HARVARD FOREST

BULLETIN NO. 29

FIFTY YEARS OF MANAGEMENT AT THE HARVARD FOREST

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HARVARD FOREST
PETERSHAM, MASSACHUSETTS
1960

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INTRODUCTION

When forestry was first talked about seriously in the United States, about 1880, this country was a small nation of approximately 50 million people, with an economy geared to animal power and steam engines. By the turn of the century the population had increased fifty percent, and the economy was about to expand on a new power base of internal combustion engines and electricity. At the same time foresters were caught up in the forefront of a new liberal political movement. During the last fifty years the population has again doubled; and the economy now stands at the beginning of a new era based on atomic energy. Also during this time forestry has gradually gotten out of the salons and into the woods, so that foresters must increasingly produce results that carry conviction, rather than convince owners by what Fernow * called "propaganda".

Because forest resources have been in the thick of this turmoil of change, their uses have been continually redefined. As new demands for wood, water, grazing, and recreation have daily become more important, "multiple use" is no longer simply an academic theory but is an insistent management problem. While most of the old uses for wood continue, many have lost their importance; and wholly new products have become prominent. During the last fifty years, while the population doubled and the gross national product tripled, the amount of lumber used has remained remarkably constant. Total industrial wood consumption rose only 15 percent between 1900 and 1952 (U.S. Forest Service, 1956). However, less conventional uses based on wood fiber have grown by leaps and bounds. The next fifty years are likely to produce even greater changes in the form of wood products and in the other demands made upon our forest resources.

Early in this century the original ideas of forestry provided a rational argument for the use of this resource that was enthusiastically promoted by many prominent people. These ideas helped prevent the complete disposal of the public domain and led to the setting up of the National Forests. But the basic concept of management which came from these ideas made little headway with forest industries, which were then essentially migratory. Today the wood-using industries have settled down, and many have hired foresters to procure their wood and help

* Dr. B. E. Fernow, Chief, Division of Forestry, U. S. Department of Agriculture, 1886 to 1898.

manage their forest lands. The U.S. Forest Service has exchanged its role of custodian of forest lands for one that involves active forest use and development; and even private owners of woodlots are becoming interested in improved practices. In this setting of continuous change in demands and objectives, as well as in the forest resource itself, the need is increasingly felt for new and better guidelines. Consequently, over the years the ideas of "management intensity", "input-output", "operating unit analysis", and, most recently "investment opportunity", have been discussed in an attempt to devise methods of analysis that will help managers to make better decisions about the use of their forest and other resources in a dynamic and changing situation.

Here and there a few people are beginning to give thoughtful consideration to the role that management must be prepared to play in forestry. Traditionally, forest management has been largely concerned with the "application of business methods and technical forestry principles to the operation of a forest property" (Society of American Foresters, 1950). Recently there has been some interest in such new fields as administrative management; but so far the emphasis is primarily on organization, efficiency, and evaluation. Experience at the Harvard Forest suggests that all these activities are carried out under very uncertain conditions, and that the success of resource development is greatly affected by the capacity of managers to cope with risk and uncertainty in their planning process. Although imperfect knowledge about the course of future events is not unique to forestry, the long production period needed for forest crops makes the problem of uncertainty so central to forest management decisions that it is of necessity receiving more serious consideration as the population pressure on resources leaves less and less room for trial and error methods.

A test of the early ideas about forest management was started at the Harvard Forest fifty years ago, and the history of this half century of progress clearly shows the need for basing management programs on a continuing appraisal of biological and economic probabilities. The inherent uncertainties of forest production favor a management concept that provides enough program flexibility to take advantage of the promising new opportunities suggested by accumulating information and experience, and one that at the same time provides a hedge against an unfavorable turn of events.

In order to understand the basis of forestry at Harvard, it is necessary to look back to 1903, when the subject was first taught. Although the whole field was new to the United States, a definite set of objectives had already been developed in Europe. These ideas were imported almost intact and summarized by Gifford Pinchot (1905) when he said, ". . . a forest may yield its best return in protection, in wood, grass, or other forest products, in money, or in interest on the capital it represents. But whichever of these ways of using the forest may be chosen in any given case, the fundamental idea in forestry is that of perpetuation by wise use; that is, of making the forest yield the best service possible at the present in such a way that its usefulness in the future will not be diminished, but rather increased".

From this and other contemporary statements, it is clear that the forest was thought of as a renewable natural resource, which, if properly handled, could produce a wide variety of values. Although this concept was the root of the idea that was later developed into "multiple-use", in 1905 there was little concern about whether or not all objectives could be achieved simultaneously. Management plans were generally made for some single dominant purpose, with the more or less tacit assumption that the other values would follow.

Thus Pinchot said, "A forest well managed under the methods of practical forestry will yield a return in one of the ways just mentioned. There are, however, four things a forest must have before it can be in condition to render the best service" . . . : protection from fire, overgrazing, and theft; strong and abundant reproduction; growing space enough for every tree; and finally, a regular supply of trees ready to cut. This last point he elaborated at considerable length, ". . . the amount of wood taken from a healthy forest and the amount grown by it should be as nearly equal as possible. If more grows than is cut, then the forest will be filled with overmature, decaying trees; but if more wood is cut than is grown, then the supply of ripe trees will be exhausted, and the value of the forest will decline".

The concept of perpetuating the values of a forest by wise use was translated into a plan of action that focused attention almost exclusively on the production of timber by sustained yield. Parallel ideas were applied to grazing; but no body of management theory of comparable elegance was developed for the production of water and recreation. This timber management theory, that has been the continuing core of forestry practice, is biologically oriented, and apparently assumes that maximizing physical production over the years will automatically yield the largest income stream and the highest rate of interest on invested capital.

Fernow (1899, p. 21) had considerable doubt about this assumption which he spelled out when discussing the fact that German forestry was returning three to four percent on invested capital. "If, then, in a country with dense population, where in many places every twig can be marketed, with settled conditions of market, with no virgin woods which could be cheaply exploited and come into advantageous competition with the costlier material produced by managed properties, with cost of labor low and prices of wood comparatively high — if under such conditions the returns for the expenditure of money, skill, intellect in the production of wood crops is not more promising, it would seem hopeless to develop the argument of profitableness in a country where all these conditions are the reverse, and a business man considers a six percent investment no sufficient inducement".

