AN ABSTRACT OF THE THESIS OF

Kevin R. Birch for the degree of Master of Science in Forest Management presented on June 9, 1989.

Title: Determining the Cost of Old-Growth Set-Asides On the OSU College Forest

Abstract approved: Signature redacted for privacy.
K. Norman Johnson

The objectives for the use of the Oregon State University college forest include providing both facilities for research and teaching, and providing funding through timber harvest. The older age-classes of the forest are valuable for attaining both objectives. The opportunities and costs of removing acreage in the older age classes from the timber harvest base were examined.

Harvest schedules were developed using a model II linear programming formulation with the OSU Forestry Model. The harvest schedules used the current management policies of the forest managers and different levels of set-asides with a non-declining even flow of volume constraining the harvest level. The current rotation age of 90 years was found to be constraining the harvest level in the first

four decades, therefore a set of harvest scheduling runs using a 60 year rotation age were done.

Using the existing management policies and a rotation age of 90 years, the managers of the college forest can set-aside the oldest 686 acres of the forest without reducing the current harvest level. The cost of the set-sides (calculated as the difference between present net values of 100 year harvest schedules with and without the acreage removed) was between $5500 and $4500 per acre depending on the amount of acreage removed. The change in rotation age produced only slight changes in the cost of set-asides.

The current harvest level could be increased immediately to a level near long-term sustained yield by using a rotation age of 60 years. This would increase the present net value of the harvest schedule by about $5 million.

By using a rotation age of 90, more age classes can be represented on the forest over time. After four decades the harvest volume can be increased to the long-term sustained yield level. At that time the harvest would be obtained from fewer acres than if the forest was on a 60 year rotation.

DETERMINING THE COST OF OLD-GROWTH SET-ASIDES ON THE OSU COLLEGE FOREST

by

Kevin R. Birch

A Thesis
submitted to
Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

Completed June 9, 1989
Commencement June 1990

APPROVED:

Signature redacted for privacy.

Professor of Forest Management in charge of major

Signature redacted for privacy.

Head of department of Forest Management

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented June 9, 1989

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DETERMINING THE COST OF OLD-GROWTH SET-ASIDES ON THE OSU COLLEGE FOREST

INTRODUCTION

The Oregon State University college forest consists of 14,378 acres of forest land located in the Oregon coast range. The land is administered by the Forest Properties Department of the OSU College of Forestry. The college forest provides a wide variety of outputs including timber, water and recreation as well as jobs and work experience for students.

Among the most important outputs of the college forest are the facilities it provides for teaching and research. Diversity of age class structure is a critical element necessary to maintain the range of opportunities for teaching and research now being provided by the college forest. As the population becomes more urbanized, natural timber stands increase in value as a social good for recreation and as wildlife habitat. This will cause public pressure for set-asides of older timber to increase (Walt,1986). It is important to examine forest policies now in order to provide for future demands.

Harvesting of timber on the college forest is also an important activity. It provides needed funds used to finance research and teaching, jobs and experience for students, and examples of forest management techniques used for instruction. For these reasons a constant level of timber harvest and cash flow provided through timber harvesting is a desirable output. The management policies employed on the college forest now, will determine the level of these and other outputs which can be provided in the future. Therefore, a strategic planning model needs to be adapted for use on the college forest in order to help understand the implications of different management policies, and to ensure a continuous supply of these valuable outputs.

Problem

The objectives on the college forest include providing both a high timber harvest level and cash flow, and representing older age-classes on the forest. The presence of older age-classes of timber can be insured through the use of old-growth set-asides. Old-growth set-asides would prohibit timber harvesting on designated areas of the forest. Since much of the commercial value of the forest is in the older age-classes, the two goals are in direct conflict. Can older age-classes be set-aside while maintaining the current level of timber harvest? And what impacts will the current management policies have on both the age-class structure of the forest and the level of timber harvest and cash flow?

We wish to evaluate the cost of old-growth set-asides under the current management policies of the college forest. Due to "the allowable cut effect", the value of old-growth set-asides cannot be calculated as the value of the standing timber, because there are multiple use constraints and constraints on the harvest flow. (Binkley,1984). In this case the harvest is constrained by the forest policy of producing an even-flow of revenue and harvestable volume. To determine the cost of old-growth set-asides, different harvest schedules must be compared.

A harvest schedule will be developed using the current management policies of the college forest and no old-growth set-asides. This schedule can then be used as a base line when comparing other possible harvest schedules. The impacts of different levels of old-growth set-asides on the timber harvest level and cash flow from the forest will be examined by increasing the amount of acres set-aside in other runs. As different levels of old-growth set-asides are considered, comparison of the total discounted value of these new harvest schedules with the value of the base line run will allow a cost for old-growth set-asides to be calculated in terms of the current management practices.

Problem Size

The problem consists of allocating harvest and non-harvest areas on the 14,378 acres of forest land. These acres are divided into two forests, McDonald and Dunn forests with 11,947 acres and the Blodget forest with 2445 acres. For this problem only the McDonald and Dunn forests will be used. These forests contain the older aged timber and are being considered for set-asides. The forests are divided into nine tracts, 89 compartments, and 692 stands. For simulation purposes 408 acres were removed from the data base as permanently non-stocked acres, 47 acres were removed as recreation reserved areas, and 66 acres were removed as dedicated to long term research.

Objectives

The objectives of this study are three-fold:

1. To provide the OSU Forest Properties Department with a strategic planning model adapted for use on the college forest and capable of analyzing decision making policies.

2. To determine the costs of old-growth set-asides on the college forest, in terms of reductions in value,

using the current management policies.

3. To evaluate the current management policies to determine if alternative policies exist which can reduce the cost of old-growth set-asides.

LITERATURE REVIEW

Forest policy analysis of this sort has been done in the past mainly using two techniques: linear programming and binary search. Linear programming has been used extensively by the USDA Forest Service and private industry while the Bureau of Land Management, Weyerhaeuser and others have relied on binary search (Johnson and Tedder 1983). In addition to these two techniques a third approach (referred to here as "shadow price search") developed by Hoganson and Rose (1984) will be discussed.

Binary Search

Binary search is an algorithm which tries to find the largest even-flow of harvest or discounted net revenue which can be maintained over a given period of time, subject to user specified ending conditions. The algorithm is called binary search because there are only two possible alternatives: increase the harvest level, or decrease the harvest level. Davis and Johnson (1987) define the steps of the algorithm as:

1. Set the amount of first-period harvest volume.
2. Select the stands to harvest from the inventory list to provide the needed harvest volume using priority

rules.

3. Grow all stands for one period, creating the forest structure by age and volume just before second-period harvest.
4. Repeat steps 2 and 3 for each subsequent period, checking at each iteration to see that the required harvest can be achieved. If not, return to step 1 and reduce the first-period harvest.
5. After the harvest in the final planning period, check the residual forest structure to see whether it meets ending requirements. If there is too much inventory, return to step 1 and increase the first-period harvest. Then repeat steps 2 through 5.
6. When the ending condition at step 5 converges to within a certain percentage of the desired ending condition, stop the process and report the latest first-period harvest level as the maximum sustainable harvest level.

Many different variations and computer models exist which employ this basic technique including SIMAC (Sassaman et al. 1972), ECHO (Walker, 1976), and TREES (Johnson et al. 1975 and Tedder et al. 1980).

Since binary search considers only one decision variable, the level of harvest, all other variables must be specified by the user. This creates both advantages and disadvantages when compared with linear programming. Johnson and Tedder (1983) identify the advantages of binary search as ability to (1) portray the inventory in greater detail, (2) shift acreage more simply in and out of the forest inventory base, (3) produce analysis at lower cost, and (4) find feasible solutions more easily.

Some of the disadvantages with binary search are also related to using a single decision variable. Harvest priority is normally set as either oldest stand first or minimum value growth first, and one rule cannot be optimal for all circumstances. Since all management regimes and thinning alternatives must be specified prior to the analysis the model cannot choose the optimal combination of treatments for each stand.

Linear Programming

Linear programming has been used extensively in forest planning. The objective function is usually specified to maximize present net value, or volume over the planning horizon, subject to constraints such as leaving a specified amount of ending inventory, leaving a given number of acres in a certain age-class over time, and not allowing the harvest level to fluctuate more than a given amount. Because a linear program is able to simultaneously consider all possible management alternatives, it can determine the optimal solution for the information it is given. Two different mathematical structures, called model I and model II by Johnson and Scheurman (1977), have been used in forest planning. The basic difference between the two is the way in which regenerated acres are handled. In model I the acres in different existing stands, regenerated in the same period, are carried as separate stands in the future rotation. In a model II formulation all the acres regenerated in the same period, that will receive the same treatment, are accumulated into a single management unit, regardless of stand origin. Several forest planning models such as MAX MILLION (Clutter, 1968) and RAM (Navon, 1971) have used the model I formulation, while MUSYC (Johnson and Jones, 1979) and FORPLAN (Johnson and Stuart, 1985) allow either type of formulation to be used.

The advantages of linear programming over binary search as identified by Johnson and Tedder (1983) are its ability to (1) simultaneously consider alternative yield trajectories for the same acres, (2) portray unusual yield trajectories, (3) constrain portions of the inventory, and (4) find the optimum. Linear programming can choose among multiple management regimes for the same acres at the same time. It also has the advantage, through shadow prices, of identifying the variables that are constraining the objective function.

Convery and Ralston (1977) suggest that some of the limitations of linear programming are due to the fact that an objective function must be specified. Only one goal is in the objective function and all other goals or objectives must be specified as constraints. Therefore, optimal solutions are truly best only in terms of the one goal or objective function that is optimized. They also suggest that data requirements for forest plans, both in terms of quantity and quality for use in linear programming models, are often so high that the method is inappropriate. Assumptions designed to circumscribe these high requirements have the effect of reducing the power of the algorithm that is utilized.

Shadow Price Search

Another harvest scheduling approach was developed by Hoganson and Rose (1984) and studied by Eldred (1987). It is a heuristic approach which combines some of the advantages of linear programming and binary search.

Shadow price search assumes that future timber output levels are difficult to predict and that small violations of constraints are not critical. Instead of solving the primal linear programming problem, shadow price search starts with the dual feasible problem and works toward primal feasibility. The heuristic approach decomposes the linear program into sub-problems for each stand-type and uses dynamic programming to solve for the optimal harvest schedule for the stand type. The amount harvested in each period is used as a constraint linking the dual problems with primal problem. Shadow prices (dual variables) are estimated for the harvest in each period, and the dual problems are solved assuming the shadow prices are correct. The algorithm then checks to see how close to primal feasibility the solution is, if it is outside a pre-set range, the shadow prices are re-estimated and the problem is solved again.

Eldred (1987) found that the "shadow price search" algorithm produces harvest schedules with similar harvest patterns and present net worth as those produced by a linear program. One of the strengths of the algorithm is that it always finds a solution that is optimal for the harvest levels that result. The running time for the algorithm was less than that of linear programming but greater than that of binary search. The shadow price search technique is capable of handling many stands with relatively small volume in each. The shadow prices associated with the technique give limited approximations of the cost of meeting harvesting constraints. One problem Eldred found was that the shadow price adjustment procedures are arbitrary and there is no guaranty of convergence on a solution. Another problem is that only one linkage constraint may be used, where a linear program can specify multiple constraints. Shadow price search seems to be a promising technique for the future but it is still experimental and not available as a publicly documented or commercially distributed harvest scheduling model.

Model Chosen

A model II linear programing formulation with the OSU FORESTRY MODEL was chosen for use in this study. The linear program allows a maximization and alternative yield streams to be considered simultaneously. The OSU FORESTRY MODEL's input conventions were designed to allow the inventory to be represented in great detail. The model specification allows number of trees per acre, basal area, and volume to be represented for both softwoods and hardwoods. The high cost associated with linear programming models has also been overcome by designing the OSU FORESTRY MODEL to be used on a micro-computer instead of a main frame computer.

CURRENT MANAGEMENT POLICIES
ON THE COLLEGE FOREST

The following information was obtained through personal interviews with the forest manager and his staff, and from examination of past annual reports.

Land Allocations

The college forest consists of about 14,378 acres of forest land. Of this land 408 acres are considered to be permanently non-stocked. This area consists of grass balds, rock pits, power lines, reservoirs, and other lands. About 47 acres are devoted strictly to recreation. This area is mainly in Peavy Arboretum. Another 66 acres of the forest is reserved for long-term research projects. The remaining 13,875 acres are in the timber base. Deducting the area in the Blodget tract, 11,426 acres remain in the timber base for use in this simulation (Table 1).

Of these acres 448 are proposed to be removed from timber harvest consideration and designated as old-growth reserve areas. These areas were left in the timber base for simulation purposes, but will be withdrawn during the analysis using an oldest first rule. An additional 635 acres of the timber base have greater than 75 percent hardwood basal area and will not be considered for timber harvest. These lands are considered to be predominantly in the riparian zone and will be left as buffers.

Table 1 Land Allocations For McDonald Forest

Item		Acres
Permanently Unstocked Areas		408.1
Recreation Reserve Areas		47.0
Long Term Research Areas		66.1
Timber Base		11426.0
Proposed Old-growth Reserve	448.0	
Unavailable Hardwood acres	635.3	
Total McDonald & Dunn		11947.2

Regeneration

The goal of the forest is to have between 250 and 350 evenly distributed, free to grow, Douglas-fir trees per acre established within five years after harvest. To accomplish this goal the school forest plans to use a system of site preparation, planting, and chemical control of grass.

Monitoring of regeneration success will be done with stocking surveys at stand ages of one, three, and five. During these stocking surveys additional treatments of inter-planting, or vegetative control will be prescribed.

Site preparation will be accomplished using a technique of piling and burning logging residues where slopes are less than 20 percent and machines can pile the brush. On steeper slopes crews will cut and spray brush by hand.

The sites will be planted to a density of 360 trees per acre the winter after harvest using 2-0 Douglas-fir seedlings.

During the first or second year after planting all sites will be sprayed to reduce competition from grass.

Seedling survival and competition with broad-leaved species will be checked during stocking surveys. If there are less than 200 evenly distributed trees per acre on the site then inter-planting will be done to bring the site up to a level of 300 trees per acre. If less than 200 trees per acre are not in a free-to-grow condition (over-topped by competing vegetation) the site will be sprayed to reduce competition from broad-leafed species.

Commercial Thinning

The college forest's objective is to commercially thin each stand with greater than 60 percent softwoods at least twice during a rotation. The first thinning is to be done between age 30 and 40. The forest goals are to take 30 percent of the stems, 15 percent of the volume, and leave about 150 square feet of basal after the first thinning.

The goals for the second commercial thinning are to enter the stand about 10 years after the first thinning between the ages of 40 and 60. At this time the forest manager would like to remove 40 percent of the stems, 20 to 25 percent of the volume and leave the stand with about 160 square feet of basal area.

Existing stands which have greater than 40 percent hardwood basal area will not be thinned. These stands will be converted to softwoods at the time of harvest.

Final Harvesting

Final harvest is done using the clear-cutting technique. Stands are chosen for harvest on the basis of slowest net growth per acre first. There is a target rotation age of 90 to 100 years on McDonald and Dunn forests. There is a harvest goal of producing 4.5 million board feet of softwood timber from McDonald and Dunn (at least 0.75 - 1.0 million from thinning) annually. Depending on market conditions, annual fluctuations in the harvest volume of up to 25 percent are acceptable.

No harvesting is planned in pure hardwood stands. All hardwood stands (greater than 75 percent hardwood basal area) were assigned to the No Harvest category (NOHARV) because of the lack of commercial value in these stands. These stands are also predominantly in riparian areas and will be left as buffer zones.

Mixed stands greater than 90 years of age, with at least 25 percent softwood basal area, and at least 10 MBF of merchantable softwoods per acre will be harvested and converted to Douglas-fir.

METHODS AND PROCEDURES

To develop the harvest schedule for the college forest a linear programming formulation was chosen. This will allow the maximum present net value of the forest, under each set of management alternatives, to be compared when determining the cost of set-asides. The base-line run will use the current management policies of the college forest and no set-asides, subsequent runs use increased amounts of acreage set-aside or relaxed harvesting policies.

A linear program of the following form will be used:

MAX $c \quad x$

SUBJECT TO

$x \quad <= \quad b \qquad j = 1 \; .. \; n$

$a \quad x \quad >= \quad a \quad x \qquad j = 1 \; .. \; n$

WHERE

x = acres of stand i in period j

c = net revenue from harvest of stand i in period j

a = yield of stand i in period j

b = acres in stand i

n = the number of periods

k = the number of stands

In the following sub-sections is a discussion of the procedures used to enter the management policies of the college forest into the OSU Forestry Model.

Organizing The Inventory Data

Information was taken from the college forest inventory for use as a data base in the model. Data was taken at the stand level, then stands with similar stand characteristics were aggregated into analysis areas. The analysis areas are the smallest units of land recognized within the model. A listing of the analysis areas, with all the inventory information used in the model can be found in Appendix B. Within the analysis areas individual stands were combined by age into five year age classes. The information taken from the inventory and its use in the OSU Forestry Model will be described below.

The OSU Forestry Model uses up to six levels of identifiers to describe the characteristics of stands. Management practices can then be applied to analysis areas based on one or any combination of these identifiers. All six of the identifiers were provided for use by the college forest but only identifiers #3, #4, and #5 were used in this study.

The college forest inventory uses a combination of forest, tract, compartment, and stand numbers to identify the physical location of stands. Tract and compartment numbers were chosen for use as the identifiers # 1 and # 2. They allow physical location to be taken into account when specifying management policies.

Identifier # 3 uses the major species in the stand. Stands with less than 40 percent hardwood basal area were categorized by the major softwood species in the stand. This was either Douglas-fir (Pseudotsuga menziesii) or western hemlock (Tsuga heteraphilla). Stands with between 40 and 75 percent hardwood basal area were classified as mixed stands (MX), and stands with greater than 75 percent hardwood basal area were considered as hardwoods(HD).

King's site class was taken from the inventory for use as Identifier # 4. It was chosen to allow different management prescriptions to be applied to areas based on the differences of site class.

