for this purpose is similar to the one fitted by Murphy (1982). The following equation was developed for predicting future sawtimber basal area in this study:

$$B_{SA2} = e^{[0.2428207642*(1-A_1/A_2)]} * \frac{(B_2 * B_{SA})}{B_1} + B_2 * (1 - e^{[0.1458396493 \cdot (1-A_1/A_2)]}) \qquad \text{------------------------------(10)}$$

$R^2 = 0.99$
Root MSE = 0.71138
when B_{SA2} = sawtimber basal area at age A_2
B_{SA} = sawtimber basal area at age A_1
A_1 = the younger of ages A_1 and A_2
A_2 = the older of ages A_1 and A_2
B_2 = total basal area at age A_2
B_1 = total basal area at age A_1
e = the base of the natural logarithms
b_1, b_2 are parameters to be estimated.

Equation (9) and (10) can be used to project total and sawtimber basal areas, which are quantities needed to predict volume with the equations presented in Table 4. Sawtimber basal area data to fit equation (10) was obtained by adding the basal areas of trees greater than 20 cm (8 in) in DBH and expressing the figures in a per acre basis.

Summarizing, equations (9) and (10) were used to estimate basal area yield for the plots under different management regimes or thinning alternatives. B_1 was entered in all the cases as the residual basal area left after the thinning. Once the basal areas were projected, equations of type (7) were used to predict volume for the products of interest at different stand ages. Behavior of the residuals were checked for all selected equations. None of them presented trends.

a)

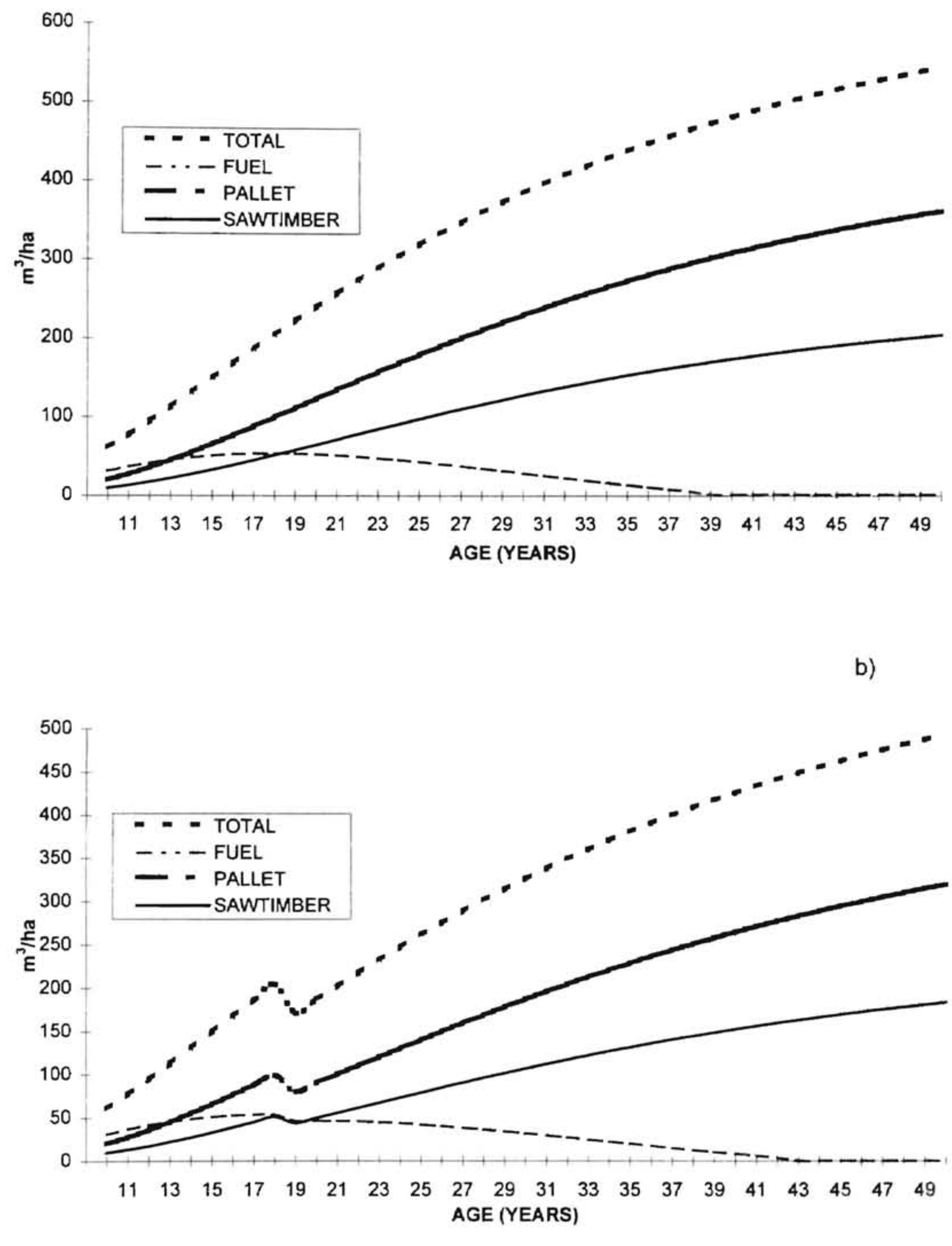

Figure 4. a) Yield projections of merchantable products for the unthinned regime, and b) for the regime that prescribed leaving 80% of initial basal area in the Xopanac stand.

4. ECONOMIC ANALYSIS

4.1. Estimates for the analysis

Price values for wood products, costs of silvicultural labors, and discount rate here considered are real (do not include inflation). Nominal price values were deflated using the consumer price index (CPI) at base year 1994 for wood products as reported by the Mexican Stock Market (INEGI, 1997). Cash flows (revenues minus costs) at thinning and harvest ages are taken as average or expected values.

Prices and costs

Wood products prices for the period 1989-93 were taken from the Secretariat of Agriculture and Water Resources (SARH, 1994). Prices for 1994 came from a report published by the Mexican Secretariat of Agriculture Livestock and Rural Development (SAGAR, 1994). 1995 prices were slightly modified from Secretariat of Environment, Natural Resources, and Fishery -SEMARNAP-, (SEMARNAP, 1997a). For the last 2 years price data are preliminary and represent the market value reported in the region. In this analysis an average price for the period from 1989 to 1994 was used for all products as the benchmark price. Prices form 1995 to 1997 are presented to observe prices trend under high inflationary conditions.

Table 5. Real and market price of products used to calculate revenues in Mexican pesos per cubic meter (M$/m^3). All values are constant prices at 1994 (CPI base year 1994 = 100).