He obviously believed (1891, p. 15) that current economic, social, and forest conditions in the United States would not justify sustained yield management, and he proposed a simpler set of guidelines for owners and for government policy. "Before, however, we may apply the finer methods of forestry management as practiced abroad, it will be well enough to begin with common-sense management, which consists in avoiding unnecessary waste, in protecting against fire, in keeping out cattle where young growth is to be fostered, and in not preventing by malpractice the natural reproduction".

Despite Fernow's early dissenting voice, the ideas epitomized by Gifford Pinchot's writings soon dominated the thinking of foresters in the United States. However, no experience was available in this country to document the results of sustained yield over time, or to show the difficulties likely to appear in putting such a program into effect. Thus the problems that would have to be solved by forest managers were largely undefined, and this fact, plus the lack of experience data, was a considerable handicap in demonstrating the worth of forest management principles.

Harvard Forest Case History

Therefore, in 1907, when a wooded tract in Petersham, Massachusetts, was offered to Harvard for forestry purposes, it seemed not only an ideal aid for teaching, but also afforded an excellent opportunity to put forest management into practice on a commercial scale. An added inducement to try out sustained yield was the fact that no money came with the land, and the University had stipulated that the Harvard Forest must be self-supporting. The growing stock, therefore, was viewed as an endowment fund that could be made to produce income every year. Thus the Harvard Forest was started with three general purposes in mind: to demonstrate forest practices that could serve local landowners and show the value of sustained yield; as a field laboratory for student training; and as a research station to extend the scientific knowledge of forestry.

A roster of the Forest's students is ample evidence of the success of the teaching program, and a long list of bulletins, papers, and articles have been published that attest to its value as a research station. Most of these documents, however, describe research stimulated by the detailed biological problems encountered in managing the woods. Relatively little has been published about the other problems and opportunities faced by the Forest's managers, or about the over-all results of the sustained yield program.

The Forest Situation The forested area in 1907 included about 1,600 acres, a figure that was gradually increased to 2,200 acres by planting and acquisition. The original stands contained a little under 12 million board feet of merchantable sawtimber, 90 percent of it being old field white pine less than 70 years old. In addition, there were nearly 12,000 cords of wood in smaller trees. Thus the initial stocking per acre averaged 7,300 board feet of timber plus 7.5 cords of wood. Sawtimber growth on the whole property was estimated at 225 M.b.f. per year.

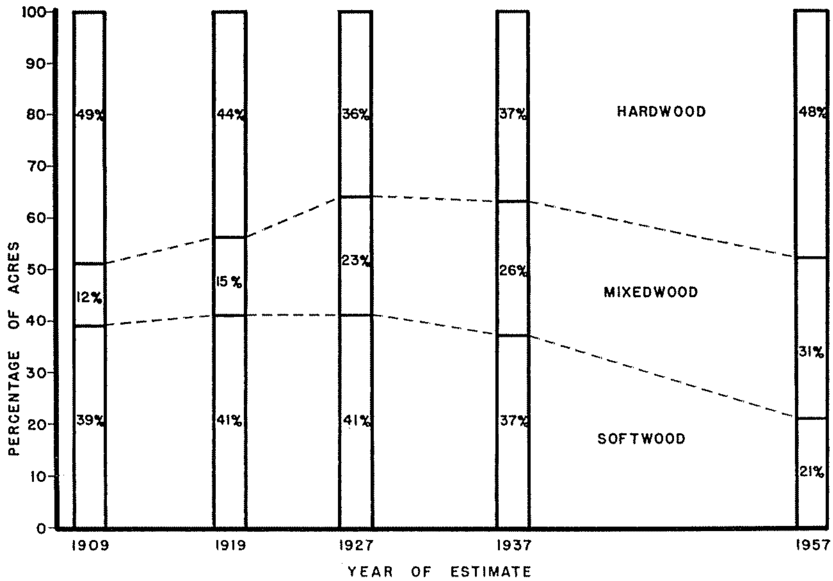
The left-hand bars of Graphs 1 and 2 show how the stands were distributed by cover- and age-classes. Nearly half the area supported hardwood, but mostly of cordwood size. The sawtimber was concentrated mainly on the 39 percent of the area classed as softwood. Only a small part of the area, 12 percent, had very young stands, a little over a third of the land had sawtimber, while about half the area had pole-sized stands. The other bars show how these proportions changed over fifty years of management.

The Market Situation In 1907 the Millers River Valley, just five miles north of the Forest, was the center of the country's wooden box industry. In addition, cooperage, toy, and match factories were very active, and helped create a steady demand for white pine at stumpage prices that had for some time stabilized between $6 and $8 per M.b.f. A ready market and an abundant growing stock made the production of white pine sawlogs the logical base for the first management plans at the Forest. However, within a few years, local plants were buying hardwood logs of good quality at comparable prices, so other species were worked into the program.

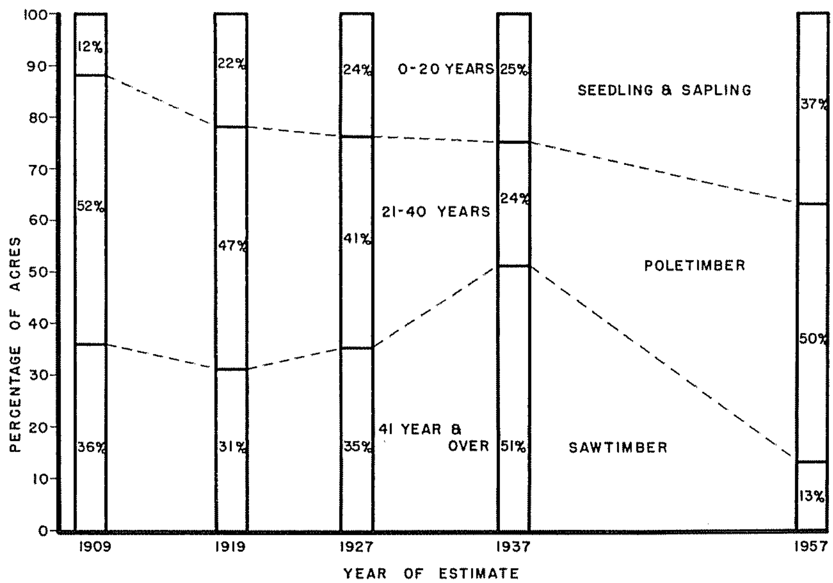
By 1921 R. T. Fisher, Director of the Forest, was able to state that, "There are now no species and practically no size either of hardwood or softwood which cannot be marketed either at a profit or at least without loss . . . The result of such a varied and convenient market has been that the greatest difficulty in handling forest crops is largely eliminated, namely, the presence of species that cannot be sold".