A measure of operability was chosen for use as identifier # 5. Forest policy is to use tractor logging in areas with a slope less than 25 percent, and to use cable yarding where slope exceeds 25 percent. Average slope from the inventory was used to classify stands as either tractor (TR) or cable (CA), with 25 percent being the dividing point. This will allow better estimation of costs.

Aspect was used for Identifier # 6. Two categories were recognized North and East (NE), and South and West (SW). Average stand aspects of north, northwest, northeast, or east were grouped into NE and aspects of south, southeast, southwest, or west were grouped into SW. After reviewing past records, it was felt that these two groupings best represented the past use of different vegetation control techniques.

Other stand level information taken from the inventory for use as input in the model was stand age, King's site index, and stand acres. The inventory lists many stands as being two storied. In these cases the age used was the average of over-story and under-story age weighted by the basal area in each category. For multi-storied stands a combined site index is reported. This was used as the site index for the entire stand. Age is only reported for the softwoods in the inventory, therefore it was also used as the age for the hardwoods in the same stand.

The rest of the information used by the model for its data base came from the diameter class tables in the inventory. The OSU Forestry model recognizes both a softwood and a hardwood category within an analysis area. The information gathered from each stand was basal area, trees per acre, total cubic foot volume. The diameter class tables in the inventory are organized by species, and all of the softwood species were combined into one category for use in the model.

The diameter class tables in the inventory included a diameter class for trees from 0.1 - 2.0 inches. Large numbers of trees per acre were reported in this diameter class making the average diameter of the stand misleading when used for purposes of calculating log valves. After examining the heights of this diameter class, when compared to the rest of the stand, in all cases of stands over the age of 20 the 0.1 - 2.0 inch class was found to be over topped. Therefore, trees per acre, basal areas, and volumes associated with the 0.1 - 2.0 inch diameter class were removed from the data used in the model.

Table 2 shows that, using the equations adapted for the model, there is no practical difference between the volumes calculated for stands grown with or without the 0.1 - 2.0 inch diameter class. Six stands of various ages and trees per acre were taken from the inventory data and grown for ten years with the equations. In table 2 the resulting volumes and basal areas after growth are very similar.

Table 2 Comparison of Basal Area, Trees Per Acre, and Volume Calculations On Stands Grown For Ten Years With and Without the 0.1 - 2.0 Inch Diameter Class

Without 0.1 - 2.0 inch diameter class

STAND AGE	TPA	BA	CUFT/AC
25	62.5	83.2	473.5
46	148.7	74.5	1293.6
51	112.9	140.4	3222.7
63	188.0	185.3	5423.6
65	107.7	78.5	3466.3
79	87.9	116.3	2847.0

With 0.1 -2.0 inch diameter class

STAND AGE	TPA	BA	CUFT/AC
25	140.7	82.0	473.5
46	301.6	75.5	1318.4
51	112.9	140.4	3222.7
63	545.2	185.7	5423.6
65	222.6	121.9	3491.1
79	183.7	117.6	2847.0

volume. To develop the equations site indexes of 80, 100,

Growth And Yield Equations

The growth and yield equations used in the OSU Forestry model were suggested by Brian Greber using a form borrowed from Clutter (1983). Using the <u>Stand Projection System</u> (SPS) growth and yield simulator (Arney, 1985) to generate data, and linear regression to fit the equations, a series of equations were developed to predict basal area growth, change in trees per acre, and volume growth.

The system of equations approach was chosen because it allows more detail to be represented in the model and increases the speed of the model. The most common approach to predicting growth and yield has been the use of a series of tables which represent the volume of analysis areas at different ages. The forest is stratified into analysis areas with similar conditions and a yield table is created for that analysis area. All the stands within that analysis area receive the same volume at a given age. In contrast, with the use of equations all stands within the analysis areas are allowed to have a separate and distinct volumes. The other advantage to equations is speed of calculation. Computers are able to preform computations faster than they can access information in a table.

Equations were developed to predict basal area growth, change in the number of trees per acre, and cubic foot volume. To develop the equations site indexes of 80, 100, 120, and 145 were specified. For each site index stands from age 20 to 130 at 10 year increments were grown with SPS. Starting values of trees per acre and basal area were randomly generated as input parameters and checked to be within logical ranges by SPS. Using this information as input for SPS the stands were grown for five years. Output from the SPS runs was then used as input for regression analysis to develop equations predicting the desired information.

A list of the regression equations and the coefficients can be found in Appendix A.

Table 3 shows the yields predicted by the equations compared to actual volumes from the inventory. The yield equations represent regional averages and in most cases slightly over-predict the existing volumes on the college forest inventory. To overcome this problem, the OSU Forestry Model inputs the actual volume and calculates an incremental increase in the volume.

Table 3 Volume Predicted By Growth and Yield Equations Compared With Volumes On the College Forest

		VOLUME	
AGE	BA	PREDICTED	ACTUAL
40	116	3592	3293
50	102	3247	2939
60	158	5629	5983
70	176	7923	7442
80	169	7532	6779
90	193	7108	7604
100	223	10845	10291

On the college forest most stands are mixed conifer and hardwood. The equations for these stands use Douglas-fir as the conifer species, because it is the predominant softwood on the forest, and red alder as the hardwood species because it is the only hardwood species available in SPS.

Management Policies On The College Forest

The following sub-sections of the paper define the forest management policies used on the college forest and illustrate how the policy was entered into the OSU forestry model.

Timber Harvest. The policy on the college forest is to produce a sustainable flow of volume and cash from the timber harvest. The forest managers have never done an in depth harvest scheduling analysis to determine the sustainable harvest level on the college forest. Historically the harvest level has been set by the forest manager and his staff. One of the questions to be answered by this study is whether the current level of harvest can be maintained if the proposed 448 acres of older timber are removed from consideration for harvest.

On McDonald and Dunn forests a minimum rotation age of 90 was used. The rotation age and harvest goals were obtained from personal communication with the forest manager.

The forest policies of even-flow and a minimum final harvest age of 90 (Table 4) were modeled with linear programming. Present net worth at a four percent interest rate was maximized for 10 decades subject to constraints to ensure a non-declining yield of timber volume over time. Only choices for management that met the minimum rotation age policy were allowed.

The most recent annual reports have shown an annual harvest averaging about 1 million cubic feet (4.5 million board feet) of volume harvested per year. As different amounts of acreage are removed in the analysis, the harvest level produced will be compared to the existing level of 1 million cubic feet per year.

Table 4 Timber Harvest

Area	Rotation Age	Harvest
Mc & Dunn	90	Even Flow

Commercial Thinning. The commercial thinning options within the OSU Forestry model are keyed to relative density and age. The age controls were set to allow thinning between the ages of 30 and 60 to coincide with the college forests policies.

The relative density controls were difficult to set to reflect the forest's policies. These guidelines are generally in terms of basal area. The relative density controls were adjusted until the model produced either two or three light commercial thins between the ages of 30 and 60. The total acreage and volume thinned by the model were also examined to see that they were close to existing levels produced by the forest.

A relative density factor of 50 was chosen as the minimum value which must be met before commercial thinning would take place. At this time the stand will be thinned back to a relative density of 40. Using the relative density factor of 50 as the trigger for commercial thinning ensures that the stand will not reach a high level of competition and cause mortality. Thinning to a relative density of 40 produces a series of light thinnings which does not reduce volume growth. The relative density factor of 40 was also chosen because it simulates a level of thinnings close to the total acreage and volume now thinned from the college forest.

Existing Management Intensities. Several silvicultural treatments are used on the college forest. They include chemical release (RL), commercial thinning (CT), and final harvesting (FH). Acres were assigned to different combinations of these treatments, as shown in Table 5, based on stand characteristics and the policies of the forest managers.

The mixed stands which have between 40 and 75 percent hardwood basal area were assigned to the final harvested only category (FINHAR). This reflects the forest manager's policy of not commercially thinning stands with this large a hardwood component.

All hardwood stands (greater than 75 percent hardwood basal area) were assigned to the No Harvest category (NOHARV) because of the lack of commercial value in these stands. These stands are also predominantly in riparian areas and the forest manager plans to leave them as buffer zones.

Softwood stands between the ages of 0 and 10 were given two possible alternative yield trajectories. The linear program was allowed to choose between the commercial thin final harvest (CTFH) option, or the intensive management option which included release (release commercial thin final harvest RLCTFH). The effects of the release treatment were assumed to be removal of the hardwood competition and attainment of greater basal area at age 20. Softwood stands from age 11 - 60 were assigned to the CTFH intensity to reflect the college forests policy of commercial thinning. Softwood stands over age 60 were assigned to the final harvest only option (FINHAR).

Table 5 Existing Management Intensities

	Components			Management
Species Type	RL	CT	FH	Intensity
Hardwood				NOHARV
Mixed			X	FINHAR
Softwoods				
Age 0 - 10		X	X	CTFH
	X	X	X	RLCTFH
Age 11 - 60		X	X	CTFH
Age 61 - 500			X	FINHAR

Transitional Probabilities After Harvest and Regeneration

Mixed Stands. After harvesting, mixed stands will be planted with Douglas-fir seedlings and receive a chemical release treatment. According to research done on the Siuslaw National Forest (USDA Forest Service, 1980), after control of vegetation 80 percent of the stands attained full stocking with Douglas-fir seedlings. Therefore, 80 percent of the mixed stands will transfer to the Douglas-fir identifier after regeneration (Table 6) and 20 percent of the acres will remain as mixed stands.

Douglas-fir. Regeneration of Douglas-fir stands will be accomplished by planting Douglas-fir seedlings. Due to the forest managers estimate that 60 percent of the stands would benefit from release and the 20 percent failure rate for release treatments, 12 percent of the harvested Douglas-fir acres will be assigned to the mixed category and the remaining 88 percent will be assigned to Douglas-fir (Table 6). This percentage is similar to the percentage of mixed stands currently on the forest (14 percent).

Table 6 Transitional Probabilities

Donor Species	Receiver Species	Proportion
Douglas-fir	Douglas-fir	88 %
	Mixed	12 %
Mixed	Mixed	20 %
	Douglas-fir	80 %

Future Management Intensities. The linear program was given a choice of treatments for use in Douglas-fir stands (Table 7). A less intensive treatment (PLCTFH) which includes planting (PL), site-preparation (SP), and commercial thinning (CT); and an intensive treatment {PLRECT which includes site-preparation (SP), planting (PL), release treatments (RL), commercial thinning (CT) and final harvest (FH)}.

The mixed stands will not be commercially thinned. All mixed stands will be assigned to plant (PL), release (RL), and final harvest (FH) (PLRLFH, Table 7).

Table 7 Future Management Intensities

	Component					Management
Species	SP	PL	RL	CT	FH	Intensity
Douglas-fir	X	X		X	X	PLCTFH
	X	X	X	X	X	PLRECT
Mixed	X	X	X		X	PLRLFH

Reforestation Density. The stocking surveys done on the college forest do not include data on hardwood trees or success of release treatments. Therefore, it was not possible to determine accurate stocking level distributions for regenerated stands in many of the management intensity categories. It was assumed that stands receiving release treatments would have 291 Douglas-fir trees per acre and 80 square feet of basal area at age 20 (Table 8). The 291 trees per acre and the basal area of 80 square feet were obtained from SPS runs using a site index of 115 (the average site on the college forest) and the 300 tree per acre goal of the college forest at age 10.

Estimates for the management intensities without release and for the mixed stands came from the college forest inventory. In each case an average value was calculated from the college forest inventory using stands in the 15 to 25 year old age class which had data available.

I felt that due to the practices used 15 to 25 years ago on the college forest, the stands in that age class would accurately represent the stocking levels achieved without herbicides. Stands from the softwood category averaged 287 softwood trees per acre with 50 square feet of basal area and 92 hardwood trees per acre with 15 square feet of basal area. Stands from the mixed category averaged 137 softwood trees per acre with 39 square feet of basal area and 200 hardwood trees per acre with 51 square feet of basal area.

Table 8 Reforestation Density

Species	Management Intensity	Softwood TPA	Softwood BA	Hardwood TPA	Hardwood BA
Douglas-fir	PLCTFH	287	50	92	13
	PLRECT	291	80	0	0
Mixed	PLRLFH	137	39	200	51

Cost Data

Costs for regeneration were obtained through communication with the forest manager and his staff (Table 9). Two site preparation techniques will be used depending on the site. Pile and burn will be done on sites with less than 25 percent slopes, where tractors can be used. On steeper slopes the unit will be hand slashed and treated with herbicides. All units will be sprayed for grass. This cost includes an estimated 90 percent aerial and 10 percent ground spray. Release from broad-leaved competition will be done with a combination of aerial broadcast spraying and basal spraying, depending on the site.

Table 9 Costs

Action	Cost Per Acre
Stocking Surveys	$ 1.65
Planting	$ 144
Site Preparation	
Pile and burn	$ 70
Grass spray	$ 17
Slash and treat	$ 32
Release	
Broadcast	$ 41
Basal spray	$ 40

Revenue

Revenue net of logging and hauling costs in dollars per thousand cubic feet by quadratic mean diameter (QMD) was obtained from the forest plans of the Siuslaw Notional Forest (Roland, pers. comm.) (Table 10). The forest service prices were used because not enough data could be found in the college forest records to develop a price by diameter relationship for the college forest revenues. These prices were only applied to the softwoods in this study because the college forest does not market hardwood logs from the forest.

When compared with net revenues for recent sales on the college forest the values obtained were fairly close to the values in Table 10. However, the values for thinning revenue in Table 10 seem to be somewhat low and the values for small diameter final harvests appear to be high. The forest service prices were used because they were the best information available.

Table 10 Net Revenue From Timber Harvest

QMD	$ / MCF
Thinning	
10 - 12	103
12 - 14	221
14 +	361
Final Harvest	
10 - 12	724
12 - 14	781
14 - 16	827
16 - 18	885
18 - 20	931
20 - 22	976
22 - 24	1010
24 - 26	1030
26 - 28	1050
28 - 30	1060
30 - 32	1080
32 - 36	1090
36 - 38	1110
38 - 40	1140
40 +	1050

Conversion Factors

Board foot per cubic foot conversion factors (Table 11), were developed to convert merchantable cubic foot volume (5" minimum diameter to a 4" top, 33′ logs) to merchantable board foot scribner volume (9" minimum diameter to a 6" top, 33′ logs). To develop the conversion factors SPS was used to create a data base of stands with different volumes and diameters. Regression analysis was then used to predict the ratios based on the quadratic mean diameter of the stand.

Table 11 Board Foot Per Cubic Foot Ratios

QMD	BF/CF
0-7	1.63
7-8	2.08
8-9	2.47
9-10	2.82
10-11	3.14
11-12	3.43
12-13	3.69
13-14	3.94
14-15	4.17
15-16	4.38
16-17	4.58
17-18	4.77
18-19	4.95
19-20	5.12
20-21	5.29
21-22	5.44
22-23	5.59
23-24	5.73
24+	5.86

Comparison of Volume Yields Used In The OSU Forestry Model With DFSIM

Table 12 shows a comparison of the yields used in the OSU FORESTRY model with those from DFSIM. It can be seen that the yields used in this study are slightly on the conservative side in most cases. The yields for sites 1, 2, and 3, even with intensive management, are all slightly less than the 100% yields from DFSIM. The yields for site 4 are higher than those predicted by DFSIM.

The table also shows the present net value (PNV) for the regenerated stands, under both management regimes. The values were calculated using the costs and revenues listed in the earlier sections, a 4 percent discount rate, and a 90 year rotation age.

Table 12 Volume and Present Net Value for Regenerated Stands With and Without Intensive Management At a Rotation age of 90, Compared With Volume Estimates From DFSIM

DF	VOL/AC (MCF)		DFSIM VOL		PNV $/AC	
SITE	W/O INT	W/INT	70%	100%	W/O INT	W/INT
1	17.7	18.9	14.1	20.1	422	518
2	14.0	15.0	11.2	15.9	274	341
3	10.6	11.5	8.5	12.1	139	150
4	8.7	9.4	6.2	8.8	35	58

DFSIM yields reduced by 3% to convert from total cubic feet to 5" minimum diameter to a 4" top.

ANALYSIS AND CONCLUSIONS

McDonald and Dunn forests only (not Blodget) were analyzed to find a sustainable harvest level and to determine the cost to the college forest of removing acreage in the older age classes. These forests were used because they are the only ones being considered for set-asides by the management of the college forest.

Calculation of Long-Term Sustained Yield

Long-term sustained yield (LTSY) was calculated using the cubic foot yield of softwoods at culmination of mean annual increment (CMAI) for each site class and species. CMAI was used as a physical measure of the forests ability to produce volume. Using the equations in the OSU Forestry Model, CMAI of the cubic foot volume occurred at age 70 for the Douglas-fir stands and 90 for the mixed stands.

Acreage distributions for future stands in each site class were assumed to be 88 percent Douglas-fir and 12 percent mixed due to the transitional probabilities discussed earlier.

In Table 13 the acreage in each site class is multiplied by the per acre volume at CMAI and summed across each species. The total volume contribution from each species is divided by the rotation age for that species, and the two contributions are added together. This calculation represents the highest volume that would be produced on a "fully regulated forest" (Davis and Johnson, 1987).

Table 13 Long-Term Sustained Yield

DF SITE	ACRES	MCF/ACRE CMAI (70)	TOTAL MCF
1	315.4	15.3	4825.6
2	4858.7	13.1	63649.0
3	4016.6	9.5	38157.7
4	466.2	7.8	3636.4
TOTAL	9659.9		110268.7
Contribution to LTSY		/ 70 =	1575.2
MX		CMAI (90)	
1	43.0	8.1	348.3
2	662.6	6.3	4174.4
3	547.7	4.2	2300.3
4	55.9	3.1	173.4
TOTAL	1309.2		6996.5
Contribution to LTSY		/ 90 =	77.8

LONG TERM SUSTAINED YIELD = 1653.0 MCF/YEAR

Harvest Scheduling Runs

Harvest scheduling runs for this study were done with the OSU Forestry Model. The runs use all of the management policies of the college forest put into the context of the model as shown in the sections above and a non-declining even flow (NDEF) constraint to represent the forest management's desire for a stable timber harvest. The objective function of the linear program was to maximize present net value with a 4 percent interest rate. The base run used a minimum harvest age of 90 years and no older acreage set-aside. Successive runs had an increasing amount of acreage removed from the data base in the older age classes. Age classes over age 100 were assumed to have (or be able to develop) the stand characteristics which would be valuable to preserve. There are currently 1283 acres of Douglas-fir stands over the age of 100 in McDonald forest. Successive runs set-aside increasing amounts of this acreage on an oldest first basis.