Year	Sawlogs Real (market)	Pallet-logs Real (market)	Pulpwood Real (market)	Fuelwood Real (market)
89	204.4 (120.6)	122.5[1] (72.3)	98.9 (58.4)	75.0 (44.3)
90	206.5 (133.7	123.9 (80.2)	97.8 (63.3)	79.5 (51.6)
91	196.9 (153.8)	118.0 (92.2)	97.0 (75.8)	75.0 (58.6)
92	197.3 (171.3)	118.4 (102.8)	98.9 (85.9)	78.4 (68.1)
93	179.2 (175.5)	107.5 (105.3)	88.6 (86.8)	69.5 (68.1)
94	187.9 (185.9)	112.7 (111.5)	93.3 (92.3)	62.6 (62.0)
95	198.9 (214.2)	119.3 (128.5)	97.0 (104.5)	27.8 (29.9)
96	209.9 (320.0)	125.9 (192.0)	100.7[2] (153.6)	19.6 (30.0)
97	212.6 (400.0)	127.5 (240.0)	102.0 (192.0)	26.2 (10.0)

[1] Whole column was estimated as 60% of sawlogs price
[2] Estimated as 48% of sawlogs price for 96 and 97
Source: SARH (1994), SAGAR (1994), SEMARNAP (1997).

Data in Table 5 show a fairly constant price for the wood products, except for periods of high inflation in the country where the real price of wood tends to increase (1989-90, and 1995-97). These data suggest that in periods of high inflation, Mexican prices of wood increase, in real terms, at a higher rate than general inflation. In periods of low inflation wood prices caught up well with the inflation rate. Unfortunately the available data is too limited to reach a definitive conclusion. In the first part of this study an average price of the wood products was used to carry out all operations. Later, in the sensitivity analysis the prices were varied to observe any changes in the outcomes.

Thinning and harvesting costs were estimated by forestry consultants working in the implementation of forest management plans in the region (Table 6). Specifically, data reported by Almonte (1992) and Morales (1991) on harvest and thinning respectively. In this analysis the harvesting costs are estimated to remain constant through the analysis period. All operations are carried out manually (chainsaw for cutting) and/or animal traction (for the skidding).

Land price per hectare is estimated at M$2290/ha (US$373/ha) --Morales, 1997. This estimation corresponds to the market price in the region for stands of similar characteristics and conditions paid in the first half of 1997. The value was deflated to 1994 using CPI (INEGI, 1997).

Table 6. Estimated harvesting and thinning costs (M$/m^3). Values at base year 1994.

	Cost		
Activity	**Sawlogs**	**Pallet-logs**	**Fuelwood**
Harvesting	52.1	52.1	46.4
Thinning	22.4	22.4	20.0

Note: Unitary thinning costs are usually higher than harvesting costs. However, sources available for this study provided the costs as presented above.

Discount rate

Definition of the appropriate discount rate for specific projects has long been a debatable subject and no consensus has been reached up to date (Clutter *et al.,* 1983; Fortson, 1986; Price, 1993; Klemperer *et al.*, 1994). However, most analysts seem to agree that such rates are individually defined by investors or managers for each specific project and relevant investment horizon (Guttenberg, 1950; Fortson, 1986; Rose *et al.*, 1988; FIRA, 1993; Klemperer *et al.*, 1994). They also mention that it is extremely difficult to find the information to empirically estimate discount rates since judgment values such as risk aversion are invariably relevant in its definition. Therefore, defining here a discount rate as the most appropriate for analyzing thinning alternatives would not be in any sense a real representation if this matter. Instead, in this analysis, a real risk free discount rate of 5% is used as a starting point. Such rate corresponds to the average interest (computed using the available data from the last 13 years) paid for investing in Mexican commercial paper bonds due in 28 days (INEGI, 1997). These bonds are a monetary instrument that might be seen as an alternative investment to owners of forest lands. Commercial paper bonds were selected among other alternative monetary instruments because they earn a more constant and higher interest rate. Later, the 5% discount rate will be varied through a sensitivity analysis to allow decision makers under different situations (and of different degree of risk aversion) select the analysis that uses the discount rate that better represents their investment conditions. To calculate the real interest rate for commercial paper bonds, the general CPI was used instead of the CPI for wood products.

Risk and taxes

Defining a representative and accurate risk premium for the Mexican investment conditions in forestry is even more challenging than estimating the risk free discount rate. Constant changes experienced in the Mexican Laws in the last 5 years, uncertainty concerning the path that current political parties will lead the country toward, and current economic and social conditions make it extremely difficult and time consuming to estimate a credible and well supported risk premium. An estimation of such an important parameter is beyond the scope of this thesis.

For the case here considered, a sensitivity analysis is thought to be enough to provide a good estimation of expected outcomes if changes in the main elements of the analysis considered occur --interest rate (including changes in the risk premium), planning horizon, harvesting costs.

No taxes are considered because according to Mexican regulations on this matter, forest properties belonging to ejidos (communities of people that have the constitutional right to utilize and enjoy the profits and advantages of national lands, and which currently own approximately 80% of the total national forest lands) are not subject to any type of taxation. Due to the same reason, no tax levies are paid for forest products that are a direct result from forest exploitation activities and that have not been transformed in any degree. In this study it is assumed that resulting products are sold as raw material at roadside because that is the prevailing case in practice in the Chignahuapan, Puebla region. Final harvest is considered as clearcut.

4.2. Economic model

In this study present certainty equivalent of attained wealth (PAW) was selected to define the best thinning regime tested because it is well known that the main goal of the forest practice in Mexico is to maximize the wealth gains of all future net revenues resulting from pre-established management regimes. This goal can be achieved (unambiguously and consistent with the theory of investment choice) if the thinning alternative that maximizes the PAW value is chosen (Lewis, 1985) This criterion follows:

$$PAW = \sum_{t=0}^{m} \sum_{i=1}^{n} \frac{P_{it} * Q_{it}}{(1+r)^t}$$

when PAW = present certainty equivalent of attained wealth
P = price of good i in period j
Q = amount of good i in period j
i = an index for goods
t = an index for years or periods
r= discount rate.

The PAW model as here stated does not consider either regeneration cost, or annual revenues and costs. The stands were naturally regenerated and returns come only from wood forest products, which are taken into account at thinning and harvesting ages. The fact that no taxes are paid and that any other administrative cost is included in the harvesting cost makes other costs or revenues irrelevant to the analysis.

Besides, a maximum PAW value allows definition of a parallel objective of this study: to approximate the optimal harvest age for patula pine stands. Data used in this study did not allow to estimate a definitive rotation age.

Present certainty equivalent of attained wealth characterizes appropriately the investment conditions under which Mexican forest managers should base their decisions (for one rotation period, and considering selling the land at the end for the same or a different use) under the new forestry regulations. Reforms to the Forestry Law approved and published in the Official Newspaper of the Mexican Federal Government in May 20, 1997, clarify that under new Agrarian Rules forest owners have the right to decide on the best use of their lands. They also can decide if such a use will be carried out by themselves or by leasing or selling the land. Additionally, the PAW model assumes no-reinvestment of the wealth created during the planning horizon, which adequately represent the investment behavior of the ejidos (the major producers of wood products in Mexico). Ejido members (ejidatarios) have low income earnings and most of the time are struggling to achieve a long desired better standard of living. The availability of net gains early in the production cycle (resulting from thinning) is used to partially satisfy such a high time preference. Put in other words, ejidatarios prefer to consume most of the wealth created during the production cycle, instead of reinvesting (saving) for future consumption. Thus, current Mexican investments conditions in the forest sector are adequately represented by the PAW model.