In addition, there were many portable mill operators and woods workers in the area cutting and sawing pine logs. For the first few

GRAPH I. PERCENTAGE DISTRIBUTION OF ACREAGE BY COVER CLASSES



GRAPH 2 PERCENTAGE DISTRIBUTION OF ACREAGE BY AGE OR SIZE CLASSES



years the Forest had its own woods crew and sold logs delivered at a centrally located mill site on the property. Later a mill was hired, and finally one was purchased, so that logs were sawed and sold as lumber on-the-sticks or delivered at nearby plants. As it was cheaper during the depression to hire a mill than to own one, the Forest disposed of its mill. After the hurricane of 1938, logs were sold until another mill was acquired in 1949.

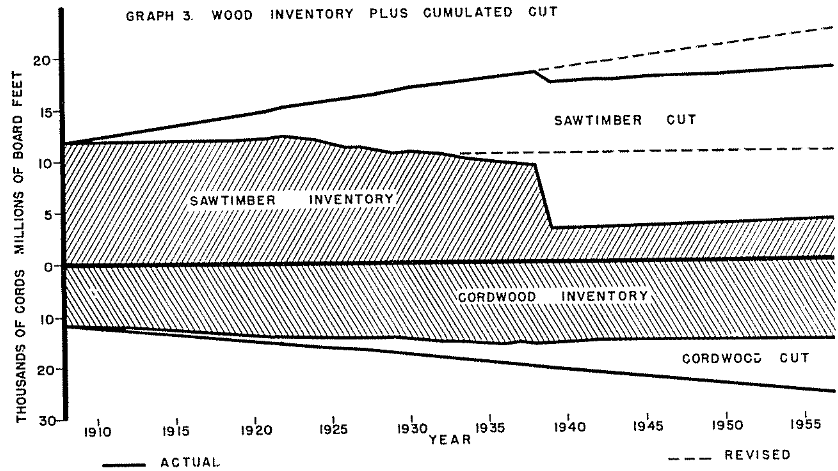
The Management Program Followed

A moderately well-balanced growing stock, stable markets for sawlogs, the need for a continuing income, and the desire for documented experience all made sustained yield an attractive management program. A rotation of 60 years for pine and 80 years for hardwood seemed most suitable, and a cutting budget equal to growth was set up. Operations were geared to stay within the allowable cut, at least during 5- to 10-year periods, and a record system was started to measure the development of the growing stock and to keep track of the amounts cut, the costs, and the cash returns.

Volume Development Graph 3 shows how the sawtimber and cordwood inventory changed over time and how the cut of wood accumulated. During the first 14-year period, from 1908 to 1922, the annual cut varied from 50 to 350 M.b.f. but averaged 195 M.b.f. plus 85 cords of wood, well within the allowable cut. That this harvest was approximately equal to sawtimber growth is shown by the fact that the inventory estimate held almost steady at about 12 million board feet. At the same time the cordwood inventory increased by about 2,500 cords. During the next 16 years, from 1922 to 1938, annual operations averaged 420 M.b.f. plus 190 cords. This total was apparently a bit more than the growth of the larger trees because the estimated sawlog inventory declined about 3 million feet, although a gain of about 1,500 cords of small wood was realized. This reduction in sawtimber stock was largely unintentional, and apparently resulted partly from the fact that the periodic cruises gave an over-optimistic view of growth, and partly from an attempt to maintain income in a period of falling prices. The amount of "over-cutting" would have shown up fairly soon and could have been corrected; but before this could happen the hurricane of 1938 blew down over 6 million feet of the remaining sawtimber.

The hurricane of 1938 which struck the northeastern United States on September 21st, devastated thousands of acres of land in New England and took several hundred lives. No storm of such magnitude had been

MANAGEMENT PROGRAM FOLLOWED AT THE HARVARD FOREST

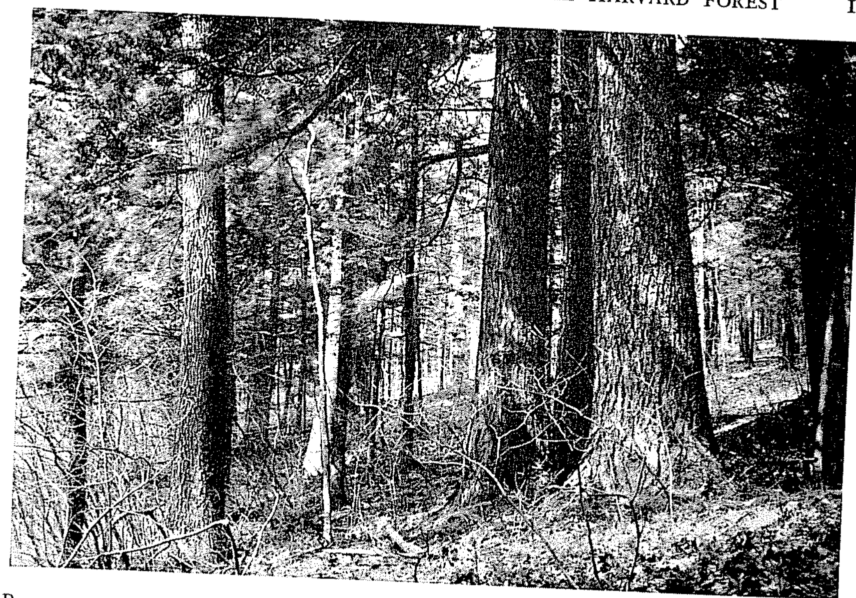


Estimates of yearly inventories are based on the measured cumulation of products cut plus a two percent growth allowance, and on periodic timber cruises.

known in this part of the country since 1815. Practically every owner of woodland was affected. In order to keep the market for logs and lumber from being completely demoralized, the Federal Government set up an agency, the Northeastern Timber Salvage Administration, to buy logs, saw as many as possible immediately, and store the remainder in various ponds until they could be released without glutting the market. When World War II broke out in Europe the following year, the demand for wood began to increase rapidly, and all the hurricane lumber was sold within a few years.

Salvage on the Harvard Forest was prompt; but, even so, an estimated million feet of lumber were lost in splintered trees and in logs that did not meet grade specifications. Most of the salvage logs were sold to the Northeastern Timber Salvage Administration. The small stumpage realized was more than used in cleaning up the woods and in reducing fire hazard.