Harvest scheduling runs were done with zero acreage removed, all acres over an age of 130 years (323 acres) removed, all acres over 120 years of age (686 acres) removed, and all acres over 100 years of age (1283 acres) removed. The withdrawals were taken in an oldest first order on the assumption that this rule described the desirability of the stands as well as any rule. In determining the cost of set-asides this procedure produces an average cost for each acre removed.

After the first set of runs was complete it became apparent that the rotation age of 90 was constraining the harvest level, as well the NDEF constraint. To relieve this constraint, a set of runs (one for each withdrawal level) with a rotation age of 60 was also done.

Harvest Volume

Figure 1 shows that at the middle of the first period before harvest the bulk of the acreage (53%) is between 30 and 60 years of age, while the age classes over 90 years of age make up only 18% of the forest. These age classes are split into 11% between 90 and 120 years of age, and 7% over 120 years old.

When compared with the long-term sustained yield harvest level of 16530 MCF per decade calculated in Table 12, a much lower harvest level of 11760 MCF per decade can be sustained for the first four decades until these younger age classes can be harvested (under NDEF with a rotation age of 90 and all acres in the timber base; see Figure 2). After period 4 the forest is able to maintain a harvest very close to LTSY.

As acreage is removed from the older age classes of the timber base the sustainable harvest in the first four periods understandably decreases. With the 323 acres over the age of 130 removed a harvest level of 10915 MCF per decade can be harvested for the first 4 periods, and 16129 MCF per decade there after (Figure 2).

If 686 acres are removed from the forest a harvest of 10144 MCF per decade is sustainable from the forest for the first 4 decades. This harvest level is very close to the amount of 10000 MCF per acre per decade (4.5 MMBF per year converted with a factor of 4.5 BF/CF) currently being harvested on the college forest.

When the 1283 acres are removed from the timber base, the harvest level falls below the current harvest to a level of 8000 to 9000 MCF per decade.

The inventory, harvest, and growth of the forest with a rotation age of 90 and no acreage set-aside can be found in Table 14. The table shows a pattern of increasing inventory and decreasing growth during the first four periods while the younger age classes grow to harvestable age. After the fourth period the harvest volume increases to a level close to LTSY. The inventory reaches its peak in period 5 when the age class with the most acres (age 50 in the first period), reaches harvestable age. After period 5 the inventory declines. It will continue to decline until harvest and growth are in balance.

Table 14 Inventory, harvest and growth with a rotation age of 90 and no acres set-aside (MCF per decade)

PERIOD	INVENTORY	HARVEST	GROWTH
1	57960.891	11759.771	15530.811
2	61731.930	11759.769	15276.683
3	65248.844	11759.769	15027.878
4	68516.953	11759.768	14132.416
5	70889.602	16352.672	12918.242
6	67455.172	16352.673	13052.696
7	64155.195	16352.672	14009.816
8	61812.340	16352.675	13059.562
9	58519.227	16352.676	14137.121
10	56303.672	16352.675	

THIS REPORT SHOWS THE TIMBER INVENTORY BEFORE HARVEST AT THE MIDPOINT OF THE PERIOD, THE VOLUME HARVESTED THAT PERIOD AND THE VOLUME CHANGE (GROWTH) IN THAT PERIOD.

By using a rotation age of 60 and no set-asides the forest can sustain a harvest level very close to LTSY now (Figure 3). With a 60 year rotation age, the harvest schedules for all withdrawal levels produce a greater harvest than is currently being taken from the forest.

The inventory, harvest and growth for a harvest schedule with a rotation age of 60 and no set-asides can be seen in Table 15. It shows a much different pattern than was found with the 90 year rotation age in Table 14. With a 60 year rotation the inventory is declining through the harvest schedule, and the harvest starts at a much higher level. This is the result of the additional acreage being available for harvest from the existing stands.

When compared with the 90 year rotation, the actual amount of ending inventory on the forest is reduced by over 10 million cubic feet (23 percent) by using a 60 year rotation age.

Table 15 Inventory, harvest and growth with a rotation age of 60 and no acreage set-aside (MCF per decade)

PERIOD	INVENTORY	HARVEST	GROWTH
1	57960.887	16201.665	
			13985.220
2	55744.441	16201.660	
			13084.430
3	52627.211	16201.668	
			12592.445
4	49017.988	16201.663	
			12105.835
5	44922.160	16201.660	
			15657.988
6	44378.488	16201.670	
			16978.584
7	45155.402	16480.184	
			16704.598
8	45379.816	16480.180	
			16206.594
9	45106.230	17557.984	
			15649.180
10	43197.426	17557.984	

THIS REPORT SHOWS THE TIMBER INVENTORY BEFORE HARVEST AT THE MIDPOINT OF THE PERIOD, THE VOLUME HARVESTED THAT PERIOD AND THE VOLUME CHANGE (GROWTH) IN THAT PERIOD.

Annual Harvest Comparison

When the board foot harvest of the schedules with different set-aside levels is compared with the goals for the college forest, the same pattern encountered with the cubic foot harvest emerges. Table 16 shows that during the first decade the board foot harvest of each of the 60 year rotation aged schedules produces a volume in excess of the current harvest on the college forest.

The board foot harvest volume for the 90 year rotation age schedules only drops below the current harvest when 1283 acres are removed from the timber base (Figure 4). A removal of the oldest 686 acres on the forest still allows for a harvest slightly in excess of the current harvest level.

Figure 4 also shows the more erratic pattern associated with the board foot harvest produced by the harvest plans. While the cubic foot volume harvested stays at a constant level, the board foot harvest oscillates due to changes in the size of the timber cut and the amount of volume coming from commercial thinnings.

Table 16 also compares the average level of acreage thinned and final harvested on the college forest in the most recent annual reports with the levels generated by the harvest schedules during the first decade. Acreage thinned on the college forest has been between 29 and 257 acres annually while final harvest acreage has been between 104 and 162 acres.

The harvest schedules with 60 year rotations final harvest substantially more acres than are currently being harvested on the forest with each level of set-asides. The other treatment levels during the first decade fall within the ranges currently being experienced on the college forest.

Figure 5 shows the acres thinned and final harvested for the first five periods by the harvest schedule with a 90 year rotation age and no acreage removed. This pattern is typical of all the harvest schedules. The linear program harvests the largest, highest value timber in the first period and relies heavily on lower valued commercial thinnings to make up the volume in the second period. The average annual per decade acreage harvested and thinned still fall within the range experienced (Table 16) on the college forest in the past several years. In Table 16 the per acre volume from the harvest schedules is greater than the volume harvested currently on the college forest. There are several possibilities for why this happens. First the harvest schedules may be concentrating on harvesting larger timber during the first decade. Second since all volume is harvested at the middle of the period, the stands have grown for about ten years since the inventory was done. Third the inventory may overestimate the volume on the college forest.

Table 16 Comparison of Annual Harvest Levels on the College Forest With the First Decade of the Harvest Schedules

	First Period Annual Level		
Harvest Schedule	MMBF /YEAR	ACRES THINNED	ACRES HARVESTED
Current Harvest			
Average	4.500	158	126
High	4.916	257	162
Low	2.509	91	104
Rotation Age 90			
W/O 0 AC	5.696	124	121
W/O 323 AC	5.159	124	117
W/O 686 AC	4.688	124	108
W/O 1283 AC	3.615	124	87
Rotation Age 60			
W/O 0 AC	7.525	113	199
W/O 323 AC	6.936	108	201
W/O 686 AC	6.428	108	193
W/O 1283 AC	5.722	108	186

Effects of Intensification

All the harvest schedules described above allowed the linear program to choose between two different levels of management intensity (w/o int PLCTFH, and w/ int PLRECT) for the regenerated stands. The volumes and present net values with and without intensification for the 90 year rotation can be seen in Table 11. Except for periods 2 and 3 on the 90 year rotations (as mentioned above), all the stands receive the more intensive treatment.

One unexpected result was found in the 90 year rotation age runs. During periods 2 and 3 the site class 3 regenerated stands were not put into the intensive management category as they were on all other harvest schedules. Several factors contributed to this result. First the final harvest volume of a 90 year rotation is not available during the 10 decade harvest plan if the stand is regenerated after the first period (and the ending inventory is not valued). Second the value of the commercial thinnings alone is not sufficient to cover the intensification costs and produce a positive present net value in the context of the forest-wide analysis. And third the volume from the thinnings is not available until after the first four periods when it is needed most. The effect of putting these lands into a lower management intensity is to push the harvest from commercial thinnings on these lands back in time. Since the commercial thins alone do not add to the present net worth of the harvest schedule, and there are a surplus of stands available for harvest in periods 5 and 6, the linear program chose to spend less on these stands and accepts a slightly lower harvest level to produce a slightly higher present net value.

Table 17 shows the effects of intensification on the 60 year rotations to be far greater than on the 90 year rotations. On the 90 year rotations intensification causes an increase of only 65 thousand cubic feet (MCF) per period during the first four periods (0.56 percent) and an increase of 734 MCF in the periods after that. By contrast on the 60 year rotations, intensification increases the harvest by 733 MCF in each of the first six periods (4.74 percent).

Table 17 Harvest Volumes With and Without Intensive Management For Rotations of 60 and 90 With No Acreage Removed

Intensity		MCF/Period	MCF/Period
Rotation Age 90			
	Periods	1 - 4	5 - 10
W/O INT		11695	15619
W/ INT		11760	16353
Rotation Age 60			
	Periods	1 - 6	7 - 8
W/O INT		15469	15469
W/ INT		16202	16480

Revenue and Value

Figure 6 shows the revenue per decade over time from the forest under the 4 different set-aside levels and a rotation age of 90. With no set-asides the revenue is about $9 million per decade for the first four decades then the revenue jumps to a level of about $13 million. Each level of withdrawal lowers the revenue generated until the schedule with 1283 acres removed produces a revenue of about $6 million per decade.

In contrast the revenue per decade generated from using a rotation age of 60 years (Figure 7) and no set-asides, produces a constant revenue between $11 and $13 million. With 1283 acres removed the 60 year rotation age has a per period revenue of between $9 and $11.5 million.

All of the harvest schedules produce a pattern in which revenue declines in the second period. The goal of the linear program is to produce the highest possible PNV. In these harvest schedules the linear program has harvested the highest net value stands in the first period and relied heavily on lower valued commercial thinnings for volume in the second period. A harvest schedule with an even flow of cash could be produced but it would add another constraint to the model, lowering the PNV, and partially obscuring the cost of the set-asides.

The cumulative present net value (PNV) of the harvest schedules over time for the 90 year rotation can be found in Figure 8 and for the harvest schedules with 60 year rotations can be found in Figure 9.

Table 18 shows the total cumulative present net value of each of the harvest schedules, the amount of acreage removed from the timber base, the total cost of setting aside the removed acres, the average cost per acre of the set-asides, and the incremental cost per acre of increasing the amount of land set-aside.

The average cost of setting aside an acre changes depending on the value of the standing timber, the amount of timber removed from the harvest schedule, and the rotation age. The oldest age classes contain the most valuable timber and the highest volumes. Therefore, the average per acre cost of the removals shown in Table 18 declines.

The average cost of the set-asides in this study ranged from $4543 per acre to $5553 per acre. This is consistent with earlier work. Hunt (1986) studied the cost of old-growth set-asides on public lands in northwest Oregon. She examined differences in Forest Service and Bureau of Land Management harvest schedules with different levels of old-growth removals. She reports per acre cost ranges of $3436 to $5408 for old-growth preservation.

By allowing timber to be harvested at a younger age, the harvest schedules with a rotation age of 60 produce a higher PNV for each level of withdrawals because the older timber does not have to be metered out over as long a period of time. For this reason the value per acre of the acreage being set-aside is slightly greater on the harvest schedules with the 90 year rotation age.

The 60 year minimum rotation age relaxes an additional constraint on the harvest and makes another 38 percent of the current forest available for harvest in the first period (Figure 1). The 60 year harvest schedules can produce a 27.5 percent increase in cumulative PNV over the 90 year rotation with no acreage removed (29.9% w/o 322 ac., 32.5% w/o 686 ac., 39.2% w/o 1283 ac.).

Table 18 Cumulative Present Net Value Of 100 year Harvest Schedules And Cost Of Set-asides

1 M$ PNV	2 ACRES REMOVED	3 M$ COST	4 AVE $/ ACRE	5 INCREM. COST
Rotation Age 90				
24279	0	0	0	0
22491	322	1788	5553	5553
20908	686	3371	4914	4349
18050	1283	6229	4855	4787
Rotation Age 60				
30955	0	0	0	0
29220	322	1735	5388	5388
27712	686	3243	4727	4143
25126	1283	5829	4543	4332

4 (AVERAGE COST / ACRE) = 3 / 2

5 (INCREMENTAL COST / ACRE) = CHANGE IN 3 / CHANGE IN 2

Table 19 show a comparison of the per acre costs of set-asides calculated as the differences in the values of the harvest schedules, with the stand level values calculated as the value of the standing timber plus the value of a 100 year timber rotation. The values of the set-asides on a stand level are far greater than on the forest level under an even-flow constraint because the affect of removing the timber is not metered out over time.

Table 19 Per Acre Values of the Set-Asides From the Harvest Schedules Compared With Per Acre Stand Values

Harvest Schedule	Schedule Value	Stand Value
Rotation Age 90		
W/O 0 AC	0	0
W/O 323 AC	5553	8855
W/O 686 AC	4914	7570
W/O 1283 AC	4855	7334
Rotation Age 60		
W/O 0 AC	0	0
W/O 323 AC	5388	8960
W/O 686 AC	4727	7678
W/O 1283 AC	4543	7460

Acres By Age Class

One trade off for producing higher present net values with a younger rotation age is in the age class structure of the forest. Figures 10 through 13 show the age class structure of the forest over time for the 90 year rotations and Figures 14 through 17 show the structure of the 60 year rotations.

With a 90 year rotation age the acreage is spread over more of the age classes, offering greater diversity of opportunities for research and teaching. Figure 10 (90 year rotation, no set-asides) shows that the age classes between 60 and 120 continue to be one-third to one-half of the forest over time. In contrast, (Figure 14) using a rotation age of 60 removes all of the acres over age 90 by the fourth period, and the 60 to 90 age class by the seventh period.

The effects of not setting aside older stands can be found in Figures 10 and 14 (90 year rotation and no set-asides, 60 rotation and no set-asides). Regardless of rotation length after the first period the majority of the stands over age 120 are cut. With the 90 year rotation the forest retains acreage in the 90 to 120 year old range over the entire plan. With the 60 year rotation age all of the softwoods in the 90 to 120 age class are cut by the fourth period.

Conclusions

The current harvest level of 4.5 million cubic feet per year can be maintained with the proposed set-aside level of 448 acres. The college forest can maintain the current level of timber harvest and cash flow under the existing management policies, including a rotation age of 90, and set-aside the oldest 686 acres of the forest. After four decades of the existing policies the harvest can be increased to the long-term sustained yield level.

The cost of old-growth set-asides are similar with a 60 or a 90 year rotation age. Reducing the rotation age to 60 years, allows harvest to increase, but only reduces the cost of set-asides by about $200 per acre. The cost of removing the oldest 322 acres was about $5500 per acre and costs were between $4500 and $5000 per acre for the acres removed from the harvest schedules above that level.

An opportunity exists to increase the harvest level, and the present net value from the forest over time, by harvesting from the younger age classes on the forest. A rotation age of 60 would allow the forest to immediately increase the cut to about the long-term sustained yield capacity of the forest. This increases the present net value of the harvest schedule by about $6.7 million (27 percent) depending on the level of set-asides.

With a 90 year rotation age the harvest must remain lower for the first four decades after which it can increase to the long-term sustained yield level. This rotation length requires much less acreage harvested per year (1/90 instead of 1/60 of the forest harvested per year when regulated) to produce the same volume, and allows more acreage to be maintained in the older age classes for research and teaching.

Figure 1 Acres by age class at the middle of the first decade before harvest.

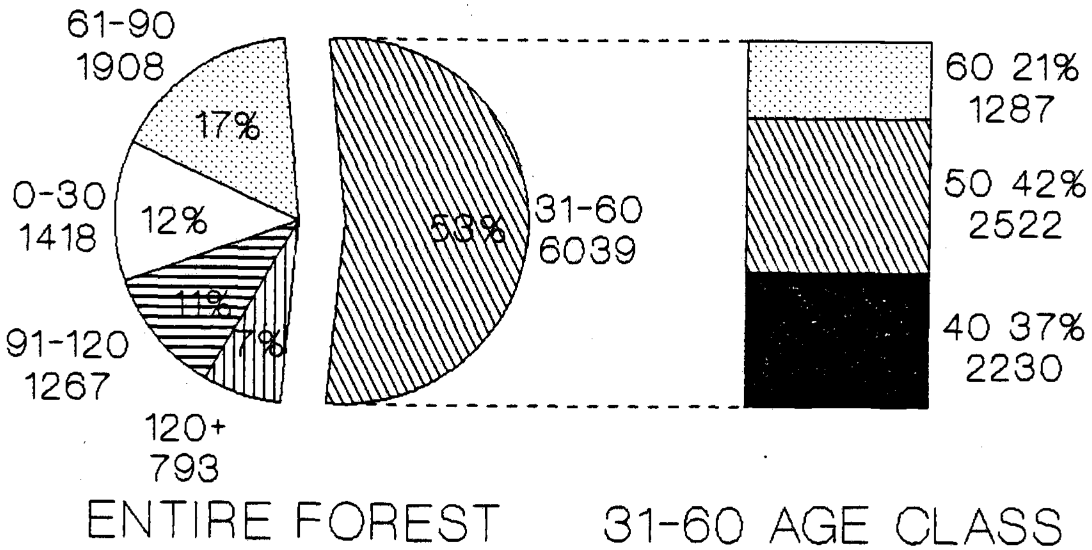


Figure 2 Harvest volume per period with a rotation age of 90. Long-term sustained yield for the entire forest compared to: Harvest with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed, and current harvest level.