If the PAW criteria is used to define the best thinning regime (by selecting the alternative that results in maximum value), at the same time it is assured that the level of growing stock left in a given plot is the one that approximates the point where marginal revenue of the growing stock and the cost of keeping it are equal. Average value growth (AVG), and equivalent annual income (EAI) were also determined to observe and compare the growing efficiency of the growing stock left after the thinning.

Value yield predictions

Using the yield models presented in the growth and yield models chapter of this thesis, sawlogs, pallet-logs, and fuelwood volumes were predicted at different points in time for the four thinning alternatives considered in each stand through a spreadsheet. Such volumes were multiplied by their respective unitary real price to obtain harvest revenue per ha at different ages. Later, harvest costs were subtracted to compute the net cash flows or revenues at thinning and final harvest age. Final harvest costs and revenues were discounted to thinning age using a real interest rate of 5%. By comparing the PAW values estimated, preliminary conclusions regarding the best thinning strategy, from the ones considered, were reached.

4.3. Best thinning alternative and harvesting age

As stated earlier, the main question to answer from this study is whether or not gains in wealth are improved by applying single thinning regimes to natural stands of patula pine. Answers reached in this study are valid only for stands managed under similar conditions to the ones here presented, and with the same assumptions holding for this analysis. In no sense does the present study pretend to achieve final conclusions regarding thinning alternatives, but to demonstrate how standard principles of economic analysis can be used to gain insights about the outcomes of management practices applied to pine natural stands.

This analysis provides answers to the question stated before by comparing expected net present values from the stands managed under different thinning regimes against a control or no thinned stand over one rotation period and for different economic conditions. The specific criterion to make such comparison is PAW. Higher values of PAW are considered more desirable. Thus, the management strategy with the higher value of PAW is considered the most beneficial in terms of gaining wealth for the owner or manager.

First, results from the thinning strategies initially planned and carried out in the experiment are presented. Later, results from a sensitivity analysis will be showed to observe how different conditions may change the outcomes.

Figure 5 shows PAW curves for the thinning treatments applied to the Xopanac stand. This stand has an average site index of 31 m at the base age of 35 years, and was thinned once when it had an average age of 19 years (ages in the stand ranged from 10 to 20 years). Maximum and minimum ages used to fit the growth and yield equations were 16 and 32 years respectively. So, PAW values projected or extrapolated outside that range must be cautiously considered. Special consideration must be given to predictions of stand PAW values at ages before 15 years due that patula pine is a fast growing species that develops rapidly at early ages. Thus, Aguirre-Bravo (1985) found that patula stands have a period of maximum growth efficiency at ages ranging from 4 to 10 years --range of data not considered in this study to fit the yield models. This author also mentioned that such period of is important to define any management goal of optimizing volume per ha and/or forest product size.

According to Figure 5 and Table 7, the treatment that resulted in the maximum gain in PAW (expressed in Mexican pesos per hectare --M$/ha) is the regime that prescribed leaving 60% of the initial basal area. Alternatively, it refers to the regime that prescribed taking out 40% of the existing basal area at age 19. This regime reaches its maximum value of PAW (M$23223) at age 30 when using a MAR of 5% and the benchmark prices and costs presented in Tables 5 and 6. This maximum value of PAW is 7, 8, and 4 percent higher than the values estimated for treatments that prescribed leaving 100, 80, and 70 percent of initial basal area, respectively (Table 6). It is clear that all thinning levels applied at age 19 were able to make up the reductions resulting from the thinning. The age at which the maximum value of PAW occurred (30 years) can be interpreted as an approximate and preliminary rotation age for thinned natural stands growing in sites of quality 31 m at age base of 35 years.

A rotation age of 30 years it by itself an interesting finding if compared with the current rotation age been prescribed in the region. Almonte (1992) prescribed a forest plan following the relevant Laws and rules of the Mexican forest authorities and suggested to harvest patula pine stands at an age of 50 years. Similar rotations are common in the region. Almonte's reasoning was that at 50 years of age patula pine trees have an abundant production of seed, which will help to regenerate the just harvested stand.

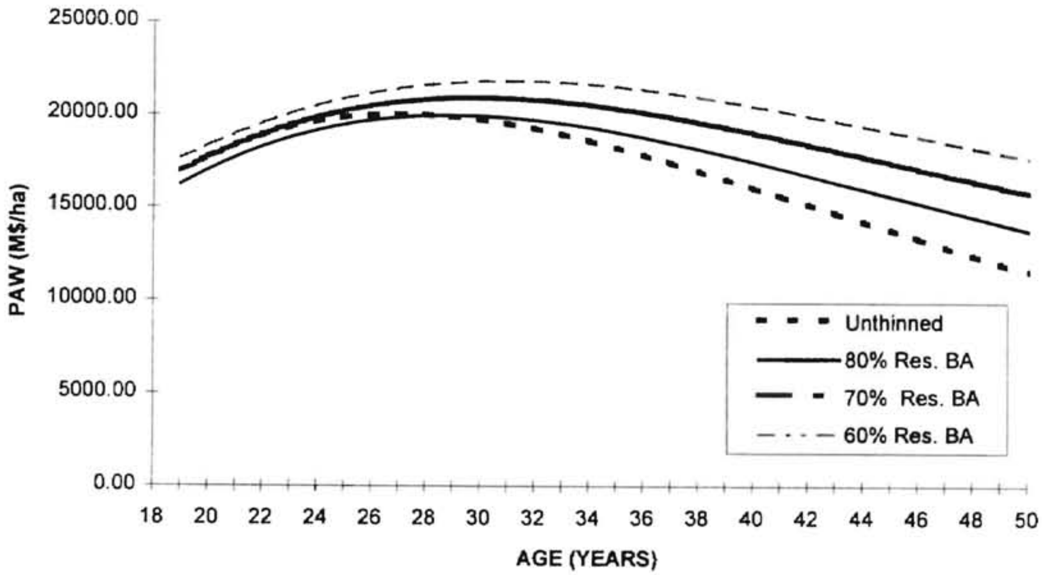

Figure 5. Present certainty equivalent of attained wealth (PAW) values for the thinning regimes prescribed to the Xopanac stand. Age of thinning was 19 years.

Table 7. Present certainty equivalent of attained wealth (PAW) values, economic harvest age (E.H.) and maximum sustainable yield rotation for the thinning regimes tested.

	Stand (age of thinning)					
	Xopanac (19 years)			Atlamajac (23 years)		
Thinning Regime	**PAW**	**Economic Harvest Age**	**Maximum Sustained Yield Rotation**[1]	**PAW**	**Economic Harvest Age**	**Maximum Sustained Yield Rotation**
Unthinned	21689	26	29	41025	26	24
80% BA	21503	28	33	41496	28	29
70% BA	22387	29	35	43117	29	33
60% BA	**23223**	**30**	**38**	**44969**	**30**	**36**

[1] Defined as the age at which mean annual increment equals current annual increment.

However, Perry (1991) reported that Mexican patula's seeds were planted in Africa in 1907, and that for 1924 (at 17 years of age), the "trees began to produce sizable amounts of seed". Also, Nepamuceno *et al.* (1994) reported a seed area of 40 years of age in production, in Mexico.