The enormous loss of merchantable timber from the hurricane made necessary a drastic revision of the cutting program. The yearly cut during the last 18 years has averaged 23 M.b.f. plus 330 cords of wood. Because the sawtimber cut has been less than the annual growth, the inventory has increased by about 45 M.b.f. per year until it is now nearly 4 million board feet. At the same time the cordwood inventory has been maintained at a fairly constant level of about 15,000 cords. During this period, the first operations completed the hurricane salvage. Then



PICTURE 1. Typical old growth stand near Harvard Pond prior to the hurricane. No cuttings had been made in this stand when the picture was taken in 1925.

a shift was made to partial harvest and improvement cuttings in the remaining older stands, and greater emphasis was placed on improvement cuttings in the cordwood areas.

Since 1908, a great deal has been learned about the silvicultural problems involved in managing pine and hardwoods. Hardwood competition from advance growth and seedlings was so vigorous on the moist upland till sites that repeated cutting back to release pine seedlings proved too expensive. Although a satisfactory catch of pine seedlings followed harvest cuts in good seed years, the attempt to keep weeding costs within reasonable bounds proved that the work was usually "too little and too late", with the result that most of the old field pine land on better sites was taken over by what finally became promising stands of transition hardwoods. In contrast, it proved easy and inexpensive to reproduce conifers on outwash sands and gravels. Between these two extremes was a large area of intermediate sites where hardwoods grew poorly and conifers might be helped to take over part of the land with fairly simple management practices (Lutz and Cline 1947, 1956; Goodlett, 1960). The use of sprays to control hardwoods developed too late to help reproduce any pine stands at the Forest; but this new technique does promise lower cost and more effective control over poor hardwoods in the young, post-hurricane stands.

PICTURE 2. The same general area after the hurricane of September 1938. A higher proportion of the trees in old field pine stands were shattered than is indicated by this picture of old growth.

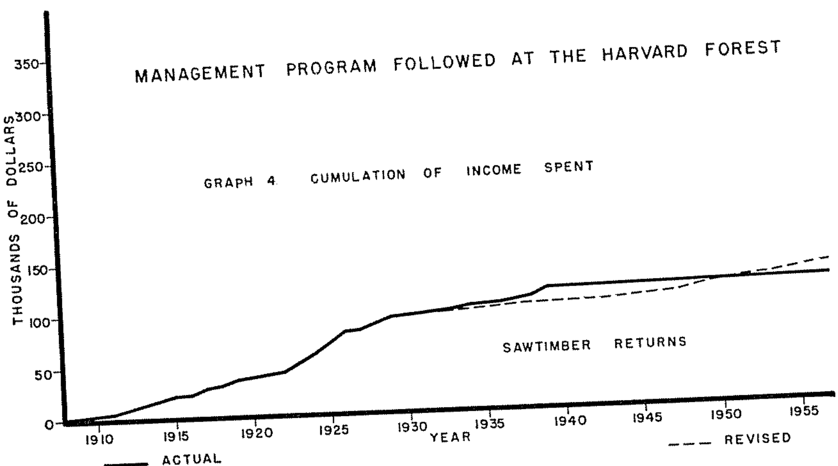
This natural shift toward hardwood in the new stands would eventually have made necessary a fairly drastic revision of the sustained yield program even without the hurricane. The pine growing stock would have gradually dwindled, and the slower growth of hardwoods on a longer rotation would have called for a downward revision of allowable cut. This adjustment would probably not have been needed for another decade or so, but after the hurricane attention perforce shifted toward hardwood management.

On balance, it seems that the sustained yield management program was successful in maintaining three-quarters of the growing sawtimber intact for thirty years. Improved control mechanisms might have made performance even better, but any gain would probably have been wiped out in the hurricane. It is now apparent that a great risk was being run by carrying such a large volume of pine sawtimber. In 1938 most pine in the 20–40 year age-class and all of that which was older was windthrown, except in a few places on the Forest sheltered from the full impact of the storm. The same degree of loss did not occur in hardwood stands until they reached 60 to 80 years of age (Rowlands, 1941). Observations to date indicate that although hurricane storms hit New England at least once a decade, the widespread devastation of 1938 comes only about once every 100 to 150 years (Brooks, 1940). These facts give a rough measure of the uncertainty due to wind devastation that managers must weigh in devising forestry programs, and suggest steps that will tend to prevent undue loss.

It is interesting to speculate about what might have happened if the older stands had escaped substantial damage from the hurricanes of 1938, 1944, and 1954, the November gale of 1950, and the tornado of 1954. If in the early '30's "overcutting" had also been recognized and the yearly cut reduced to about 200 M.b.f., it is reasonable to suppose that the pine sawtimber could have been maintained at about 11 million board feet. The total cut for the 50-year period would now equal about 12 million feet rather than the 15 million board feet actually harvested. Thus by sacrificing about 3 million feet of timber sold (much of it for a low salvage value), the Forest would now have almost 7 million more board feet of standing timber that could be cut during the next few decades and replaced by hardwood and mixedwood stands. The probable inventory of sawtimber and the accumulation of harvest is shown by the dashed lines on Graph 3.

In all probability the seedling, sapling, and poletimber stands would be of about the same caliber as those on hand today, judging from what we have learned about pine-hardwood succession and the cost of hardwood control. Thus the major physical gains in the last five decades would have been a more even flow of timber products and an increase of over one-half in net sawtimber production. Present and future sawlog harvest could also be larger and more regular than is now possible. As we now know, however, in this region the chance of hurricane devastation to susceptible pine stands gets greater every year that they are held after 20 to 40 years of age. This fact suggests that a management program which shortens rotations as much as possible in exposed areas, and develops the largest trees in sheltered areas would be a wise move to maximize the production of usable wood. Thus where the chance of catastrophic physical loss is appreciable, a program aimed at producing the largest amount of usable wood may require relaxing allowable cut principles. Although the risk of physical loss that managers must anticipate will vary from region to region, it is present in some form everywhere.

Income As Pinchot pointed out, volume produced is only one of the several objectives to be met by forest management. The flow of income over time and the accumulation of returns are also important to most owners. In fact, to the degree that market prices reflect the need of society for products, income is one way of weighing the usefulness the economy has realized from the management of a forest resource. The dollar returns, before taxes, shown in Graph 4 indicate how successful the Harvard Forest management program has been in meeting this objective.