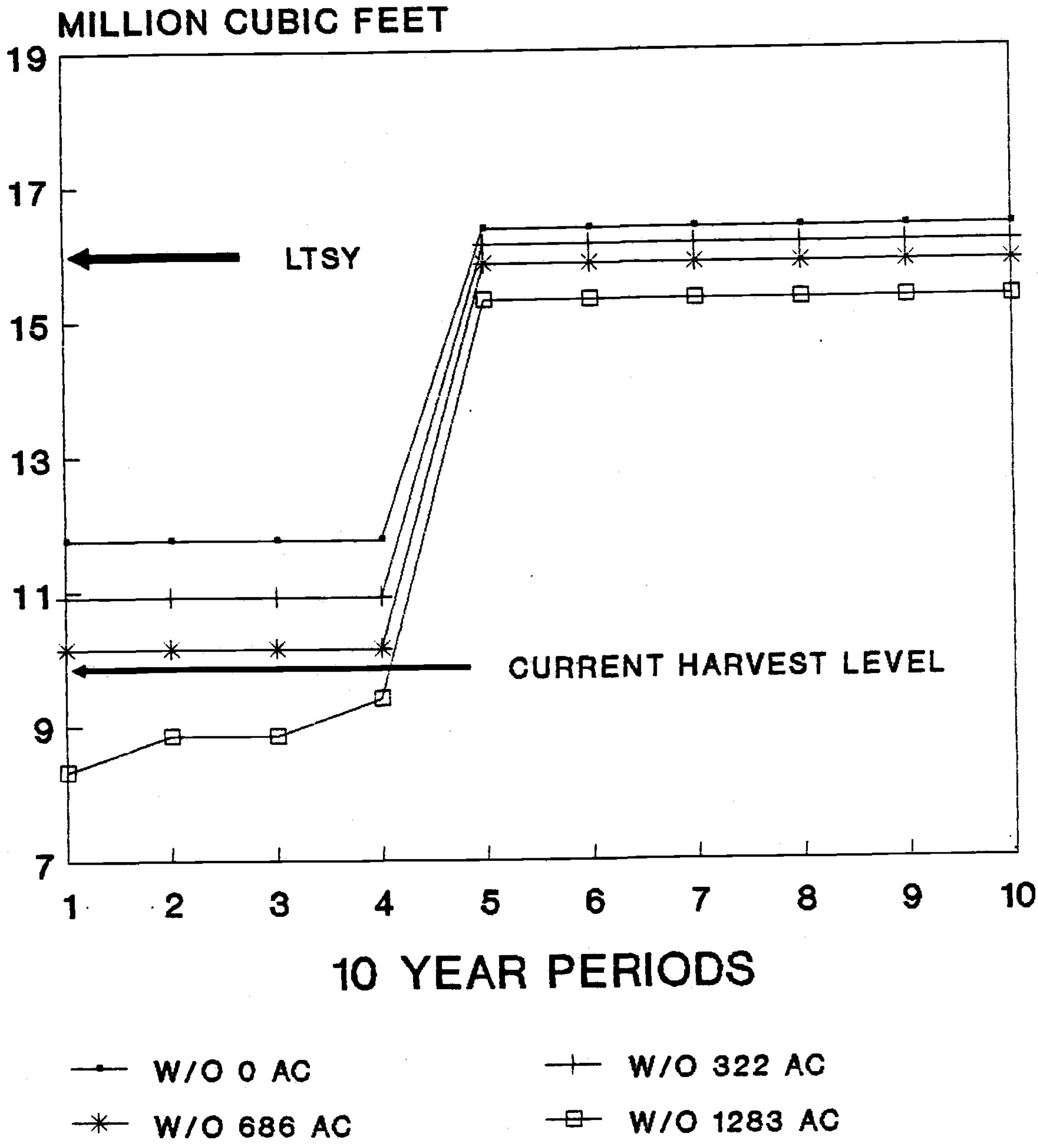


Figure 3 Harvest volume per period with a rotation age of 60. Long-term sustained yield for the entire forest compared to: Harvest with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed, and current harvest level.

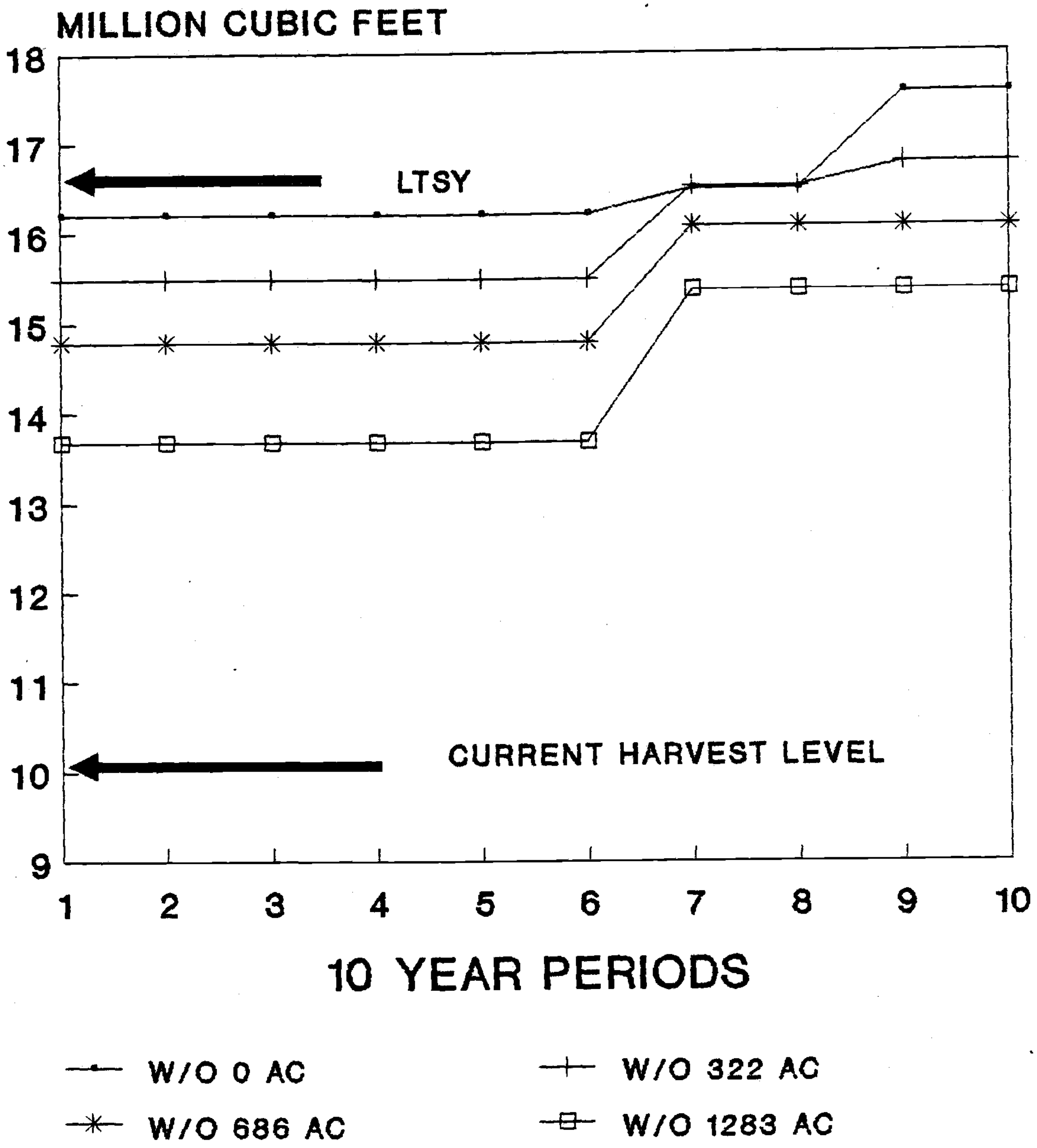


Figure 4 Board foot harvest volume per period with a rotation age of 90. Harvest with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed, and current harvest level.

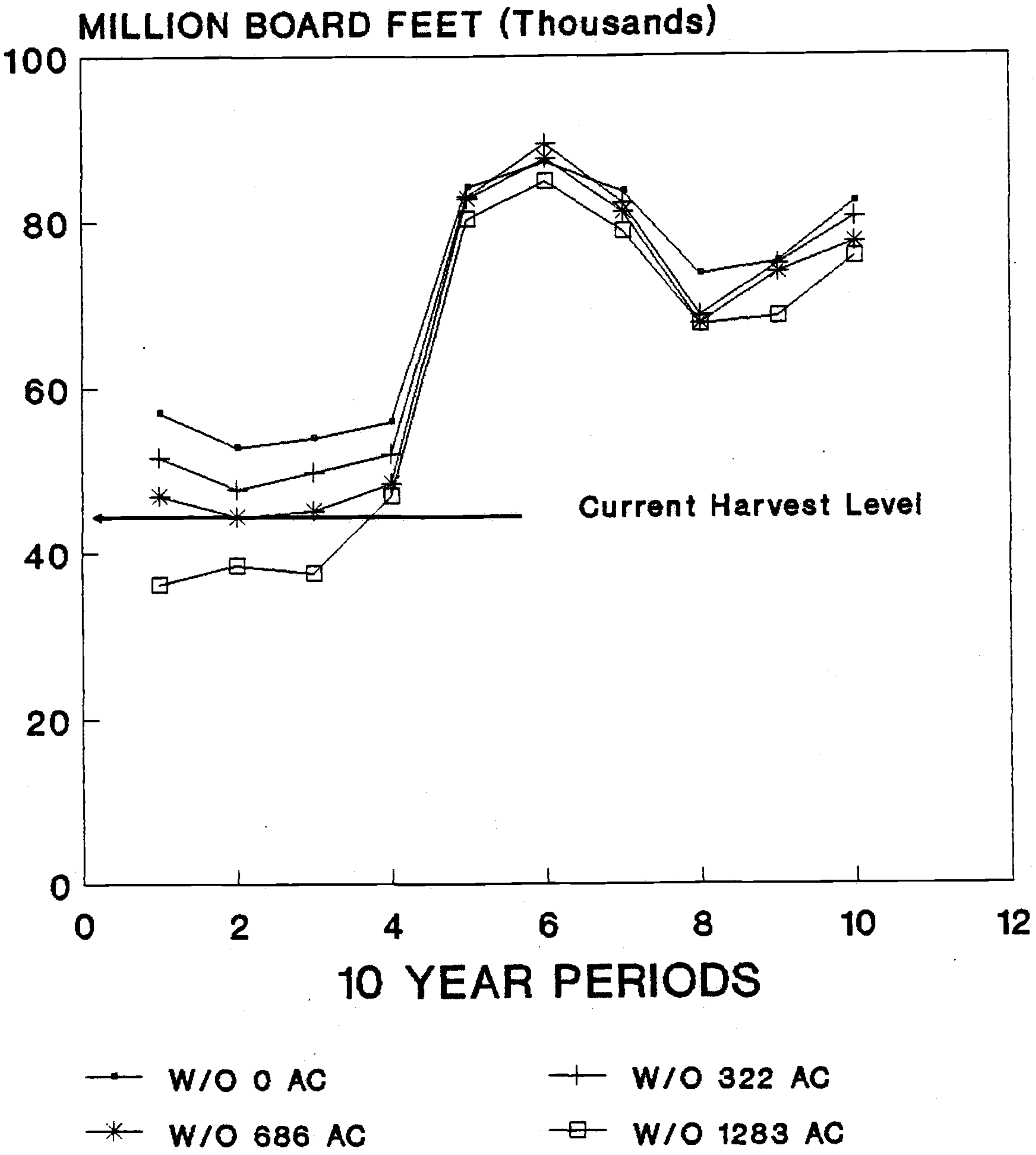


Figure 5 Acres commercially thinned and final harvested with a rotation age of 90 and no acres removed.

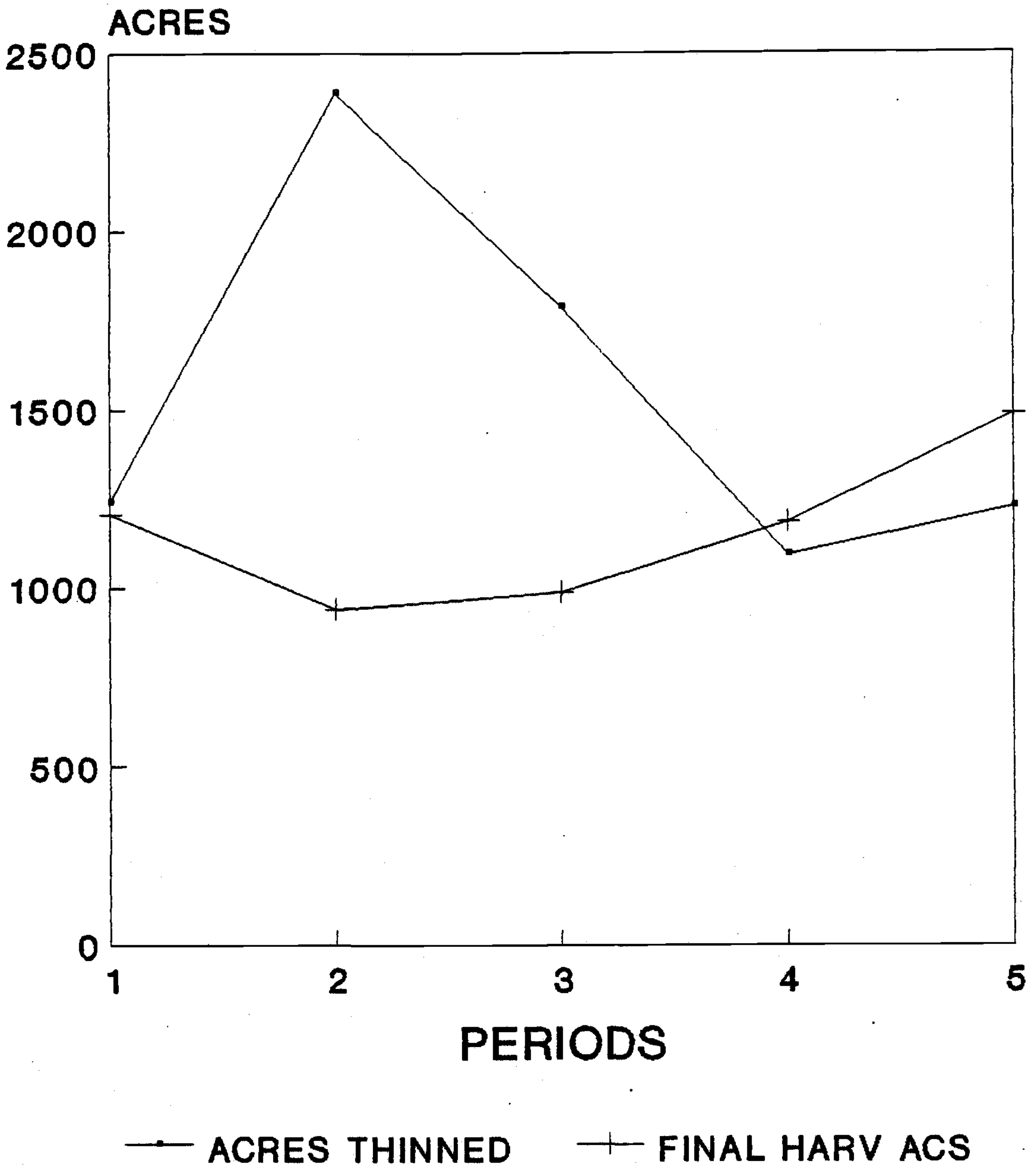


Figure 6 Net revenue per period with a rotation age of 90. Revenue from harvest schedules with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed.