Even if the species would not produce seed at younger ages, still a shorter rotation can be justified. A rotation of 50 years is nearly equivalent in time to two rotations of 26 years, which is the economically best rotation identified here when no thinning is prescribed. The gains lost by extending the rotation can be considerable. Artificial regeneration might be a better option than postponing the rotation due to regeneration establishment purposes. Figure 5 also shows that economic harvest ages for the thinned stands are longer than the one for the unthinned stand. This situation occurs because the thinning applied increased the growth rate of such stands --as will shown in the next section of results. Consequently, thinning the stands at an average age of 19 years justifies delaying the harvest in order to increase net gains for the manager.

No-thinning and thinning at 80 percent of initial basal area gave very similar outcomes. Both reduced the gains by approximately 8 percent, if compared with the best regime (Table 7). However, thinning at 80% of the initial basal area lags the rotation by two years, from 26 to 28 years. This type of information might be valuable to managers interested in smoothing the supply of raw material. For instance, if a shortage of material exists the manager could decide to go for a regime including thinning in order to harvest some of the wood at an early age to supply the mill without sacrifying much net gains. Summarizing, the economically best management alternative (of the ones described in Figure 5) for stands with a stocking level around 31 m^2/ha of basal area at age 19 is to clearcut the stand at an age of 30 years with an intermediate thinning at age 19.

Table 7 also shows the maximum sustainable yield rotation age (MSYR). It refers to the harvesting age that would maximize production in terms of total volume. As is usually the case, MSYR was similar or longer than the economically best rotation for most thinning regimes except for the unthinned control in the Atlamajac stand.

Figure 6 shows the results of the thinning regimes applied to the Atlamajac stand. This stand was allowed to grow without intervention until it had an average age of 23 years (actual ages ranged from 20 to 30). At age 23 the Atlamajac stand had a stocking of 41.81 m^2/ha and was thinned following regimes similar to the ones applied to the Xopanac stand --no-thinning, and leaving 80, 70, and 60 percent of initial basal area.

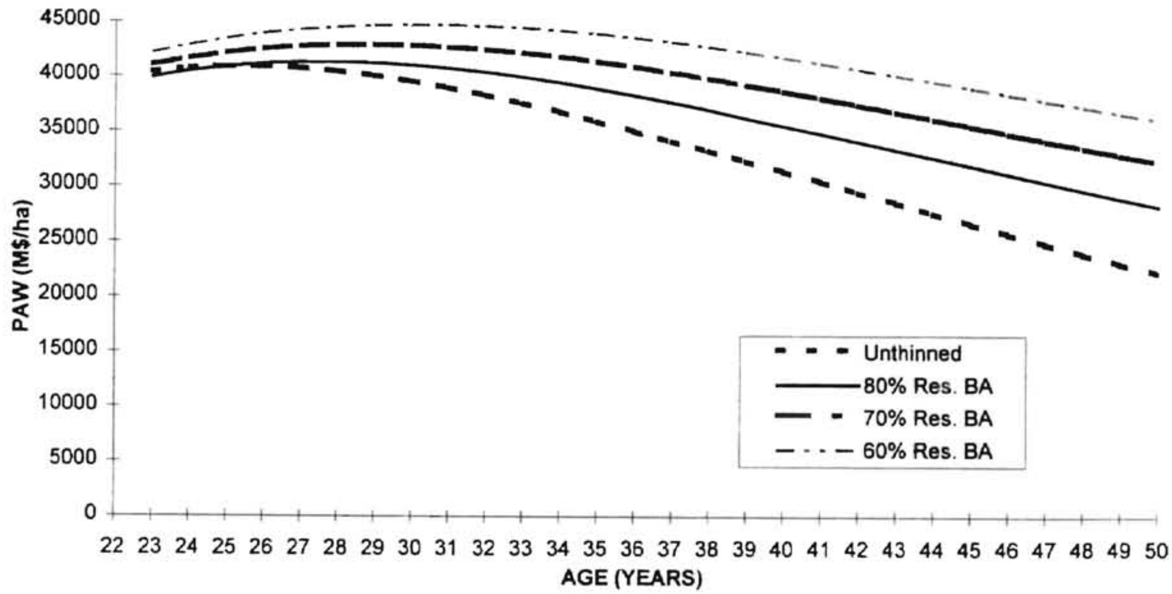

Figure 6. Present certainty equivalent of attained wealth (PAW) values for the thinning regimes prescribed to the Atlamajac stand. Age of thinning was 23 years.

An important difference to note between the Xopanac and this stand is that the former had less stocking. For instance, at age 19 (before thinning) the Xopanac stand had around 31 m^2/ha of basal area, at the same age the Atlamajac stand had 38 m^2/ha. The fact that the stands had dissimilar basal areas at a given age makes the comparisons ambiguous but give the chance to speculate about how initial growing stock may influence definition of optimal thinning regimes.

Going back to the analysis of the Atlamajac stand (Figure 6), it is observed, as before, that management alternatives that included thinning resulted in the higher values of PAW. The management regime that prescribed leaving 60 percent of the initial basal area (18.60 m^2/ha) maximized the PAW at a value of M$44969. The control and thinning regimes that prescribed leaving 80 and 70 percent of initial basal area decreased the PAW value by 9, 8, and 5 percent respectively (Table 7).

Table 7 also shows that no practical difference, in terms of PAW, can be observed between the results from the regime that considers thinning up to 80 percent of initial basal area and the no-thinning regime. However, the latter postpones the rotation by 2 years, from 26 to 28 years. Again, the best rotation was postponed from 2 to 4 years, depending on the severity of the thinning applied. The shorter rotation calculated was for the unthinned stand.

Comparing the eight thinning regimes tested in this study, it is possible to state that the over all optimum management regime is to clearcut the stand at an age of 30 years with a thinning intervention at age 23 if the stocking level of the stand is around 42 m^2/ha of basal area at the intervention age (Figure 7). If the stand has lower stocking density, the harvesting age could still be around 30 years (as results for the Xopanac stand suggest) and thinning can be justified in order to maximize PAW. However, no definitive conclusion concerning the overall optimum thinning regime can be drawn from this study since no density management was prescribed to stands at younger ages. It is necessary to develop more complete studies that include stocking management at early ages (plantation or natural regeneration), or by prescribing precommercial thinning in young stands over the whole variety of site index conditions existent in the region. Only by doing so can a better understanding on the most adequate management regimes be reached.