Over the years cordwood has been sold for fuel. As the returns have merely covered the costs of processing, no stumpage value has been realized.

The curve of the accumulated value of the yearly harvests in Graph 4 parallels that of the quantity cut during the early years when prices were relatively stable. The higher prices and larger cuts after the war steepen the curve until it levels off in spite of increased cutting when prices drop toward the depression lows. Since the hurricane, cut and returns have been very small, and the total for the fifty years now stands at nearly $118,000, or an average of $2,400 per year, equal to about $1.10 per acre per year. Of course most of this amount accumulated during the pre-hurricane years when returns averaged $3,600 per year, or $1.60 per acre per year.

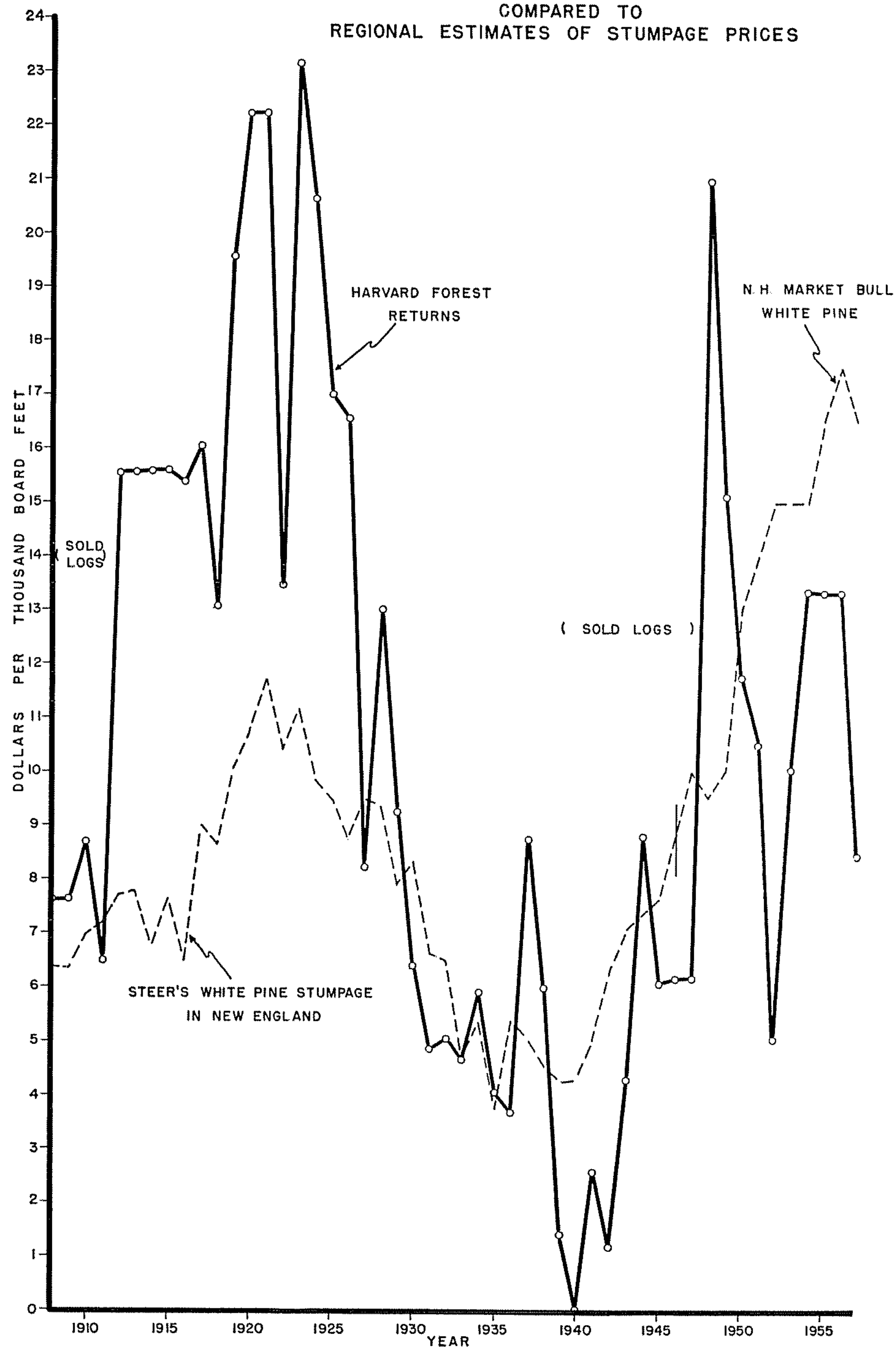
It is interesting to note that the income flow likely to have been generated from a completely successful program of sustained yield without hurricane loss would have been very little different from that actually realized. The dashed line on Graph 4 shows the probable accumulation of income, assuming the same prices as those which prevailed. Returns would have accumulated more slowly after the early '30's because of reduced cutting, but would have speeded up by the mid-'40's, and would have been somewhat greater than the amount actually realized since 1949. Today the total accumulated income would be about $132,000, or about 12 percent more than the actual. This return would be equal to about $2,600 per year, or $1.20 per acre per year, before taxes.

These average figures and the scale of the graph do not bring out the fact that the flow of income over the years has been quite erratic. Differences in returns, from a high of $23 per M.b.f. in 1923 to a low of nothing in 1940, have made income vary much more than annual cut. In operating the Forest, this fluctuation has made it hard to anticipate each year's income. If constant returns had been the objective, greater flexibility in the amount cut would have been a helpful, even if not a complete, solution.

The crucial role that prices play in determining the ebb and flow of year-to-year income is illustrated by Graph 5. Here the annual return per M.b.f. realized by the Harvard Forest is plotted with estimates of the regional average stumpage prices for white pine (Steer 1938; New Hampshire Extension Service, 1946–1957). The Forest figures are the return per M.b.f. actually realized after paying all operating costs and before taxes. These returns thus contain not only normal stumpage but also any profit that might have been made from the operation of the mill. The Forest's figures were generally greater than Steer's prices prior to the depression, and less than regional price estimates thereafter. The larger returns are due to the milling margin, a prosperous local wood-using industry, good cutting chances, and efficient operations. The later lower-than-average returns largely reflect the deteriorated condition of local industry and the higher costs of operating the scattered, low density stands left after the hurricane.