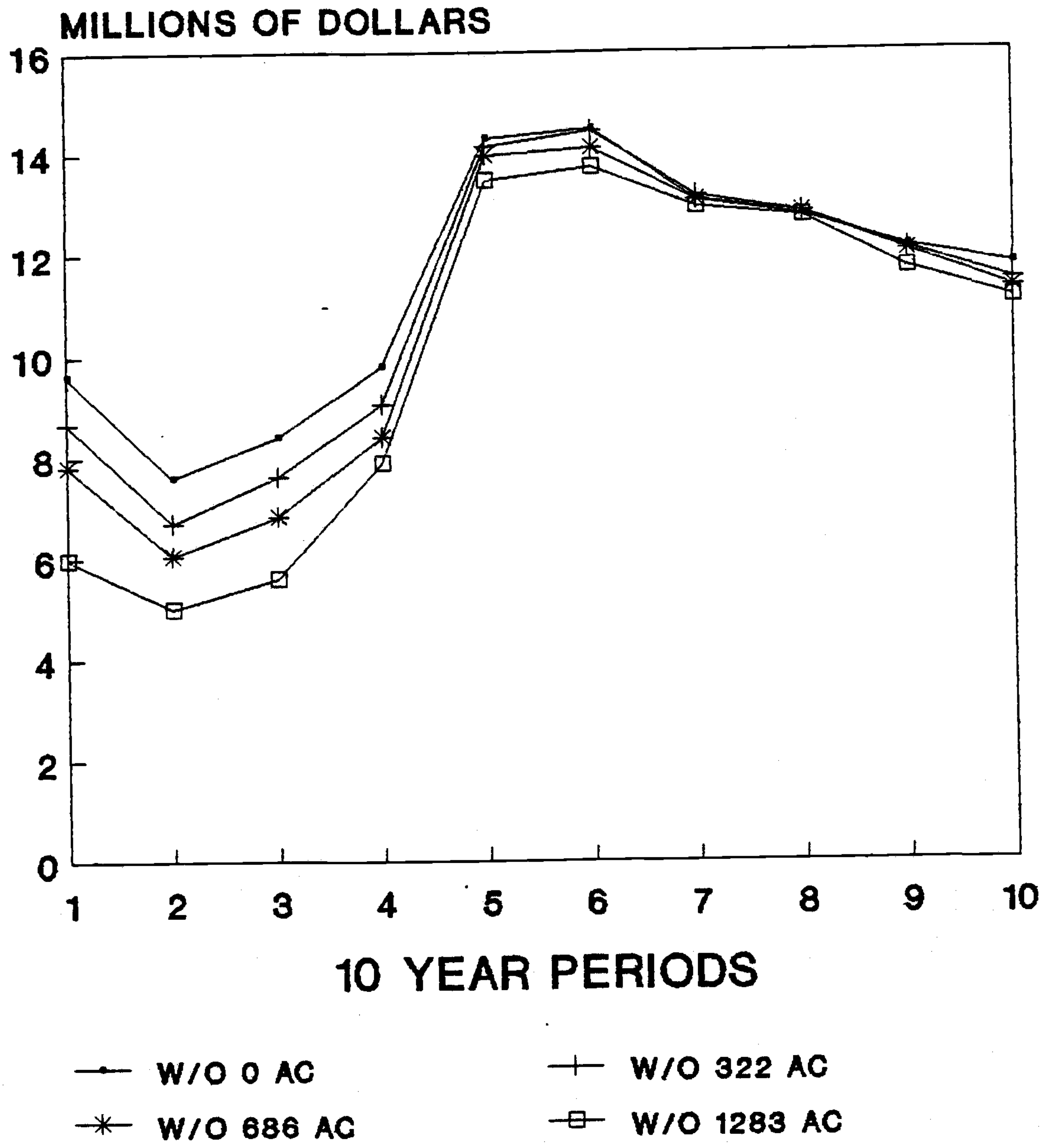


Figure 7 Net revenue per period with a rotation age of 60. Revenue from harvest schedules with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed.

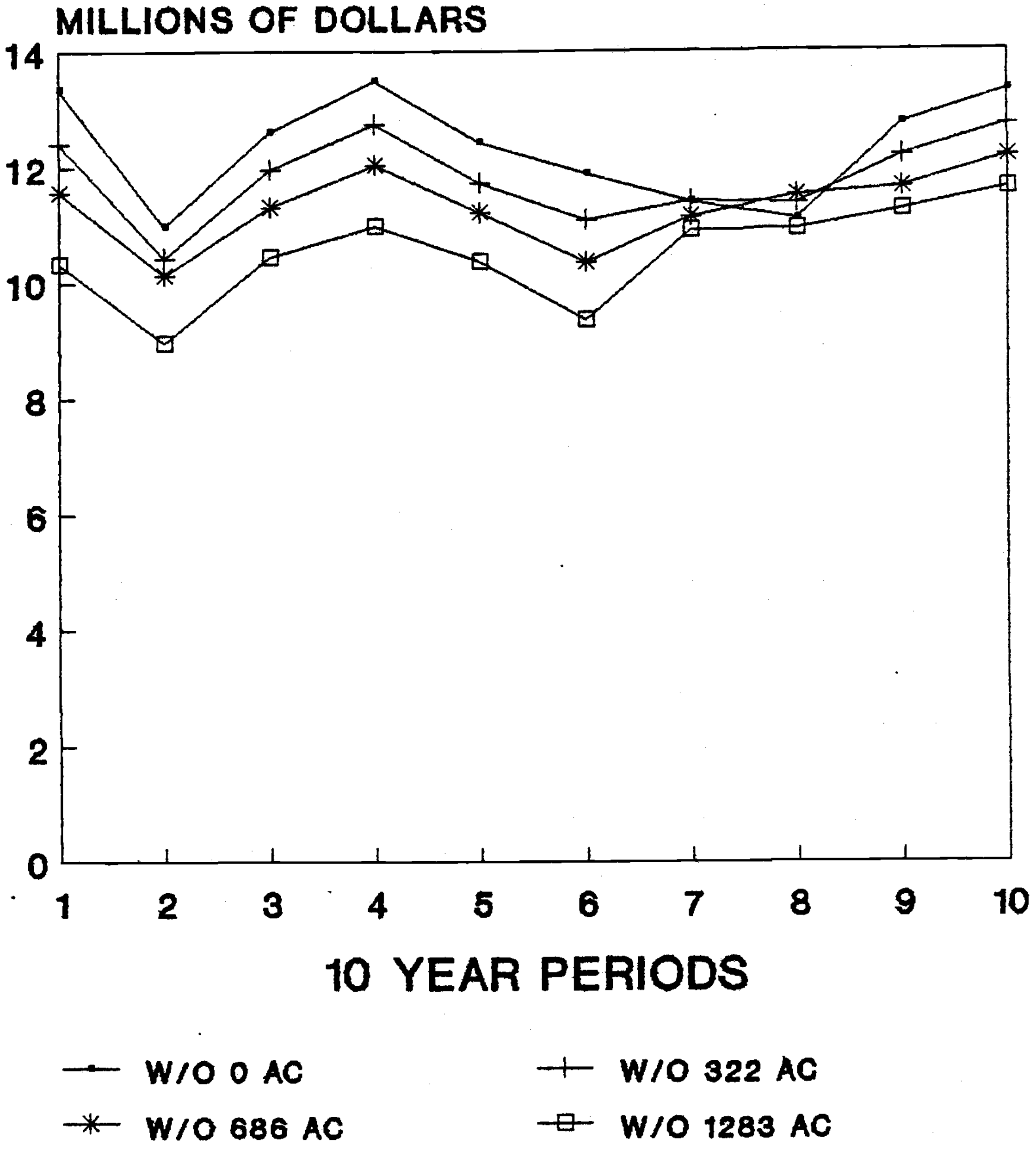


Figure 8 Cumulative present net value per period with a rotation age of 90. Values from harvest schedules with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed.

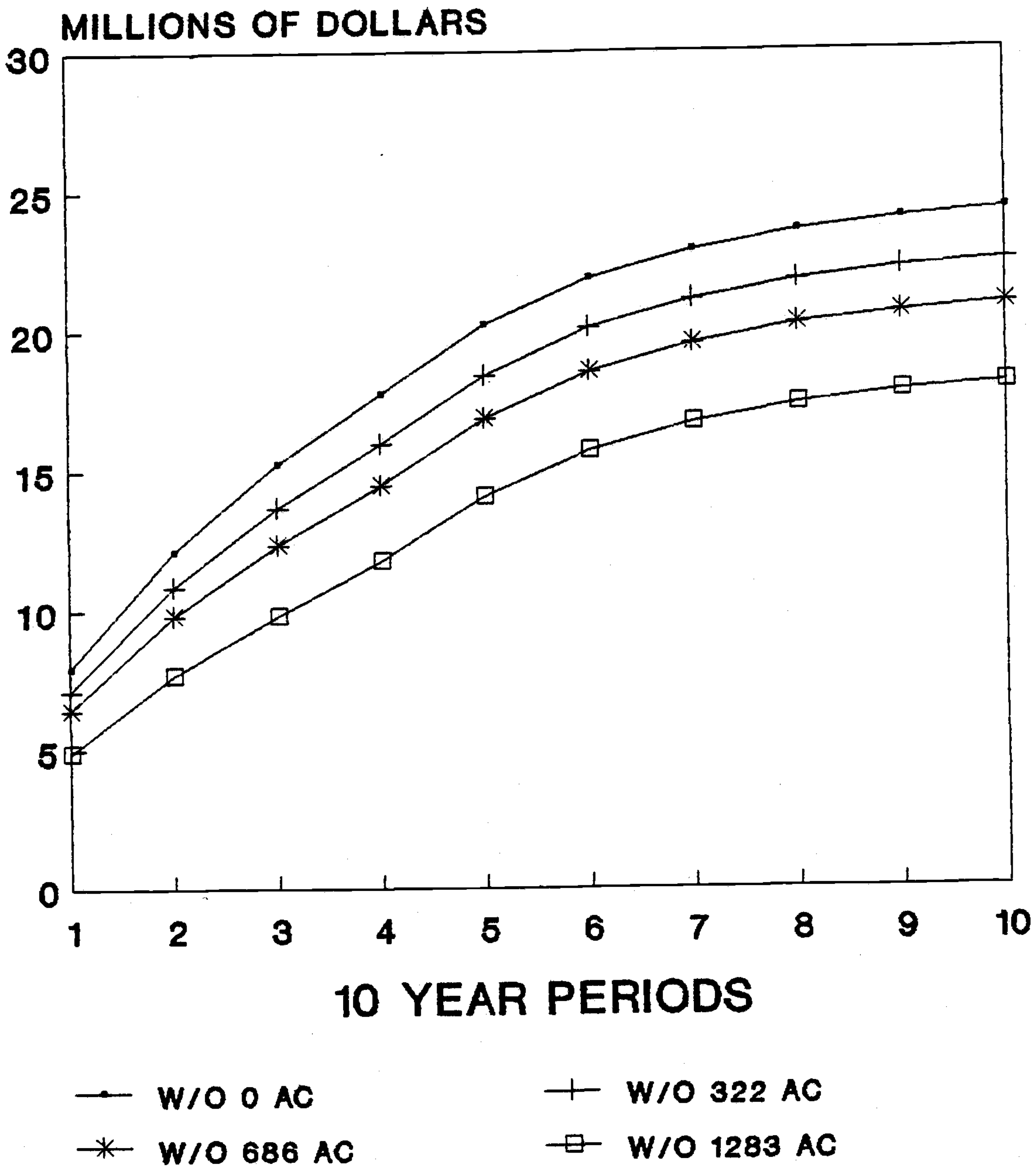


Figure 9 Cumulative present net value per period with a rotation age of 60. Values from harvest schedules with 0 acres removed, 322 acres over age 130 removed, 686 acres over age 120 removed, 1283 acres over age 100 removed.

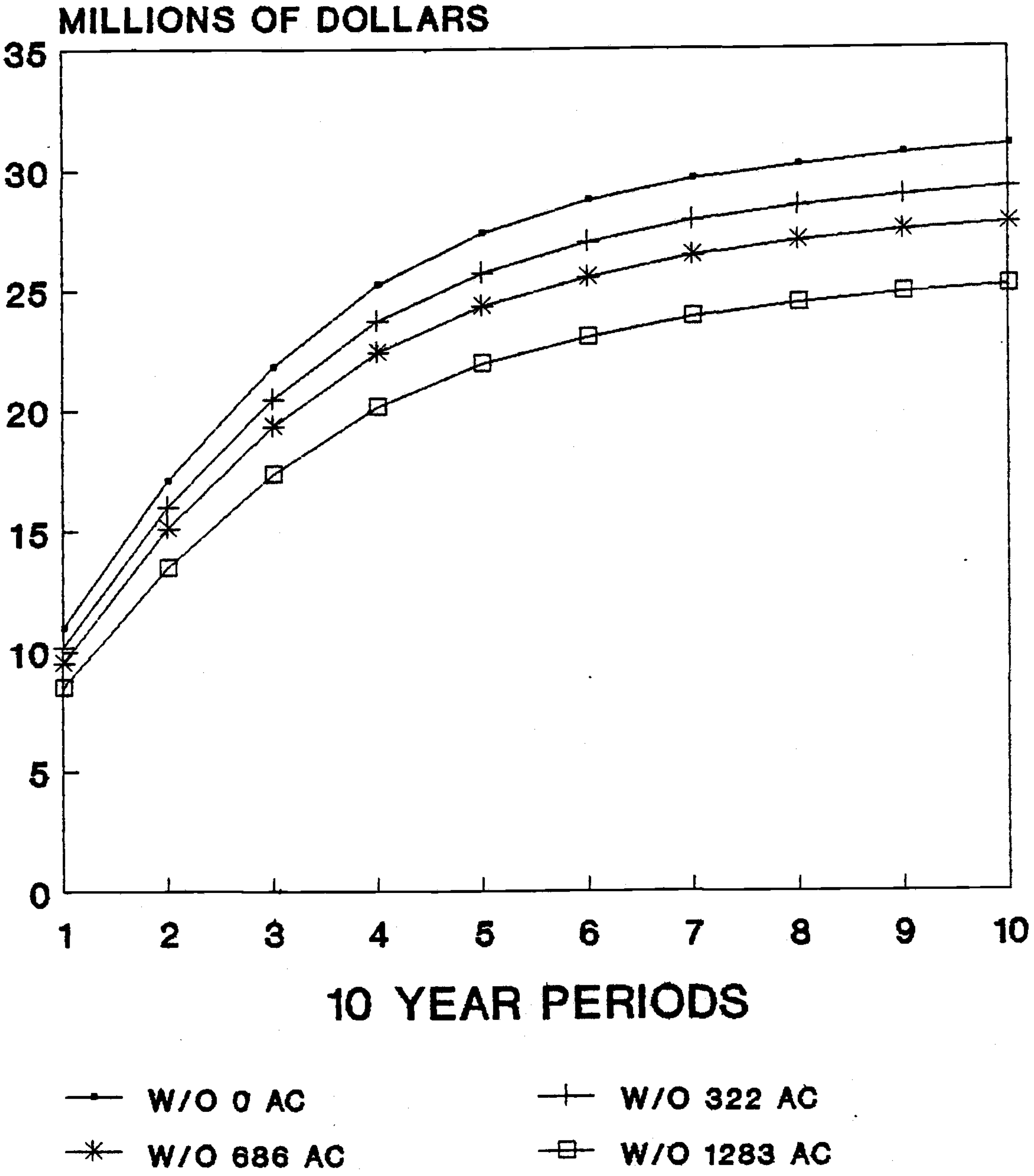


Figure 10 Acres by age class per period at the middle, of the period before harvest with a rotation age of 90. Values from a harvest schedule with 0 acres removed.

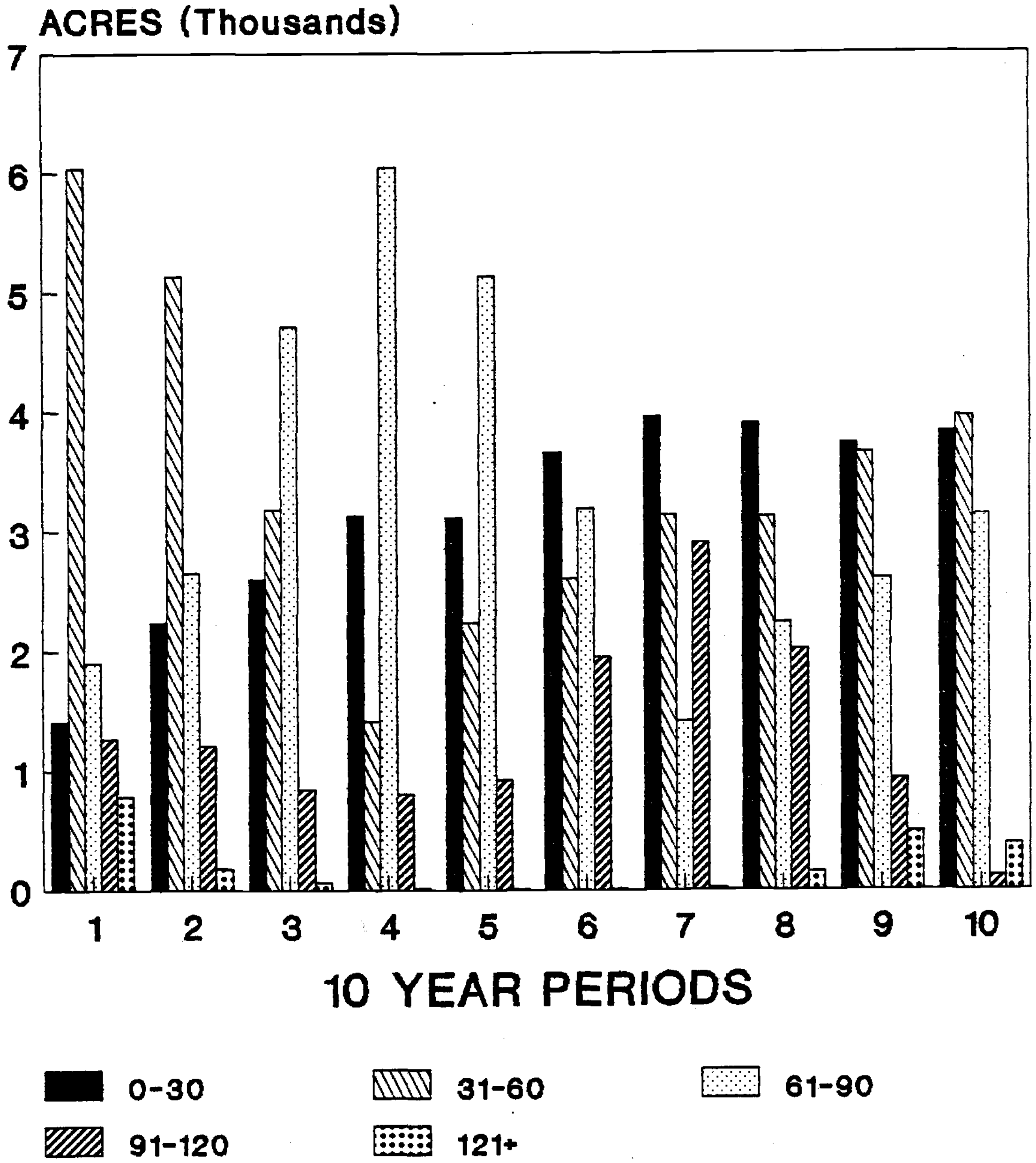


Figure 11 Acres by age class per period at the middle of the period before harvest with a rotation age of 90. Values from a harvest schedule with 322 acres over age 130 removed.