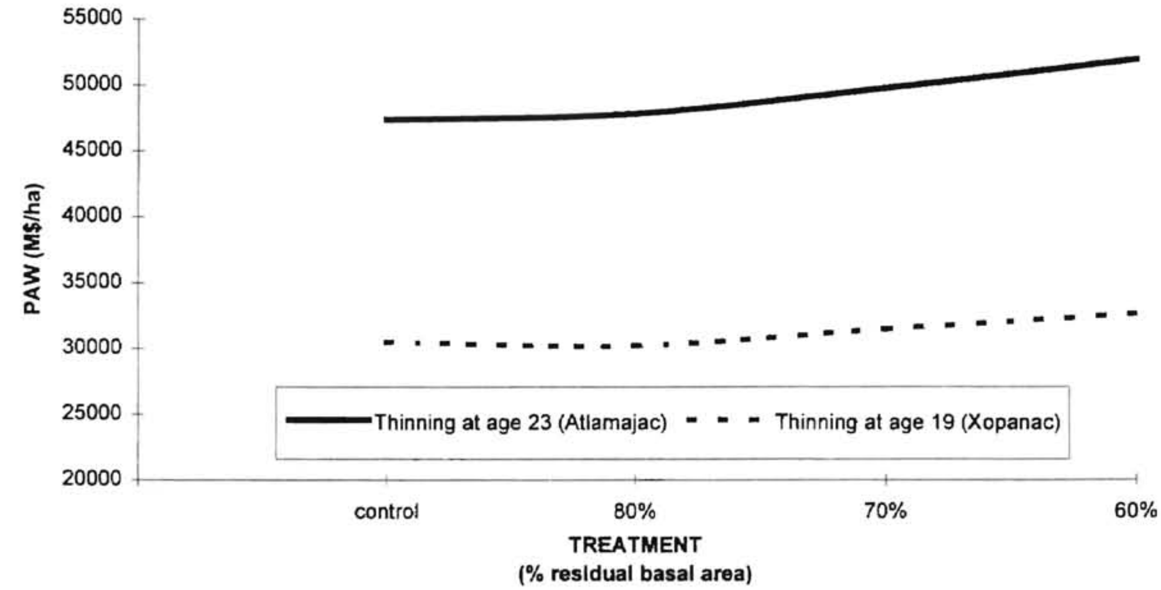

Figure 7. Effect of thinning intensity and age of thinning on PAW. Values calculated at age 30.

4.4. Financial performance of the growing stock

Analysis of the growth efficiency responses associated with thinning regimes is an important matter to consider any time an economic evaluation is carried out. In this study this type of analysis was done by calculating two financial performance indicators or criteria for the period between thinning and harvest time (30 years). The indicators used are forest value growth rate (VGR) and equivalent annual income (EAI), which are defined below.

$$VGR = \sqrt[t]{\frac{FV}{PV}} - 1$$

when FV = commercial value of stand (no land) at harvest age
PV = commercial value of stand at thinning age
t = number of years from thinning to harvest dates.

$$EAI = NPV * \frac{r(1+r)^t}{(1+r)^t - 1}$$

where NPV = $V_t/(1+r)^t + H - V_o$, net present value
V_o = commercial value of stumpage at thinning age
V_t = commercial value of stumpage at harvest age
H = net cash flow resulting from thinning
r = minimal acceptable rate of return or discount rate.

Table 8 shows the growth efficiency or financial performance of the growing stock considered in each thinning regime. It is clear from these figures that the most efficient regimes are the ones that were more severely thinned (60% of residual basal area), which is consistent with the PAW criterion reported above. This table also demonstrates that lower densities were more efficient growers of wealth than higher densities. A reduction in growing stock allows a higher rate of return and a cumulative greater PAW value at rotation age. This results support what Smith (1986) mentioned, by thinning "it is possible to reduce growing stock without greatly reducing volume growth, this becomes a way of eating one's cake and having it too". However, it is not always the case that lower growing stock results in higher gains. It may be true for a certain range of stocking levels, but if the growing stock falls below a certain range, gains can be reduced due to a loss in quality and quantity of the products, which would result in low gains per unit of area.

Table 8. Forest value growth rate (VGR) and equivalent annual income (EAI) associated to the thinning regimes tested.

	Stand (age of thinning)			
	Xopanac (19 years)		Atlamajac (23 years)	
Thinning Regime	**Value Growth Rate (%)**	**Equivalent Annual Income in M$/ha/year and (U$)**	**Value Growth Rate (%)**	**Equivalent Annual Income M$/ha/year and (U$)**
Unthinned	7	348.74 (43)	5	1.79 (0.2)
80% BA	11	871.62 (109)	12	1850.33 (231)
70% BA	17	1332.95 (166)	21	2968.35 (371)
60% BA	**62**	**1566.52 (195)**	**50**	**3873.43 (484)**

Note: VGR and EAI values were calculated for the period between age of thinning (19 years for Xopanac and 23 years for Atlamajac) and harvest age, which was considered to be 30 years.

Another finding reported in Table 8 is that the EAI value for the best thinning regime tested in the Xopanac stand (60% of residual basal area) was almost 450 percent greater than the value calculated for the unthinned stand. In other words, the unthinned stand had an average gain of M$348.74/ha/year for the period between the thinning and final harvest. On the other hand, the stand thinned at 60% of its basal area at age 19 had and average gain of M$1566.52/ha/year in the same period of time. EAI values indicate the annual amount per hectare, in monetary terms, that a particular thinning regime returns in addition to the MAR considered and used for the calculations.

VGR values indicated similar results to the ones obtained by the EAI. As expected, all thinning regimes had a VGR larger or equal to the discount rate used (5%). This agrees with the fact that all EAI values are positive. The more severely the stands were thinned, the higher were the value growth rates observed. As mentioned when reviewing this criterion, the VGR can some times be misleading because it does not give an idea of the net gains by area unit. EAI tells how much the investor will gain each year on a per hectare basis, while VGR reports the growth rate. Thus, if the investment (growing stock) were a ten-tree per hectare stand, it obviously would not result in the best gaining rate by area unit, even though the growth rate of the investment might be at its maximum (Jiing-Shyang and Buongiorno, 1997). This situation is demonstrated in the last row of Table 7, there, the over all best regime would be to thin at 60% of residual basal area at age 19, which resulted in the maximum value of VGR (62%). However, because maximization of the gains is the preestablished objective, the best thinning regime is to leave 60% of residual basal area, but when the stand is 23 years old, instead of 19 years old. This alternative resulted in the maximum value of EAI (M$3873.43/ha/year).

The right section of Table 8 contains the results for the stand thinned at age 23 (Atlamajac). Notice that the unthinned stand grew almost nothing beyond the discounting rate (5%) in terms of VGR, which agrees with a gain of only M$1.79/ha/year in terms of EAI. In practical terms we could say that this stand was only catching up with the MAR and was not generating any extra gain. All other thinning treatments grew at a faster rate. The maximum VGR and EAI values were obtained in the more severely thinned stand.

4.5. Sensitivity analysis.

A sensitivity analysis was carried out by calculating the PAW for several initial values of thinning and harvesting costs, as well as for different wood products prices and interest rates. The thinning alternative that resulted in the maximum PAW value was considered as optimal or best for the stand and conditions under which the present study was carried out.

In general, changes in the economic assumptions resulted in changes in the values of PAW. However, it resulted in little change in the best thinning regime. Thus, for instance, best thinning regime and harvest age considered for the two stands were not sensitive to timing of thinning, even though the PAW values varied.

As expected, economic harvest age increased as the MAR decreased (Table 9). However, the best thinning regime observed when using the benchmark prices and costs and a MAR of 5% was not surpassed by any other regime. Harvest age varied from 22 to 38 years and from 24 to 38 years for MAR's between 3 and 9% for the Xopanac and Atlamajac stands respectively. The main finding here is not the variation in PAW values, which depend in the input prices and costs used to compute them, but the fact that leaving 60% of the initial basal area in the stand is the best management alternative tested in this study.