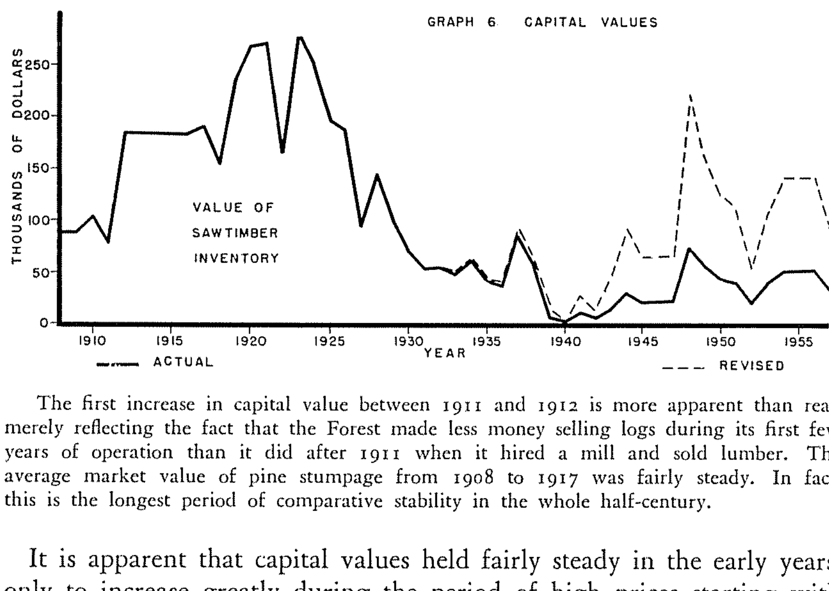
Capital Value Variation in the stumpage return from sawtimber also has had a marked effect on the capital value of the forest inventory, another of the objectives of management mentioned by Pinchot. Many owners are interested in the capital appreciation or depreciation of their forest resources, and the probable course of this development may have considerable impact on their management decisions. In Graph 6 the capital value of the sawtimber inventory each year has been esti-

GRAPH 5. ANNUAL HARVARD FOREST STUMPAGE RETURNS
COMPARED TO
REGIONAL ESTIMATES OF STUMPAGE PRICES



mated by multiplying the sawtimber volume by the return per M.b.f. realized during the current operating season. It can be argued with some validity that the unit value realized by selling the entire inventory would be different from the return from a single year's operation. It might also be suggested that regional average prices could better be used to figure capital value; this would insulate it from the vagaries of local markets. Nevertheless, local shifts in value being so close to home are likely to have a greater impact on a landowner than a regional average that masks this variation. However capital values are related to market values, the same broad outline of variation is likely to appear as that shown in Graph 6.

MANAGEMENT PROGRAM FOLLOWED AT THE HARVARD FOREST



The first increase in capital value between 1911 and 1912 is more apparent than real, merely reflecting the fact that the Forest made less money selling logs during its first few years of operation than it did after 1911 when it hired a mill and sold lumber. The average market value of pine stumpage from 1908 to 1917 was fairly steady. In fact, this is the longest period of comparative stability in the whole half-century.

It is apparent that capital values held fairly steady in the early years, only to increase greatly during the period of high prices starting with the first World War and ending about 1924. Thereafter capital depreciation occurred at a much more rapid rate than inventory volumes justified, until after the hurricane. Since then, values have been erratic but have generally tended upward. Anyone carefully considering capital value would be much impressed by the fact that during the brief span of two years, between 1918 and 1920, the sawtimber volume was stable; but its value increased by more than $110,000, a rise of over 70 percent. Conversely, in the four-year period from 1923 to 1927 the sawtimber volume lost better than two-thirds of its value, over $180,000, due mostly to price changes.

The general outline of changes in the capital value of the sawtimber inventory is estimated to be about the same even if sustained yield had been more successful and blowdown had been avoided. The dashed line on Graph 6 shows that the trend is unchanged except that the variation since the hurricane is greater, and closely follows shifts in prices. If the sawtimber inventory were about 11 million b.f. today, logging chances would be better than those we now have; and a more realistic estimate of capital value might be based on regional average stumpage prices. This would place the present capital value between 150 and 200 thousand dollars, about where it was in the early years of lumber sales. Of course with this larger inventory on hand, there would be a better chance to take advantage of any new speculative gains that might come from another large boost in prices. This opportunity for gain must be weighed against the chances of catastrophic loss, however, and in this case we now know the Harvard Forest gambled earlier and lost.

Discussion We can now judge how well three of the main objectives of forest management mentioned by Pinchot were met by the 50-year test carried on at the Harvard Forest. The primary control mechanism used to regulate cutting was the rate of wood production, especially in sawlog sizes. Although the managers were partially successful for a time, elements beyond their control devastated two-thirds of the sawtimber. Had this catastrophe not happened, however, net production of logs cut and grown might have been increased by as much as one-half. However, so far as long-run potential is concerned, the new stands would probably be about the same as the present ones. Therefore it may well be that the next fifty years will eliminate most of any volume difference that might have been developed in the first fifty years.

If we were starting over again, it seems likely that a careful assessment of stands by risk categories and a cutting program designed to reduce the area of highest risk types might have produced more usable wood. Whether or not this program could also be based on the concept of "allowable cut" would depend largely on the capacity and willingness of the manager to bear the necessary risk and his subjective balancing of possible losses and gains.

At the Harvest Forest a fairly even annual cut has not produced an even flow of income; in fact, income has been most erratic because of changing values that have been largely beyond the control of the managers. It seems unlikely that income could have been kept at a constant amount each year with any reasonable juggling of annual harvests, especially when prices took their long slide into the depression. It also seems that because of the reduced cutting required, a more successful sustained yield program without blowdown would have accumulated only about 12 percent more income than was actually realized. Thus income differences in the programs seem even less than the estimated difference in the volume that might have been produced during the last half century.

Capital values have also been closely related to changing prices, and it seems physically impossible for any inventory control program to have smoothed out the vast variation that has occurred in the last fifty years. No program of growing trees could have increased their value fast enough to have offset the major drops in prices that occurred in over half the years.

During the last fifty years at the Harvard Forest the objectives of volume production, income flow, and capital appreciation could not have been equally well satisfied by any single management program, especially one controlled exclusively by biological growth rates. Value changes and the probability of physical and market losses or gains should have been considered in addition to the likely efficiency of capital in alternative uses. If these principles had been used to guide the management of the Harvard Forest, a number of alternatives were available. Two of these possibilities will be discussed to illustrate the range of considerations that managers might have taken into account.