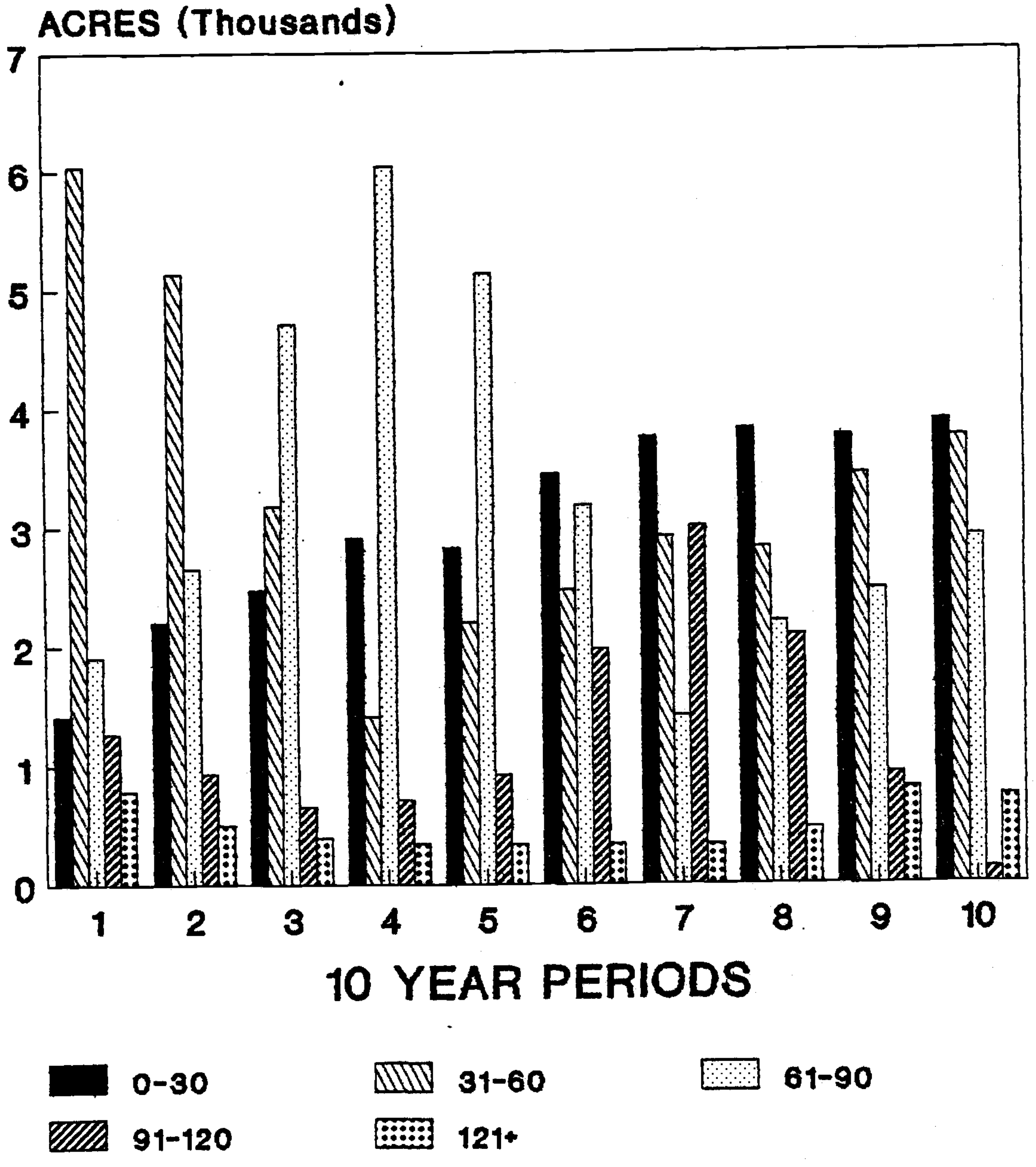


Figure 12 Acres by age class per period at the middle of the period before harvest with a rotation age of 90. Values from a harvest schedule with 686 acres over age 120 removed.

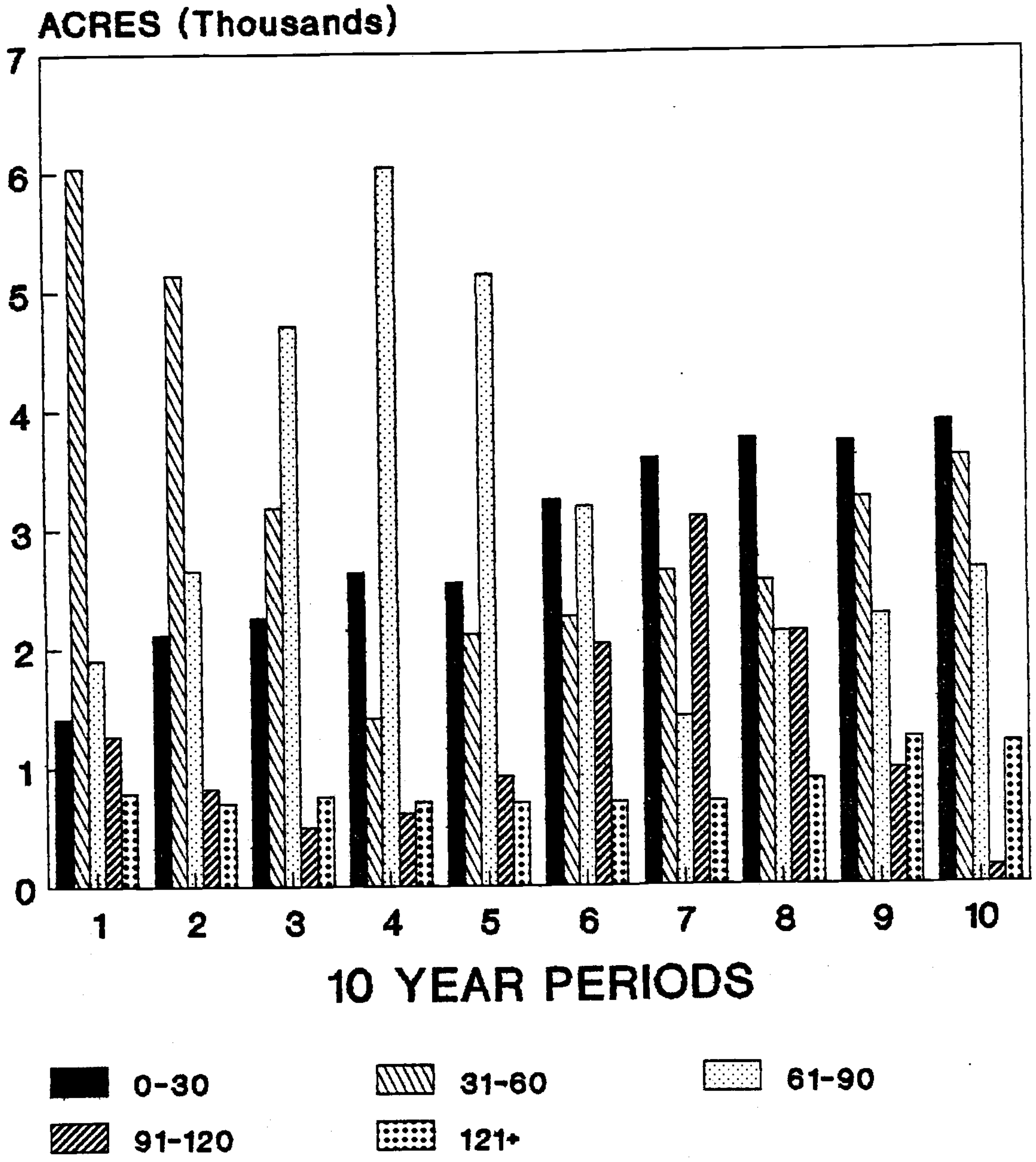


Figure 13 Acres by age class per period at the middle of the period before harvest with a rotation age of 90. Values from a harvest schedule 1283 acres over age 100 removed.

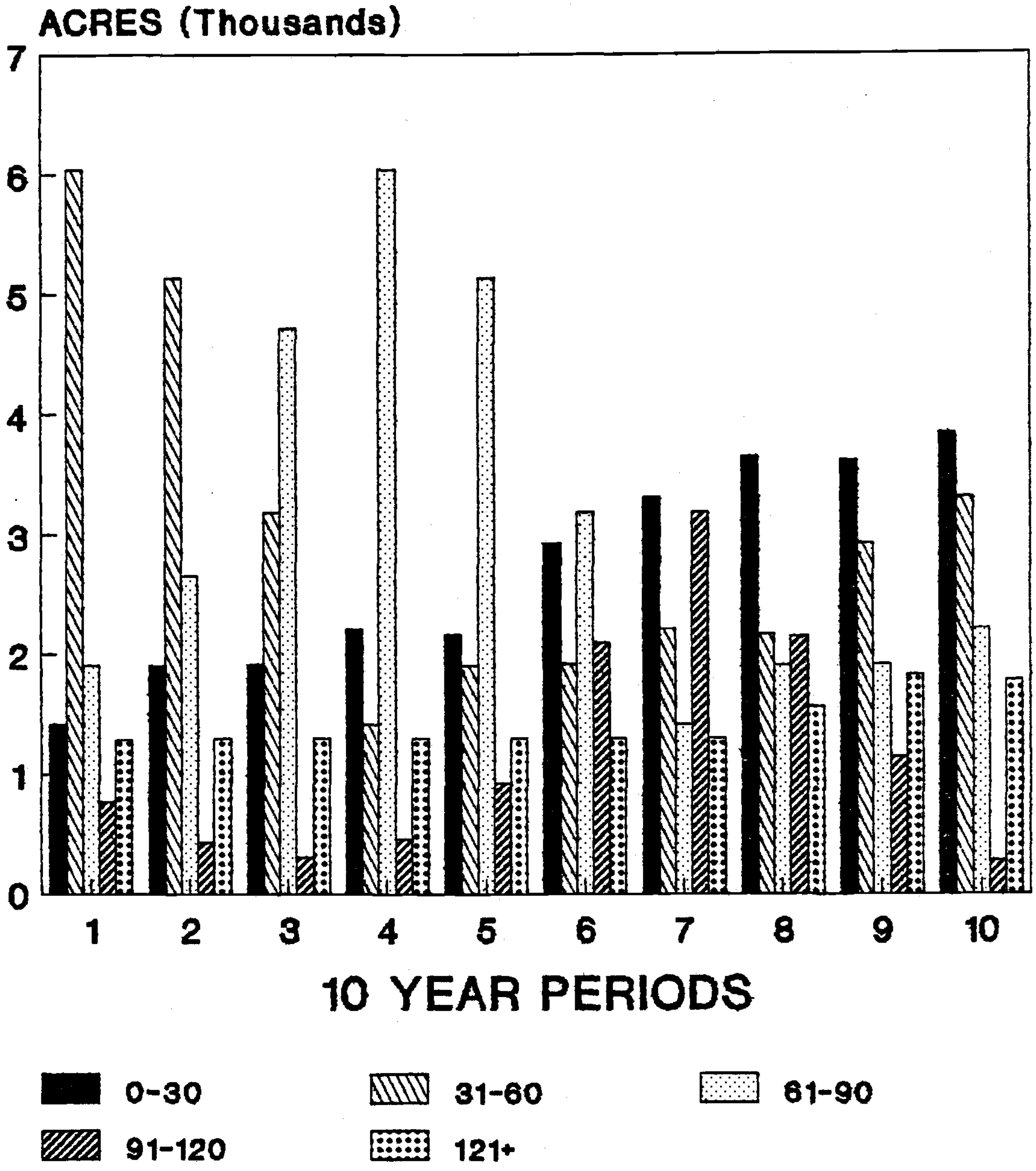


Figure 14 Acres by age class per period at the middle of the period before harvest with a rotation age of 60. Values from a harvest schedule with 0 acres removed.

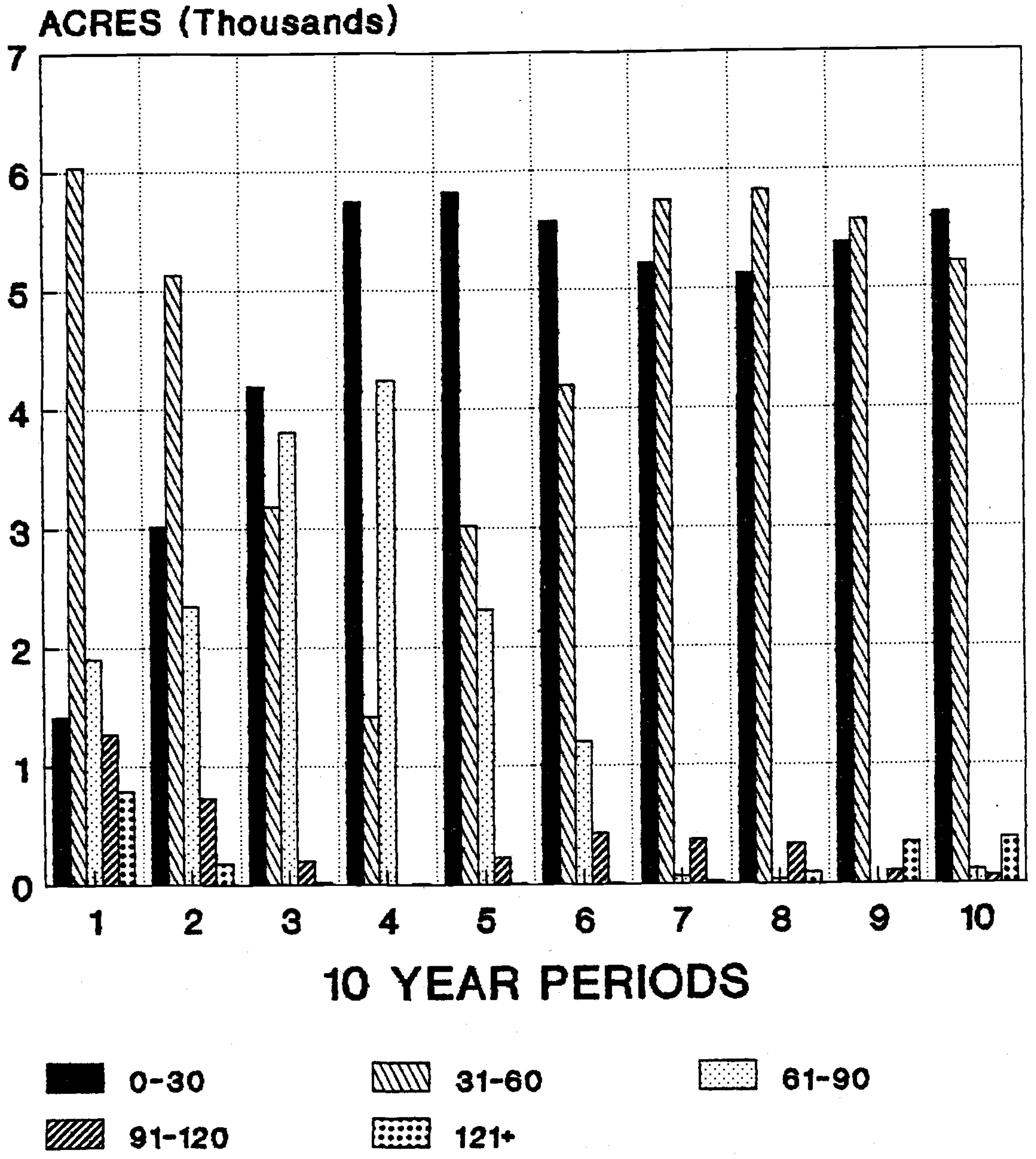


Figure 15 Acres by age class per period at the middle of the period before harvest with a rotation age of 60. Values from a harvest schedule with 322 acres over age 130 removed.

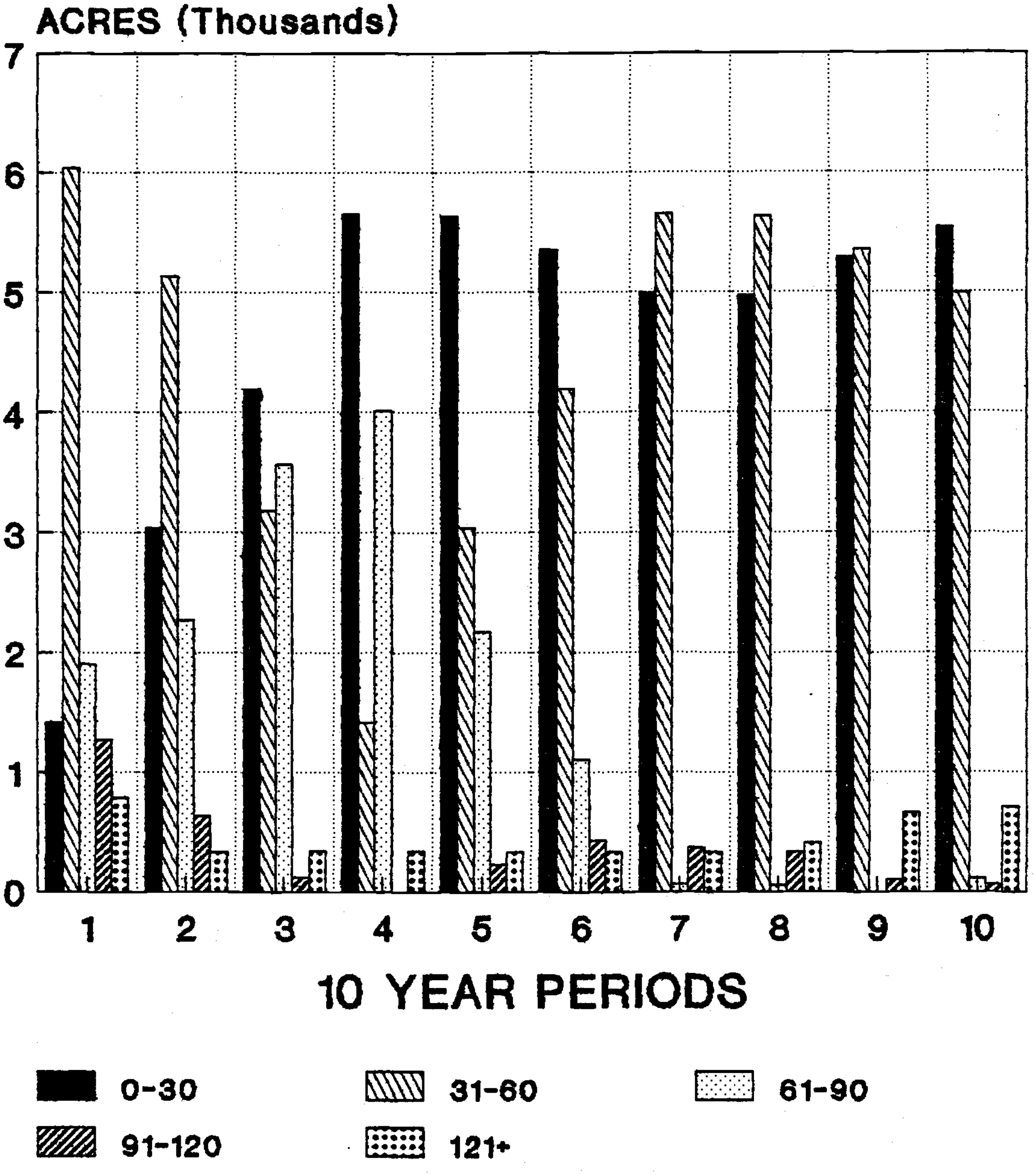


Figure 16 Acres by age class per period at the middle of the period before harvest with a rotation age of 60. Values from a harvest schedule with 686 acres over age 120 removed.