Table 9. Present certainty equivalent of attained wealth (PAW), economic harvest age and best thinning regime for different minimum acceptable rates of return (MAR's).

	Stand (year of thinning)					
	Xopanac (19 years)			Atlamajac (23 years)		
MAR (%)	PAW	Economic Harvest age	Best Thinning Regime	PAW	Economic Harvest age	Best Thinning Regime
3	27778	38	60% BA	51030	38	60% BA
5	23223	30	60% BA	44969	30	60% BA
7	21151	25	60% BA	42665	26	60% BA
9	20202	22	60% BA	42040	24	60% BA

Table 10 shows the results from simulated equal increments of the real prices on the main products (sawlogs and pallet-logs) derived from the stands. No change in the best thinning regime was found for either of the stands when reasonable changes in the real price of the products were assumed (less than 25%). However, the harvest age varied from 22 to 31 years. Similar results were found from the sensitivity analysis done for the Xopanac stand (thinned at age 19). The best thinning regime did change only when increasing the real prices of the wood products by 25 and 50% above the benchmark prices

Results not reported in Table 10 indicated that if pallet-logs had a price equal to the price for sawlogs the harvest age would decrease by five years (to 25) and the best thinning regime would be no-thinning for the Atlamajac stand. Simulating the same conditions for the Xopanac stand, harvest age would decrease by 3 years (to 27) and the best regime would be, again, no-thinning. Also. if there were no market for fuelwood, harvest age would increase by 2 years, from 30 to 32 years. However, for both stands the best thinning regime would remain unchanged. If pallet-log price decreased to pulpwood price, harvest age and best thinning regime would not change for the Atlamajac stand.

Table 10. PAW, economic harvest age (E.H.), and best thinning regime (B.T.R.) for simulated increases and decreases in the price of sawlogs and pallet-logs.

↑ or ↓ in Price. (%) of Benchmark		Stand (year of thinning)					
		Xopanac (19 years)			Atlamajac (23 years)		
Sawlog	Pallet-log	PAW	E.H.	B.T.R	PAW	E.H.	B.T.R
Price increment							
50	50	36745	27	No-Thin.	68126	26	No-Thin.
25	25	29166	27	No-Thin.	54462	26	No-Thin.
10	10	25100	30	60% BA	48190	31	60% BA
5	5	24094	30	60% BA	46488	30	60% BA
Price decrement							
5	5	22218	30	60% BA	43275	30	60% BA
10	10	21223	29	60% BA	41579	30	60% BA
25	25	18297	28	60% BA	36646	30	60% BA
50	50	13847	22	60% BA	28552	27	60% BA

If the same is simulated for the Xopanac stand, harvest age would increase by one year, from 30 to 31 years, but still thinning at 60% of the initial basal area at age 19 would be the best management alternative.

Doubling thinning and harvesting prices (a 100% increase) did change the harvest age to 32 years, but best regime did not change for the stand harvested at 23 years of age and with higher initial growing stock (Atlamajac). The same was observed for Xopanac stand; no change in the best thinning regime, but the resulting harvest age was one year longer (31 years). A 50% increase in thinning and harvesting costs did not result in important changes in any of the stands.

Finally, thinning costs higher than harvesting costs were simulated (M$55 for sawlogs and pallet-logs, and M$45 for fuelwood), but no changes were observed in the best harvest age and thinning regime.

5. CONCLUSIONS AND FINAL COMMENTS

The financial analysis carried out in this study demonstrates that, subject to the limitations of the data, thinning even-aged natural stands of *Pinus patula* increased the present value of net gains if compared with the no-thinning alternative. The best thinning regime encountered was to thin the stands at 60% of initial basal area at the age of 23 years. This regime resulted in the maximum value of present certainty equivalent of attained wealth (M$44969/ha) considering a rotation age of 30 years. This value is 9% higher than the value calculated for the unthinned stand.

An approximate economic harvest age for patula pine was estimated to be between 26 and 30 years of age. Economic harvest ages (rotations) were shorter for the unthinned stands, while economic harvest ages were longer on the more severely thinned plots. A 30-year rotation age is 20 years shorter than the 50-year rotation currently being considered in the Chignahuapan, Puebla region.

In general, reasonable changes in the discount rate, prices of wood products, and harvest and thinning costs did not result in changes in the optimal regime; even though values of the present certainty equivalent of attained wealth criterion changed. This means that the values observed in the present study are not the main finding, but the fact that net gains can be increased by intensively managing natural even-aged stands. Absolute values for any economic criteria will depend on the economic assumptions holding when doing the analysis, which rarely are constant among periods and forest managers.

The financial performance of the growing stock, measured as the forest value growth rate or internal rate of return, might be improved up to more than 50% by thinning the stands to 60% of initial basal area when they are between 19 and 22 years old and considering a 30-year rotation. In terms of the equivalent annual income criterion, thinning can increase the gains by almost 450%.

Additionally to its strong theoretical foundations, the present certainty equivalent of attained wealth (PAW) model, used in this thesis to define the best management regime, adequately represents the conditions under which forest investments are carried out by the main suppliers of wood products in Mexico; the ejidos. Ejido members (*ejidatarios*) have a high time preference (strong desire to increase current consumption) which is properly taken into account with the PAW model by assuming that wealth created during the production cycle is not reinvested but consumed.

Prices of wood products collected for the present study suggest that in high inflationary periods these prices tend to increase, in real terms. In periods of low inflation, wood product prices caught up with the inflation rate. Unfortunately the data available are limited and no definitive conclusion can be reached. However, if as expected, more data on Mexican wood prices become available in the future, it would be interesting to monitor this hypothesis. If true, and additional incentive to invest in forestry related projects could be identified for economies characterized by high levels of inflation.

This study is an initial, reduced in scope, step toward defining economically optimum management regimes for natural even-aged patula pine stands in Mexico. Much research work remains to be done to define definitive optimal management strategies that might improve the benefits derived from utilizing this species. The following are some recommendations (which apply for all species and have been stated by other authors) that could help to focus the research efforts to achieve a better understanding and management for the species: (1) It is necessary to start collecting data on costs regarding silvicultural labors (thinning, harvest, regeneration, etc.), as well as stumpage prices for different forest products (sawtimber, plywood, pallets, pulp, etc.). This information is difficult to find and necessary to carry out financial and or economic evaluations of management alternatives. (2) Better growth and yield models should be fitted to get more accurate growth and yield predictions applicable to a wider variety of stand conditions. Growth and yield models are the other necessary tool to evaluate management alternatives.

Finally, it is also necessary to develop studies on future trends for wood product prices, which will make it possible to account for some of the risk involved when evaluating management alternatives.

6. LITERATURE CITED

Aguirre-Bravo, C. 1985. Preliminary growth and yield study of *Pinus patula* natural stands. M.Sc. Thesis, Colorado State University. Fort Collins, CO. 112 p.

Almonte-Huerta, F. 1992. Estudio de manejo integral forestal del ejido Llano Grande, Chignahuapan, Puebla. B. Sc. Thesis. Universidad Autónoma Chapingo. Chapingo, Méx.. 103 p.