A Partially Diversified Capital Management Program

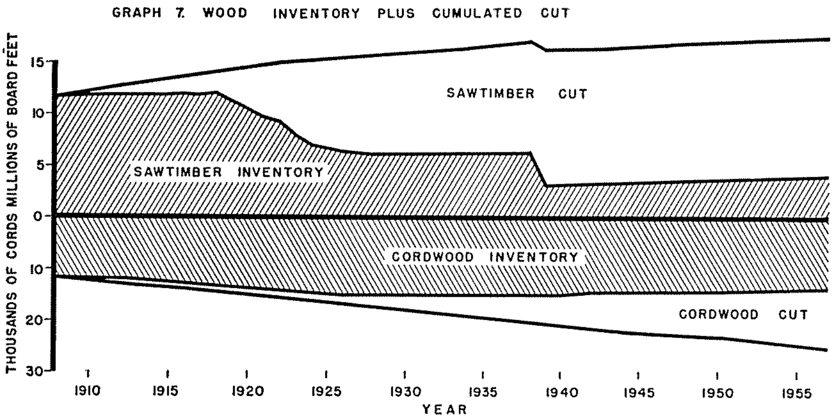
In light of the alternative investment opportunities open to the Harvard Forest, it is interesting to see what another management program might have done to reduce the risks of physical and market loss and to take advantage of what might be called speculative gains. The fact that funds could have been safely invested with the University at any time and could have earned a minimum of 4 percent shows one way of diversifying the Forest's "white pine endowment". To the degree that the sawtimber inventory could be converted to cash and reinvested with the University, the risk of forest production losses could be reduced; and if this conversion was timed properly to capture the values created by high prices, these speculative gains could have been made permanently productive. Of course the chances for growth and further speculative gain would have been correspondingly reduced for a time, and this fact suggests that some compromise between complete conversion and sustained yield management might have been desirable. If the allowable cut requirement of sustained yield had been given less attention and value and uncertainty given more consideration, then stumpage price changes and opportunity costs could have helped guide harvesting.

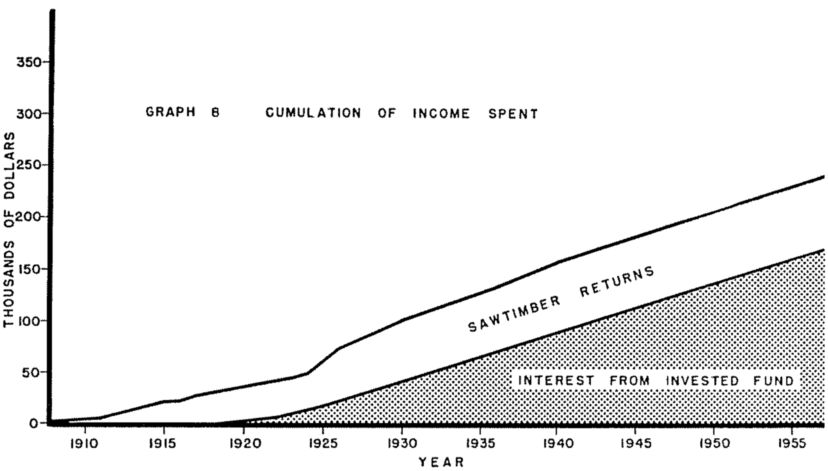
One simple and feasible alternative to strict sustained yield might have been a program that recognized the temporary nature of war-time prices and the transitional character of the old field white pine stands. Operations could have been unchanged during the 1908 to 1917 period of stable prices, but cutting could have been stepped up later to take advantage of the speculative gains resulting from high prices. Thus the managers would have helped to satisfy society's need for timber, reflected in these increased values, by cutting about half the sawtimber. Six million board feet could have been cut between 1918 and 1923, and later harvests reduced to about 100 M.b.f. a year when prices dropped. A little more than $118,000 would have been available over current spending as an investment fund, which at 4 percent would have made a steady return of about $4,700 a year, in addition to any returns from later cutting.

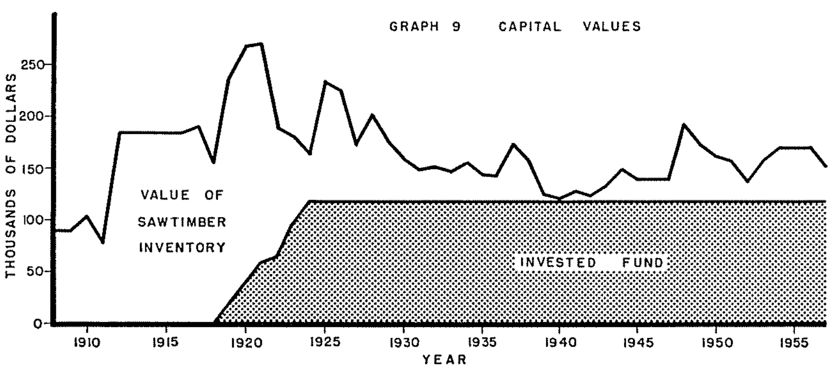
Graphs 7, 8 and 9 show what would have happened to the growing stock inventory, cumulative cut, income, and yearly capital values under this plan. Hurricane blowdown would have been less than half that actually experienced because of the smaller acreage of high-risk stands; and the post-hurricane sawtimber inventory would be practically the same as that actually realized. The major difference would appear in the younger stands where, instead of 700 acres dating from 1938, about half would be older, dating from the cuts of 1918–23. Thus there now would be less of a waiting period for these stands to produce usable products. In addition, more improvement cutting could have been done in the cordwood stands in order to keep the woods crew busy after 1923. Judging from what has been learned about the management of old field white pine stands at the Harvard Forest, this program would have resulted in new stands equally as productive as those now growing. The land could have been kept in valuable forest cover, so that long-run production would be little affected. In the short run of 50 years, the sawtimber cut would be only about 2 million feet less than that actually realized. The future flow of wood products would probably be smoother than that actually achieved because the "lumpiness" caused by 700 acres of 1938 blowdown would be reduced.

Income, of course, would have been more constant, and the total amount accumulated would now be over twice that actually realized, because the market losses of the depression years and the value and volume losses of the hurricane would have been greatly reduced. In addition, part of the speculative gains of the war years would have added a steady 4 percent earning to income. While the returns spent now total

CUTTING ACCELERATED TO REMOVE HALF THE SAWTIMBER AT HIGH PRICES







about $118,000, this alternative plan would have produced about $239,000, or a yearly average of $4,800, equal to nearly $2.20 per acre each year.