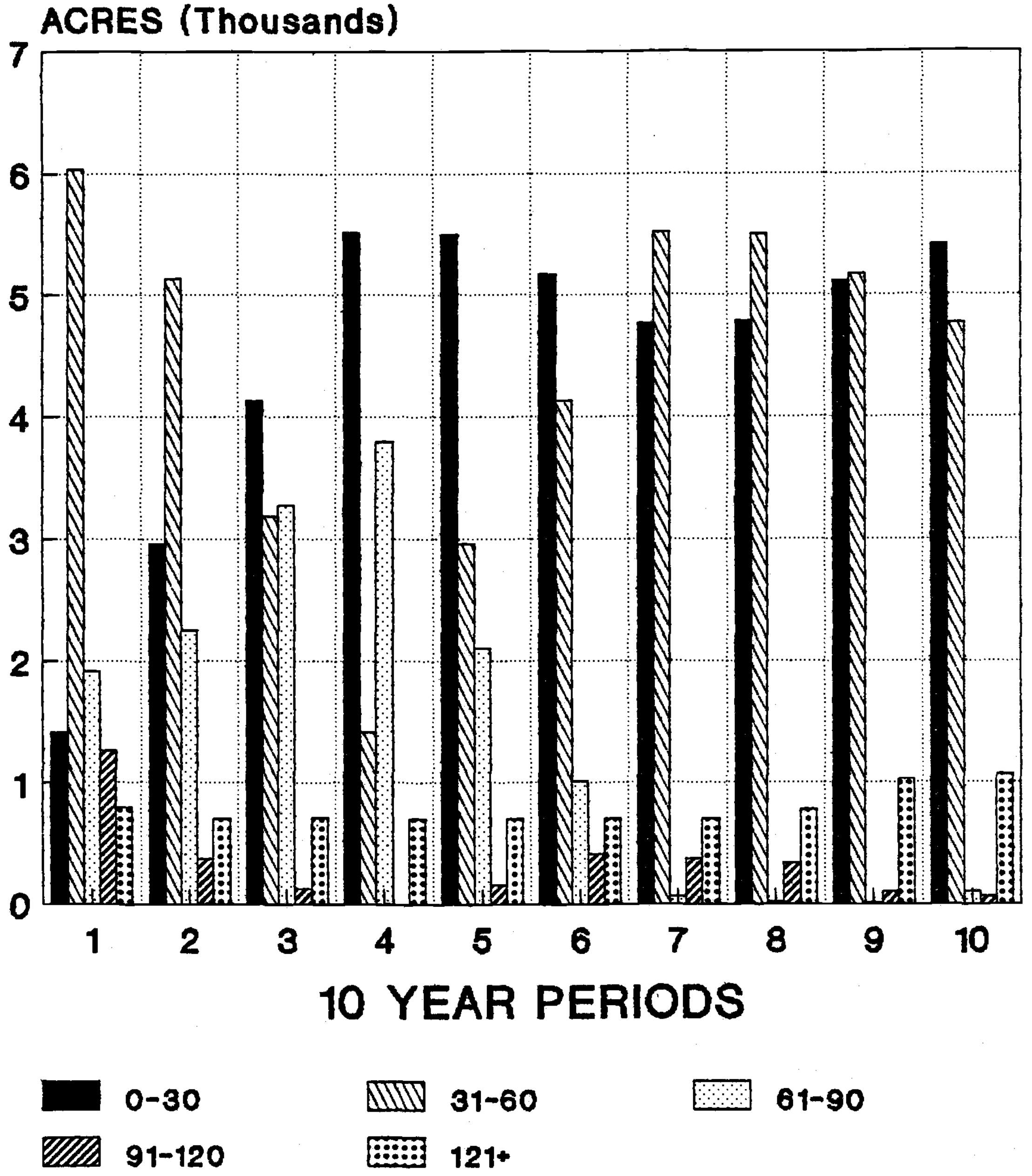
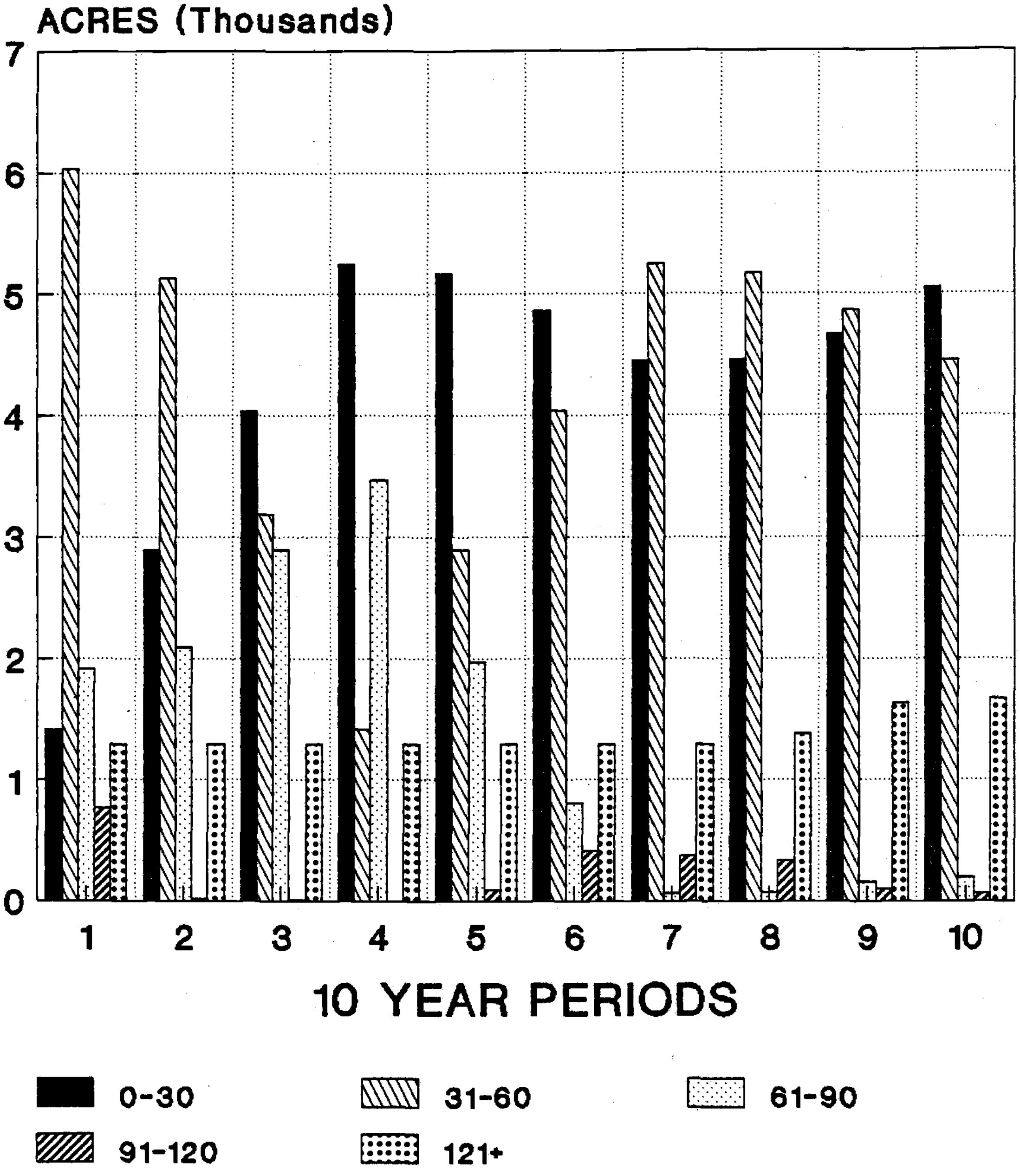


Figure 17 Acres by age class per period at the middle of the period before harvest with a rotation age of 60. Values from a harvest schedule 1283 acres over age 100 removed.



REFERENCES

Arney, James D. 1985. A modeling strategy for the growth projection of managed stands. Can. J. For. Res. 15:511-518.

Binkley, Clark S. 1984. Allowable cut effects without even flow constraints. Can. J. For. Res. 14:317-320.

Clutter, J. L., et. al. 1968. MAX MILLION-- A computerized forest management planning system. Sch. Forest Resour., Univ. GA, Athens, 61 p.

Clutter, Jerome L., et. al. 1983. Timber management: A quantitative approach. John Wiley & Sons.

Convery, F. J. and C. W. Ralston. 1977. Forestry and long range planning. Duke University. 490p.

Davis, L. S. and K. N. Johnson. 1987. Forest Management, Third Edition. McGraw-Hill, Inc. New York. 790p.

Eldred, P. 1987. Evaluation of a shadow price search heuristic as an alternative to linear programming or binary search for timber harvest scheduling. Unpublished Masters Thesis, Dept. of Forest Management, Oregon State University. 64p.

Hoganson, H. H. and D. W. Rose. 1984. A simulation approach for optimal timber management scheduling. Forest Science, 30: 220-238.

Hunt, Mary C. 1986. Harvest scheduling and economic effects of old-growth forest preservation in northwest Oregon. Unpublished Masters Thesis, Dept. of Forest Management, Oregon State University. 112p.

Johnson, K. N., H. L. Scheuramn, and J. Beuter. 1975. Oregon timber resource model-- a brief introduction. In Systems Analysis And Forest Resource Management. (J. Meadows and others, eds.). pp. 148-163 Soc Am For. 475 p.

Johnson, K. N. and H. L. Scheurman. 1977. Techniques for prescribing optimal timber harvest and investment under different objectives-discussion and synthesis. Forest Science Monograph 18.

Johnson, K. N., and D. B. Jones. 1979. A users guide to multiple use-sustained yield resource scheduling calculation (MUSYC). Timber Management. USDA Forest Service, Fort Collins, CO., 242 p. mimeo.

Johnson, K. N. and P. L. Tedder. 1983. Linear programming vs. binary search in periodic harvest level calculation. Forest Science, vol. 29 (3). pp. 569-581.

Johnson, K. N., Tom Stuart, and Sarah Crim. 1986. FORPLAN version 2-- an overview. Land Management Planning. USDA Forest Service, Fort Collins, CO.

Navon, D. I.. 1971. Timber RAM...A long-range planning method for commercial timber lands under multiple use management. USDA Forest Service Res. Pap PSW-70, 22 p . Pac Southwest Forest and Range Exp Stn, Berkley.

Roland, John. 1989. Supervisors Office Siuslaw National Forest. Corvallis, Oregon.

Sassaman, R. W., E. Hold, and K. Bergsvick. 1973. User's manual for a computer program for simulating intensively managed allowable cut. U.S. Forest Service General Technical Report PNW-1.

Tedder, P. L., J. S. Schmidt, and Gourley. 1980. TREES: Timber resource economic estimation system. Volume I-a Users Guide For Forest Management and Harvest Scheduling. Forest res. Lab. Oregon State Univers., Res. Bull. 31a, p. 81.

USDA Forest Service. Siuslaw National Forest. 1980. The effects of vegetation control on the success of conifer regeneration for the Siuslaw National Forest, Part 1. 24pp.

Walker, J. L.. 1976. ECHO: Solution technique for a nonlinear economic harvest optimization model. In Systems Analysis And Forest Resource Management (J. Meadows, B. Bare, K. Ware, and C. Row, eds). Soc Am For, Wash, D. C. 457 p.

Walt, Harold R. 1986. Of forestry, tree spikers, and the dinosaur. University of California Berkeley, The S. J. Hall lectureship in industrial forestry, Nov. 18, 1986.

APPENDICES

APPENDIX A

GROWTH AND YIELD EQUATIONS

The growth and yield equations were developed by Brian Greber for use on the Oregon Timber Supply study. A range of 50 year site indexes from 80 to 145, and ages from 20 to 130 years, were specified. Starting trees per acre and basal areas were then randomly generated and the information was used as starting stand conditions for SPS. The stands were then grown for five years and the results used as data for regression analysis.

The following information was taken from SPS for use in developing growth and yield equations. The form of the regression equations, coefficients, and comparisons to data generated by SPS can be found in the accompanying pages.

Raw Data Taken From SPS

AGE1 = initial stand age

BA1 = initial stand basal area

BA7 = initial stand basal area of 7" and larger trees

CBA1 = initial basal area of competition species

TPA1 = initial trees per acre

CTPA1 = initial trees per acre of competition species

TVOL = total cubic foot volume

AGE2 = age at end of period of growth

BA2 = basal area after growth

TPA2 = trees per acre after growth

CTPA2 = trees per acre of competition after growth

SITE = King's site index

Volume Equations

EXP (B1 * LN(SITE) + B2 * LN(AGE1) + B3 * LN(BA1) + B4/AGE1 + C1)

Douglas-fir

B1 = .903755

B2 = -.016096

B3 = .938727

B4 = -35.3511

C1 = .34821

Hemlock

B1 = .842859

B2 = .0298884

B3 = 1.0201

B4 = -31.6909

C1 = .116981

Hardwood

B1 = .881218

B2 = -.033724

B3 = .913589

B4 = -18.7847

C1 = .518534

Basal Area Equations

Douglas-fir and Hardwoods Mixed

EXP (AGE1/AGE2 * LN(BA1) + B1(1 - AGE1/AGE2) + B2 * SITE(1 - AGE1/AGE2) + B3 * SITE(1-TPA1/TPA2) + SITE(1-CTPA1/CTPA2)

Douglas-fir Component

B1 = 5.00684

B2 = .0094962

B3 = .0002472

B4 = -.000089

Hardwood Component

B1 = 2.99912

B2 = .0057664

B3 = .0022975

B4 = .0001373

Pure Hemlock or Hardwood

EXP(AGE1/AGE2 * LN(BA1) + B1(1-AGE1/AGE2) + B2 * SITE(1-AGE1/AGE2) + B3 * SITE(1-TPA1/TPA2)

Hemlock

B1 = 5.79401

B2 = .0034875

B3 = .0013016

Hardwood

B1 = 3.86553

B2 = .0205924

B3 = .0026518

Tree Per Acre Equations

Douglas-fir and Hardwoods Mixed

EXP(AGE1/AGE2 * LN(TPA1) + B1(1-AGE1/AGE2) + B2 * SITE(1-AGE1/AGE2) + B3 * BA1(1-AGE1/AGE2) + B4 * CBA1(1-AGE1/AGE2)

Douglas-fir Component

B1 = 5.23929

B2 = -.007099

B3 = .0010842

B4 = -.003852

Hardwood Component

B1 = 3.76828

B2 = -.009743

B3 = -.008125

B4 = .2060696

Hemlock and Hardwood

EXP(AGE1/AGE2 * LN(TPA1) + B1(1-AGE1/AGE2) + B2 * SITE(1-AGE1/AGE2) + B3 * BA1(1-AGE1/AGE2)

Hemlock

B1 = 6.01179

B2 = -.006921

B3 = -.003798

Hardwood

B1 = 7.01363

B2 = -.015792

B3 = -.003330

APPENDIX B

ANALYSIS AREA DATA

The following data was adapted from the college forest inventory for use as input in the OSU Forestry Model. Data for each analysis area, as it was used in the model is shown below.

Two levels of information are shown below: first is the analysis area identifiers, this is the information following the letters AA; and second is the age class information, which is indented.

An example of the analysis area information by column is, AA 1 DF 1 CA 137 86.3 analysis area number (AA 1), species code (DF), site class (1), cable operability (CA), site index (137), and total analysis area acres (86.3).