Arteaga-Martinez, B. 1985. Indice de Sitio para *Pinus patula* Schl. *et* Cham., en la región de Chignahuapan-Zacatlan, Puebla. M.Sc. Thesis. Colegio de Postgraduados. Montecillo, Méx.. 181 p.

Avery, T. E. and H. E. Burkhart. 1994. Forest measurements. McGraw-Hill, New York. 408 p.

Bentley, W.R. and Teeguarden, D.E. 1965. Financial maturity: a theoretical review. For. Science 11(1):76-87.

Borders, B.E., W.D. Greene, and M.L. Clutter. 1991 Variable bedding, planting, harvesting, and transportation costs impact optimal economic management regimes. South. J. Appl. For. 15(1):38-43.

Broderick, S.H., J.F. Thurmes, and W.D. Klemperer. 1982. Economic evaluation of old-field loblolly pine plantation management alternatives. South. J. Appl. For. 6(1):9-15.

Chang, S.J. 1984. Determination of optimal rotation age: a theoretical analysis. For. Ecol. Manage. 8:137-147.

Chang, S.J. 1983. Rotation age, management intensity, and economic factors of timber production: do changes in stumpage price, interest rate, regeneration cost, and forest taxation matter?. For. Science 29:267-277.

Chappelle, D.E. and T.C. Nelson. 1964. Estimation of optimal stocking levels and rotation ages of loblolly pine. For. Science 10(4): 471-502.

Clutter, J. L. 1963. Compatible growth and yield models for loblolly pine. For. Science 9(3):354-371.

Clutter, J. L. *et al.*. 1983. Timber management: A quantitative approach. Krieger Publishing Company, Malabar, Florida. 333 p.

Clutter, J. L., Dell, T. R., and G. H. Brister. 1981. Application of available growth and yield data for management decisions. In Proceedings of a Symposium on the Managed Slash Pine Ecosystem. Univ. of Fla., Gainesville.

Davis, L.S. and K.N. Hohnson. 1987. Forest management. McGraw-Hill. Third Edition. 790 p.

De los Santos-Posadas, H. M. 1993. Respuesta de crecimiento en rodales coetaneos de *Pinus patula* Schl. *et* Cham. relacionando variables de densidad y productividad. B. Sc. Thesis. Universidad Autónoma Chapingo, Chapingo, Méx. 47 p.

De los Santos-Posadas, H. M., J.R. Valdez-Lazalde, and A. Velázquez-Martínez. 1995. Variación de rendimiento total y commercial en rodales aclareados de *Pinus patula*. Resúmenes. II Congreso Mexicano sobre Recursos Forestales. Sociedad Mexicana de Profesionales Forestales A.C. Montecillo, México. 91 p.

Dobie, J. and D.M. Wright. 1978. Economics of thinning and pruning -A case study. The Forestry Chronicle. 54:34-38.

Duerr, W.A. 1960. Fundamentals of forestry economics. McGraw-Hill Inc. New York. 485 p.

Duerr, W.A. 1993. Introduction to forest resource economics. McGraw-Hill Inc. New York. 485 p.

Eng, H., Johnson, K.N., and Fight, R.D. 1990. Financial analysis of early stand treatments in Southwest Oregon. Res. Pap. PNW-RP-427. Portland, OR. 25 p.

Fedkiw, J. and J.G. Yoho. 1960. Economic models for thinning and reproducing even-aged stands. J. of Forestry 58(1):26-34

FIRA (Fideicomisos Instituidos en Relación con la Agricultura en el Banco de México). 1993. Criterios actuales en el análisis financiero. Bol. Informativo No. 249. 27 p.

Flora, D. F. 1964. Uncertainty in forest investment decisions. Journal of Forestry 62(6):376-379.

Fortson, J.C. 1986. Factors affecting the discount rate for forestry investments. Forest Products Journal 36(6):67-72.

Foster, B.B. 1982. Four horsemen of the NIPF apocalypse. J. of Forestry 80(11): 706-708.

Franklin, C., Hazel, D. W., and Rucker, R. R. 1990. Thinning and harvesting regimes for yellow-poplar. South. J. Appl. For. 14(3):101-103.

Gansner, D.A., S.L. Arner, and S.J. Zarnoch. 1990. Timber value growth rate in Maine. North. J. Appl. For. 7:62-64.

Clutter, J. L., Dell, T. R., and G. H. Brister. 1981. Application of available growth and yield data for management decisions. In Proceedings of a Symposium on the Managed Slash Pine Ecosystem. Univ. of Fla., Gainesville.

Davis, L.S. and K.N. Hohnson. 1987. Forest management. McGraw-Hill. Third Edition. 790 p.

De los Santos-Posadas, H. M. 1993. Respuesta de crecimiento en rodales coetaneos de *Pinus patula* Schl. *et* Cham. relacionando variables de densidad y productividad. B. Sc. Thesis. Universidad Autónoma Chapingo, Chapingo, Méx. 47 p.

De los Santos-Posadas, H. M., J.R. Valdez-Lazalde, and A. Velázquez-Martínez. 1995. Variación de rendimiento total y commercial en rodales aclareados de *Pinus patula*. Resúmenes. II Congreso Mexicano sobre Recursos Forestales. Sociedad Mexicana de Profesionales Forestales A.C. Montecillo, México. 91 p.

Dobie, J. and D.M. Wright. 1978. Economics of thinning and pruning -A case study. The Forestry Chronicle. 54:34-38.

Duerr, W.A. 1960. Fundamentals of forestry economics. McGraw-Hill Inc. New York. 485 p.

Duerr, W.A. 1993. Introduction to forest resource economics. McGraw-Hill Inc. New York. 485 p.

Eng, H., Johnson, K.N., and Fight, R.D. 1990. Financial analysis of early stand treatments in Southwest Oregon. Res. Pap. PNW-RP-427. Portland, OR. 25 p.

Fedkiw, J. and J.G. Yoho. 1960. Economic models for thinning and reproducing even-aged stands. J. of Forestry 58(1):26-34

FIRA (Fideicomisos Instituídos en Relación con la Agricultura en el Banco de México). 1993. Criterios actuales en el análisis financiero. Bol. Informativo No. 249. 27 p.

Flora, D. F. 1964. Uncertainty in forest investment decisions. Journal of Forestry 62(6):376-379.

Fortson, J.C. 1986. Factors affecting the discount rate for forestry investments. Forest Products Journal 36(6):67-72.

Foster, B.B. 1982. Four horsemen of the NIPF apocalypse. J. of Forestry 80(11): 706-708.

Franklin, C., Hazel, D. W., and Rucker, R. R. 1990. Thinning and harvesting regimes for yellow-poplar. South. J. Appl. For. 14(3):101-103.

Gansner, D.A., S.L. Arner, and S.J. Zarnoch. 1990. Timber value growth rate in Maine. North. J. Appl. For. 7:62-64.

Gong, P. 1991. Forest economics and timber harvest scheduling: and overview and analysis. Dept. of Forest Economics. Swedish University of Agricultural Sciences. 89 p.

Guttenberg, S. 1950. The rate of interest in forest management. J. of Forestry. 48(1):3-7.