An example of the age class information by column is, 30 136 2 11.2 344.0 148.8 92.0 41.0 2003.3 773.7 five year age class (30), 50 year site index (136), stocking level (2), acres (11.2), softwood trees per acre (344.0), hardwood trees per acre (148.8), softwood basal area per acre (92.0), hardwood basal area per acre (41.0), softwood volume per acre (2003.3), and hardwood volume per acre (773.7).

```
AA   1  DF 1 CA 137  86.3
     30 136 2  11.2 344.0 148.8  92.0  41.0  2003.3   773.7
```

```
         35 137 2  68.4 182.1 121.8 100.9  35.6  2968.4   879.0
         50 140 2   6.7 222.4 315.5 149.8  89.0  5210.5  1867.6
AA     2  DF 2 CA 121   2448.1
          5 122 2 123.9   0.0   0.0   0.0   0.0     0.0     0.0
         10 118 2  10.5   0.0   0.0   0.0   0.0     0.0     0.0
         15 125 2  39.6 646.6 161.7  15.0   2.7    58.9    51.5
         20 117 3   3.2 580.0   0.0  50.0   0.0     0.0     0.0
         25 129 1  11.6 442.9   0.0  68.2   0.0   163.9     0.0
         30 120 2 538.2 315.1 116.9  75.0  17.8  1344.3   319.0
         35 124 3 392.1 204.4 171.4  84.8  35.8  2083.2   743.8
         40 123 2 224.3 246.5 153.5 116.0  27.1  3296.2   585.2
         45 119 2  99.5 180.4  89.7 129.8  24.6  4191.9   603.3
         50 123 2 240.6 190.7 100.8 148.2  29.9  4966.2   723.5
         55 119 2  69.3 120.8  72.8 108.3  34.7  3706.3   809.0
         60 124 2  40.6  72.2  49.0 139.7  21.3  5663.3   595.8
         65 116 2 132.6 134.7  80.4 148.1  37.9  5473.9   925.1
         70 127 2  40.5 148.8  88.2 176.2  43.3  7441.5  1224.7
         80 117 2 175.0 116.7  73.2 169.3  30.7  6778.6   775.4
        100 120 2 173.1  78.0  58.2 222.6  31.5 10291.1  1017.0
        115 120 3  17.5  62.1  14.1 197.8  14.1  9024.9   305.2
        120 119 2  19.8  52.7  74.3 222.6  26.3 10882.3   665.7
        130 117 2  31.5  34.0  53.3 144.4  49.8  6789.8  1493.2
        135 115 2  13.5  40.1  50.1 140.0  28.6  6144.5   762.1
        140 124 2  51.2  54.2  35.3 218.3  38.3 10304.8  1225.2
AA     3  DF 3 CA 104 2405.5
          5 100 2 188.6   0.0   0.0   0.0   0.0     0.0     0.0
```

10	108	2	27.1	0.0	0.0	0.0	0.0	0.0	0.0
15	102	2	103.0	0.0	0.0	0.0	0.0	0.0	0.0
20	108	1	22.9	293.1	6.5	21.4	10.0	419.1	232.0
25	106	2	63.0	192.8	16.9	54.2	3.8	42.6	42.7
30	101	3	81.5	248.5	119.5	66.0	11.0	1058.1	123.7
35	109	2	138.2	273.4	114.0	83.2	20.3	1696.8	366.4
40	103	2	72.3	202.6	162.7	58.9	30.8	1177.7	610.4
45	107	1	29.5	378.0	163.6	112.7	28.4	2893.0	551.8
50	104	2	100.6	149.6	97.3	101.8	27.2	2939.3	627.6
55	106	3	29.9	186.8	97.0	120.6	22.9	3845.9	552.7
60	107	3	19.0	123.2	72.6	157.2	25.7	5982.7	767.4
65	104	2	30.6	129.8	47.9	103.3	22.4	3338.0	477.9
70	106	2	84.4	151.8	61.6	130.8	16.1	4586.5	348.9
75	99	3	182.9	153.3	40.7	152.1	30.8	5137.8	791.7
80	105	2	131.3	127.1	57.8	172.1	35.3	6231.9	965.7
85	107	2	9.6	171.1	47.1	135.3	25.7	4884.4	596.8
90	107	2	19.6	88.6	101.1	147.7	48.9	5645.5	1252.9
95	103	2	219.6	124.9	88.5	165.1	25.2	6628.6	609.7
100	105	2	27.9	153.0	69.6	179.1	26.5	6774.2	548.3
105	101	1	179.7	82.6	66.3	173.0	33.3	6989.7	894.6
110	104	3	95.3	52.5	142.3	168.0	25.2	6921.8	457.6
115	107	2	32.1	56.4	176.3	149.0	37.0	6257.5	851.4
120	103	2	55.9	69.3	60.8	172.5	22.4	7479.8	539.9
125	103	2	204.7	88.6	71.4	163.6	34.6	6916.9	913.5
130	106	2	53.3	89.2	56.7	194.0	40.7	8359.2	1224.1
135	111	2	114.4	88.8	102.1	200.0	30.1	9161.6	790.0

140	112	2	37.6	110.0	43.8	221.2	36.9	9749.6	1011.5
145	113	3	6.9	80.3	13.7	189.7	6.6	9028.5	132.5
165	106	2	9.1	102.5	48.5	290.0	36.8	11342.9	1083.0
185	100	3	7.6	62.4	73.2	227.0	59.2	9637.3	1697.2
250	98	0	27.4	32.9	106.6	111.1	13.7	4177.6	296.9

AA 4 DF 4 CA 92 325.8

5	94	2	17.2	0.0	0.0	0.0	0.0	0.0	0.0
10	86	2	3.2	0.0	0.0	0.0	0.0	0.0	0.0
15	93	2	15.9	0.0	0.0	0.0	0.0	0.0	0.0
20	95	1	39.7	451.5	10.4	44.1	2.4	75.5	53.8
35	94	2	55.1	175.3	39.3	51.5	5.8	896.8	110.2
45	75	2	10.6	194.4	221.9	43.6	23.4	735.5	319.6
50	90	2	9.6	62.5	76.4	36.0	2.8	670.1	28.7
80	92	3	42.5	97.0	103.3	133.3	73.0	4489.8	1916.2
85	91	2	13.4	69.4	108.3	113.1	54.8	4332.7	1432.8
90	91	2	7.3	153.8	13.9	192.8	14.4	7604.3	441.7
95	92	2	29.8	126.9	160.8	209.7	55.2	7405.0	1232.9
100	93	2	8.4	51.3	2.7	110.6	6.6	3842.7	154.3
125	90	3	40.6	104.0	108.0	161.7	60.6	6109.6	1748.4
135	89	3	7.5	158.5	13.3	123.9	40.0	5623.1	1349.4
140	92	3	25.0	71.7	12.7	274.8	20.0	11619.1	754.5

AA 5 DF 1 TR 136 205.4

5	136	2	16.0	0.0	0.0	0.0	0.0	0.0	0.0
35	135	2	106.7	169.6	87.1	115.4	17.6	3573.3	411.7
40	140	2	13.6	176.6	209.4	131.7	38.8	4594.7	872.1
45	137	2	47.4	96.9	30.5	110.9	7.5	3875.1	194.9

```
         75 135 3   21.7  98.5   44.9 219.5   8.5 10160.4   169.9

AA        6  DF 2  TR 125 2575.9

          5 115 2   40.4   0.0    0.0   0.0   0.0     0.0     0.0

         10 122 2   55.4   0.0    0.0   0.0   0.0     0.0     0.0

         15 119 2   34.9   0.0    0.0   0.0   0.0     0.0     0.0

         20 126 2   15.2 498.0    0.0  50.2   0.0   138.3     0.0

         25 122 2    4.9 480.0    0.0  60.0   0.0     0.0     0.0

         30 116 3   13.8 283.3    0.0  66.9   0.0  1068.9     0.0

         35 126 2  306.9 186.5   86.3 103.2  16.0  2903.8   336.7

         40 124 2  575.1 221.8   86.2 123.5  20.5  3738.2   474.6

         45 129 2  556.9 153.1   98.2 128.7  24.2  4467.9   566.1

         50 118 3  182.3 157.3   67.1 136.7  25.0  4675.8   600.6

         55 126 2  164.2 116.9  118.3 148.9  15.4  5767.7   413.2

         60 128 2  343.0 112.6   55.9 151.3  16.9  5944.6   388.2

         65 126 2   87.1 105.9   83.7 147.5  20.9  6049.6   474.7

         70 124 2   13.2 165.0   27.7  32.0  21.4  1249.2   725.8

         75 115 3   16.2 138.1    8.2 122.7   1.4  4334.6    22.6

         80 121 2   19.6  92.7   84.6 198.7  20.7  8387.6   453.8

         85 122 2   59.7 123.9   55.9 174.9  22.3  7235.0   524.3

         90 116 2    1.4  66.9    0.0 113.5   0.0  4773.8     0.0

         95 129 2    3.2  43.4    0.0 220.0   0.0 11238.5     0.0

        100 121 1   31.7  69.9   47.2 206.3  18.8  8970.7   430.0

        105 123 2   44.8  30.1   44.0 110.7   5.0  5117.0    99.5

        115 120 2    3.2 114.5  111.3 109.9  57.9  4499.5  1663.1

        130 116 3    2.8   5.5    0.0  40.0   0.0  1997.7     0.0

AA        7  DF 3  TR 105 1272.9
```

5	108	2	14.9	0.0	0.0	0.0	0.0	0.0	0.0
10	108	2	94.4	458.4	112.1	20.0	5.1	0.0	76.4
15	100	2	123.7	484.9	15.8	30.0	9.2	0.0	234.6
20	103	1	50.7	370.2	0.0	50.0	0.0	0.0	0.0
25	104	1	10.0	224.5	8.0	57.9	4.7	118.8	73.4
30	99	2	5.9	271.8	1.4	70.2	4.2	1286.9	103.2
35	112	3	31.6	242.1	50.7	119.4	23.4	3000.8	633.9
40	106	3	57.9	248.1	165.1	102.8	23.9	2599.6	428.5
45	105	3	140.7	247.7	115.2	90.8	35.9	2422.6	733.8
50	108	2	138.8	167.1	181.9	94.7	40.8	2847.7	826.9
55	111	2	31.7	130.2	21.9	138.1	12.8	4831.8	279.9
65	107	2	116.3	172.2	136.6	132.0	39.6	4560.6	832.3
70	100	2	18.4	41.8	6.2	59.8	4.7	1859.1	135.4
75	100	2	26.8	90.3	63.2	162.2	28.0	6000.2	768.7
80	110	1	33.0	111.6	66.7	159.2	37.6	6053.8	938.0
85	104	2	12.6	152.4	59.5	163.0	31.8	5592.4	629.3
90	100	2	73.0	111.4	52.9	161.3	32.2	6432.0	816.4
95	105	2	101.0	89.1	61.2	179.0	14.7	7292.4	305.9
100	100	2	16.7	53.4	46.2	96.4	26.5	3594.4	600.7
105	98	2	44.7	91.0	31.6	185.6	11.8	7447.5	260.9
110	102	3	71.9	46.9	31.3	162.7	11.8	7055.3	303.8
120	100	2	22.6	191.4	10.5	253.5	13.2	9689.2	388.6
125	107	2	17.1	106.6	91.1	136.6	63.0	5636.5	1939.4
130	103	2	14.4	56.3	26.5	145.0	50.0	6389.0	1920.5
140	101	3	4.1	12.2	5.4	80.0	10.0	3773.9	276.7

AA 8 DF 4 TR 89 103.9

```
         5  93 2  22.8   0.0   0.0   0.0   0.0    0.0    0.0
        10  85 2  21.8   0.0   0.0   0.0   0.0    0.0    0.0
        15  94 2   4.3   0.0   0.0   0.0   0.0    0.0    0.0
        25  82 3  12.5 275.0   0.0  60.0   0.0    0.0    0.0
        50  80 2   3.4  15.7 229.2  20.0   6.1  500.5   32.2
        80  89 2   6.0 123.9   0.0 114.6   0.0 3733.6    0.0
        95  92 2   8.9 100.1 929.4 165.6  24.0 6146.0  502.0
       105  93 2   9.5 285.9  14.1  74.4  13.4 2253.6  229.5
       135  91 3  14.7 125.8  16.2 168.5   6.2 6989.7  246.9
AA     9  HD 2 CA 119 20.0
        30 119 2  15.8  75.4 487.5  30.4  98.3  764.6 2507.4
        45 118 1   4.2  42.8 448.3  33.3 149.4  952.7 2904.9
AA    10  HD 3 CA 111 49.3
        15 111 2   7.9 124.5 1742.   5.0 106.4  116.7 1887.6
        20 102 3  19.7  84.8 428.1   4.9  65.5   41.9 1438.4
        35 102 3   6.2  87.8 178.4  22.4  80.6  373.4 2030.4
        40  96 2   6.4 371.2  31.6  87.1  30.0 1809.8  621.0
        45 101 2   9.1 107.0 568.4  20.2  69.7  348.9 1317.2
AA    11  HD 4 CA 93 18.7
        45  93 3  10.5  28.6 670.6  22.8 122.0  595.4 2131.4
       120  90 3   8.2   3.8  87.3  20.0  73.2  795.0 1698.3
AA    12  HD 2 TR 120 199.7
        15 120 3  11.3 623.1 858.9  16.9 106.7  221.3 2365.8
        35 122 3   9.7  57.3 159.2   5.6  93.8   22.1 1990.1
        40 115 3 176.6 203.3 145.8  71.2  51.8 1718.0 1206.2
        60 128 3   2.1 286.5 348.3  15.3 163.6   12.7 3621.0
```

```
AA   13   HD 3 TR 113 91.6

       20 113 1  13.0 158.4 1258.  24.4 135.0   760.1  2985.8

       25  96 2   9.5  57.4 264.7  19.4  76.1   291.3  1370.0

       30 112 3   7.9   0.0  83.7   0.0  41.9     0.0   513.0

       40 107 2  45.9 288.5 154.3  77.4  47.7  1771.1  1011.0

       50 107 2  15.3  25.6 106.6  26.2  81.6   789.0  2425.9

AA   14   HD 4 TR 93 72.5

       20  93 2   3.9 260.0 593.6  12.9  96.4   335.0  2276.7

       50  94 2  13.6   0.0 374.6   0.0 107.4     0.0  2225.5

       55  86 3  49.7   0.0 251.1   0.0  51.6     0.0  1052.6

      110  86 2   5.3   0.0 220.7   0.0 152.0     0.0  3206.6

AA   15   MX 1 CA 135 21.7

       30 135 2  21.7 133.8 110.5  48.1  54.3   898.8  1290.6

AA   16   MX 2 CA 123 340.3

        5 130 1  38.8 560.6 1003.  36.3  48.5   639.8   829.5

       15 120 3   6.1 248.3 229.2  14.6  12.8     4.4   120.6

       30 122 2  54.8 179.0 207.5  52.2  46.4  1107.8   896.1

       35 116 3   7.4  65.8  44.6  51.6  46.7  1393.4  1640.2

       40 122 1 133.2 142.4 189.3  51.5  65.8  1210.6  1505.7

       45 127 1  34.3 173.3 164.5  49.6  66.0  1387.1  1749.4

       50 119 2  20.5  85.2 180.3  65.1  80.1  1944.9  1853.5

       55 126 2   8.0 113.5 103.2  81.6  71.5  2835.0  1883.2

       65 116 3  10.8  77.5 214.9  86.3  62.3  2976.3  1244.2

       75 115 3  17.8  86.1 242.6 100.3 103.6  3240.6  2688.3

       80 118 3   8.6  34.0 125.8 112.0 102.1  4402.3  2446.9

AA   17    MX 3 CA 103 549.3
```

```
        25 101 1  45.3  70.2  51.4  14.7  25.3   245.1   573.2
        30  99 2 111.7  87.8 282.8  26.8  37.2   472.1   551.4
        35 108 2 110.7 105.8 246.5  40.7  43.3   954.5   733.9
        40 112 1  34.7 148.8 202.0  45.9  43.0  1004.1   740.7
        45 102 1  32.6  51.7 324.9  30.1  49.6   760.4   955.8
        50  99 3  34.8  51.7 436.0  66.8  50.8  1635.1  1067.6
        55 106 2  43.0  54.2 163.4  38.0  42.1  1149.7   922.6
        60 103 3  21.6  75.1 153.6  46.2  41.4  1246.2   916.5
        65 103 3  43.9  79.1 177.6  78.9  62.0  2765.9  1744.2
        75 101 2  11.5 249.3 142.7  72.5  90.3  1813.4  2401.0
        80 101 2  17.3  29.5 194.1  93.6  87.0  3576.0  1917.0
        90  99 2  32.7  77.7 134.9  64.0  74.3  2236.2  2018.3
       100 107 2   9.5 216.8 148.8 197.7 170.0  8339.3  5448.7
AA   18   MX 4 89 87.5
        20  90 2  44.2 139.4 112.4  36.4  71.1   824.6  1695.4
        30  92 2   5.8   2.7  44.8  20.0  60.0   762.0  1238.3
        45  86 2  14.1 219.2 248.5  59.1  44.7  1068.6   693.6
        50  91 3   8.4 193.7 254.0  73.7  66.4  1699.5  1448.1
        65  94 2   6.2  30.2 162.6  60.2  80.9  2141.9  2241.6
        85  85 3   8.8  18.2 229.2  60.0  47.2  1978.9   633.0
AA   19   MX 1 TR 136 45.0
        15 135 1  15.1 405.0 990.2  24.6  36.1   453.7   496.0
        20 135 3  13.1 137.9 1320.  15.2  46.6   180.9  1200.0
        35 139 1  16.8  45.5 618.5  48.1  76.7  1411.6  1484.4
AA   20   MX 2 TR 120 157.0
        35 119 2  64.6 168.3 203.9  46.5  41.6  1057.2   858.2
```

```
        40 121 3  22.6 127.5 320.9  58.0  70.2  1490.0  1460.7
        45 118 2  14.8 251.1 747.2  93.7  82.9  2487.8  1715.3
        50 121 3  39.7 104.3 121.2  70.1  63.6  2237.5  1716.8
        55 116 3  12.3  46.2 164.5  34.2  86.7  1091.8  2452.8
        70 125 1   3.0 159.8 121.7 102.1 104.7  3027.5  3029.0
AA   21   MX 3 TR 108 336.6
        35 108 2  45.8 248.3 214.4  56.9  45.0  1174.8   841.4
        40 110 2  74.5 130.8 263.9  56.1  64.2  1398.3  1300.8
        45 110 2  72.6 115.2 255.6  35.6  55.4   724.2  1241.1
        50 110 3  55.9 186.4 228.5  72.7  73.4  1936.6  1675.5
        55 111 3   8.5  78.4 245.0  55.2  75.5  1513.3  1773.3
        60 112 3  32.0 218.1 205.7  85.7  89.1  2415.3  2287.4
        65 111 2  20.9 165.8 280.3  31.9  71.6   756.6  1512.3
        75 109 3  21.7 111.8 115.7  50.4  35.1  1323.8   659.2
        85  99 2   4.7 120.8 184.2 126.1  88.7  4387.9  2282.2
AA   22   MX 4 TR 86 12.6
        45  83 3   8.8  83.6 126.8  23.2  37.9   430.5   582.2
       215  94 3   3.8  10.0 103.4  60.0 100.0  2194.7  3318.0
```