Hirshleifer, J. 1970. Investment, interest, and capital. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 320 p.

Hush, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. John Wiley & Sons.

INEGI (National Institute of Statistics, Geography, and Informatics). 1997. Banco de información económica de INEGI. http://dgcnesyp.inegi.gob.mx/cgi-win/bdi.exe.

Jiin-Shyang, H. and J. Buongiorno. 1997. Financial performance of maple-birch stands in Wisconsin: value growth rate versus equivalent annual income. North. J. Appl. For. 14(2):59-66.

Jonsson, B. and T. Jonsson. 1992. Optimal harvesting time in single- and multiple-purpose forest management. Scand. J. For. Res. 7:571-574.

Kellogg L.D. and E.D. Olsen. 1988. Economic evaluation of thinning alternatives in western hemlock-sitka spruce forest. Western J. of Appl. For. 3(1):14-17.

Klemperer, W. D., Cathcard, J. F., Haring, T., and Alig, R. J. 1994. Risk and the discount rate in forestry. Can. J. For. Res. 24:390-397.

Klemperer, W. D. 1996. Forest resource economics and finance. McGraw-Hill. 551 p.

LeDoux C. and J.D. Brodie. 1982. Maximizing financial yields by integrating logging and silvicultural thecniques. Journal of Forestry. 80:717-720.

Lewis, D.K. 1976. Principles and procedures in the economic analysis of stand treatments for timber production. University of Oxford. Ph.D. Thesis. Oxford, England. 352 p.

Lewis, D.K. 1985. Economic principles for forestry investments. In Join Proceedings of the 1985 Southern Forest Economics Workshop and the 1984 Southern Economic Association Convention. p. 151-164.

Lewis, D.K. 1986. Economics of stand management. In Proceedings of Symposium on the Shortleaf Pine Ecosystem. Little Rock, Arkansas. p. 178-210.

Lynch, T. B.; Murphy, P. A.; and Lawson, E.R. 1991. Stand volume equations for managed natural even-aged shortleaf pine in Eastern Oklahoma and Western Arkansas. Research Report P-192. Agric. Exp. Sta.. Division of Agriculture, Oklahoma State University. 11 p.

Meyer, H. A. 1940. A mathematical expression for height curves. J. For. 38:315-320.

Morales, R. A. 1991. Consideraciones silvícolas y beneficios contables de la aplicación de aclareos en *Pinus patula* Schl. *et* Cham en Chingnahuapan, Puebla. B. Sc. Thesis. Universidad Autónoma Chapingo, Chapingo, Méx. 116 p.

Morales, M. 1997. Personal communication. Forestry consultant. Chignahuapan, Puebla, México.

Murphy, P. A. 1982. Sawtimber growth and yield for natural even-aged stands of shortleaf pine in the West Gulf. USDA For. Serv. Res. Pap. SO-181. 13 p.

Murphy, P. A., E. R. Lawson, and T. B. Lynch. 1992. Basal area and volume development of natural even-aged shortleaf pine stands in the Ouachita Mountains. South. J. Appl. For. 16(1):30-34.

Newman, D.H. 1988. The optimal forest rotation: a discussion and annotated bibliography. Gen. Tech. Rep. SE-48. Asheville, NC. USDA For. Ser. Southeastern Forest Experimental Station. 47 p.

Nepamuceno-Martínez, F. *et al.*. 1994. Guía tecnológica para el establecimiento de plantaciones de pino patula (*Pinus patula*) en México. INIFAP. Guía Técnica No.4. Coyoacan, D.F. México. 49-8 p.

Perry, J. P. 1991. The pines of Mexico and Central America. Timber Press, Portland, OR. 231 p.

Price, C. 1993. Time, discounting and value. Blackwell Publishers. 393 p.

Rollins, K. *et al.*. 1995. A financial analysis of a white pine improvement cut in Ontario. The Forestry Chronicle. 71(4):466-472.

Rose, D. W., Blum, C. R., and G. J. Brand. 1988. A guide to forestry investment analysis. USDA, For. Ser. Res. Pap. NC-284. 23 p.

SARH, Subsecretaría de Planeación. 1994. Compendio estadístico de la producción forestal, 1989-1993. 267 p.

SAGAR-DGIAFFS (Secretariat of Agriculture, Livestock and Rural Development). 1994. Anuario estadístico de la producción forestal 1994. 115 p.

Schumacher, F. X. 1939. A new growth curve and its applications to timber-yield studies. J. For. 37:819-820.

SEMARNAP (Secretariat of Environment, Natural Resources, and Fishery). 1997a. Anuario estadístico de la producción forestal 1995. 115 p.

SEMARNAP (Secretariat of Environment, Natural Resources, and Fishery). 1997b. Programa de apoyos para el desarrollo de plantaciones comerciales (PRODEPLAN). Documento Divulgativo. 24 p.

Solberg B. and R.G. Haight. 1991. Analysis of optimal management regimes for *Picea abies* stands using a stage-structured optimal-control model. Scand. J. For. Res.. 6:559-572.

Straka, T.J. and Hotvedt, J.E. 1985. Economic aspects of the forest regeneration delay decisions. South. J. Appl. For. 9(2): 91-94.

Stokes, B.J. 1992. An annotated bibliography of thinning literature. Gen. Tech. Rep. SO-91. New Orleans, LA. USDA, For. Serv. 177 p.

Sutherland, C. 1970. Economics of thinning. In Proceedings of the Symposium on Management of Young Growth Douglas-Fir and Western Hemlock. OSU, Corvallis, OR. Edited by Alan B. Berg. p. 102-105.

Thompson, E. M. 1968. The theory of decision under uncertainty and possible applications in forest management. For. Sc. 14(2):156-163.

Thuesen, G.J. and W.J. Fabrycky. 1989. Engineering economy. Prentice-Hall, Inc. Englewood Cliffs.

Velazquez, M. A., *et al.*. 1992. Análisis estructural de un bosque de *Pinus patula*, como resultado de la aplicación de aclareo. Agrociencia. Serie de recursos naturales renovables 2(1):13-25.

Vela, G. L. 1976. Contribución a la ecología de *Pinus patula* Schel. *et.* Cham. Pub. Esp. No. 19. SARH, SFF, INIF, Mexico. 172 p.

Willis, R.A. and Affleck, P.N. 1990. Financial evaluation of regeneration alternatives. In Regenerating British Columbia's Forests. Vancouver, Canada: University of British Columbia Press. Editors. p. 18-29.

Worthington, N.P. and J. Fedkiw 1964. Economic considerations in management of Douglas-fir growing stock... a case study. USDA For. Serv., PNW Res. Pap. PNW-12.

Wright, J.A., Osorio, L.F., and W.S. Dvorak. 1995. Recent developments in a tree improvement program with *Pinus patula* in Colombia. For. Ecol. and Manag. 72: 229-234.

Zepeda B., E.M. and F. Almonte H. 1994. Sistema de cubicación para *Pinus patula* Schl. and Cham., de Chignahuapan, Puebla. Resúmenes, Simposio y II Reunión Nacional de Silvicultura y Manejo de Recursos Forestales. Colegio de Postgraduados. Montecillo, Mex. 58 p.

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