Total capital value, consisting of the invested fund plus the value of the sawtimber inventory, would also have been consistently greater than that realized after 1925; now, it would be over four and one-half times greater. The invested fund would have put a floor under capital fluctuations that would have greatly increased its average value over the years. Thus, this method of diversifying the Forest's "investment portfolio" would have provided a safer and more conservative program than the management actually followed, or, for that matter, than the estimated results of sustained yield without blowdown loss.

A program very much like this one could have been developed from the ideas expressed by Austin Cary in 1908. In a letter to A. C. Cline in 1934 he said, ". . . Cut of the early years was right about 200 M.b.f. That was small for the tract, but suited the circumstances perhaps, and Fisher's caution in the early years certainly served him. At one point I certainly should have done different than he did, and I put the idea before him. Scattered through the older stands was a lot of overborne and dead stuff that couldn't last till he could get around to it the way he was going. I thought it good business and good forestry both to salvage that material through prompt cutting". If the idea of expanding operations during periods of high prices and contracting them when prices were down is added to Cary's concept of physical risk reduction and a recognition of the marginal efficiency of capital in other uses, new management guidelines might have been set up. However, this procedure would have required a reappraisal of such concepts as "allowable cut" and "regulation" as basic objectives of forest resource management.

If the managers of the Forest had either been blessed with perfect foresight or had been more impressed by the risks and uncertainty of long-run forest production, they might have devised an even more cautious and conservative management program.

Reinvestment of the Entire Growing Stock Capital

Practically the whole sawtimber inventory, about 12 million board feet, could have been cut during the high prices of World War I, and the surplus return over current spending added to endowment. Under such a program, operations since 1924 would have been geared to a small sawlog cut of about 10 M.b.f. a year plus greater cutting in the cordwood-sized stands. The new stands reproduced would now be 34 to 39 years old, and it is likely that they would have about the same long-term potential as those now growing. In fact, with more income to spend each year on stand improvement, the Forest might be in better shape for future production than it now is. It is unlikely that a planned "unbalanced growing stock" would be any harder to deal with than the accidental one created by the hurricane. Graphs 10, 11, and 12 show how this program would have affected inventory, cut, income, and capital value.

Income under this program would have been at an even higher constant level than that produced by the half-cut plan. Total income would now be nearly $388,000, or better than three and one-quarter times that actually realized. Average income over the entire period would be $7,800 a year, equal to a bit over $3.50 per acre per year. Actually, yearly income since 1924, when the reinvestment was completed, would never have been less than $10,000, and would continue at this level as long as the University's investment program remains as efficient as it has been in the past.

The capital fund created by this program would have been about $249,000, making a yearly interest return of about $10,000. This program would have captured most of the peak value of the sawtimber inventory and would have placed a very high floor under capital fluctuations. During the next half-century sawtimber values would be recreated and would add considerably to the amount that would already be about seven and a half times greater than that actually realized.

Summary and Discussion

The following table summarizes the volume and value data for the several plans of management discussed so far:

Results of 50 Years of Management of the Harvard Forest Sawtimber Stands
Estimated Volume and Value from Alternative Programs

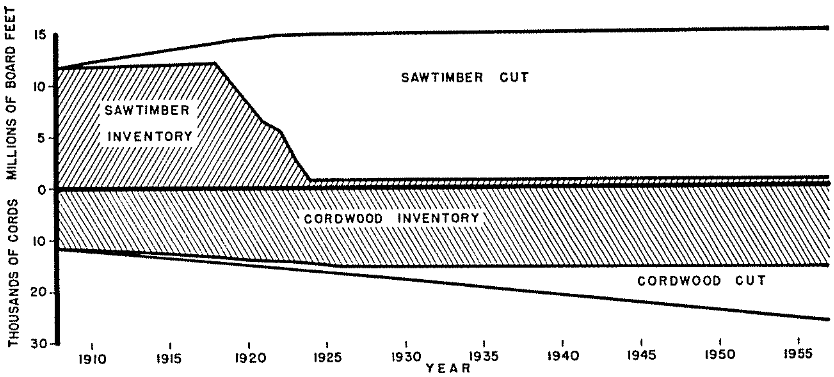
Management Program	Volume — Millions b.f. (1)				Value — Thousands $ (2)			
	Start Vol.	Cut Vol.	End Vol.	Net ST Growth	Capital Value Start	Returns Spent	Capital Value End	Net Gain
All Capital in Forest:								
H. F. Experience with Sustained Yield	12	15	4	7	$90	$120	$30	$60
Complete Sustained Yield without Wind Loss	12	12	11	11	$90	$130	$90	$130
Diversified Capital:								
Plan I, Cut ½ at Peak Prices	12	13	4	5	$90	$240	$150	$300
Plan II, Cut Almost All at Peak Prices	12	15	1	4	$90	$390	$250	$550

(1) Rounded to the nearest million board feet. Unsalvaged hurricane losses are not included with the volume cut.

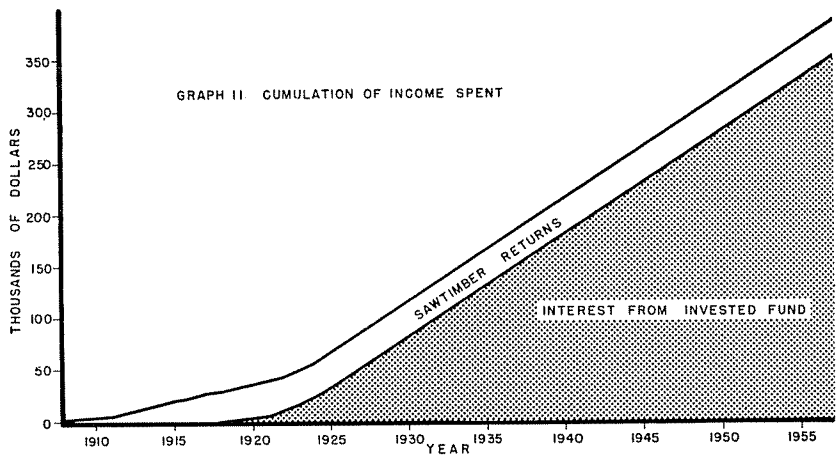
(2) Rounded to the nearest $10,000.

CUTTING ACCELERATED TO REMOVE ALMOST ALL SAWTIMBER AT HIGH PRICES

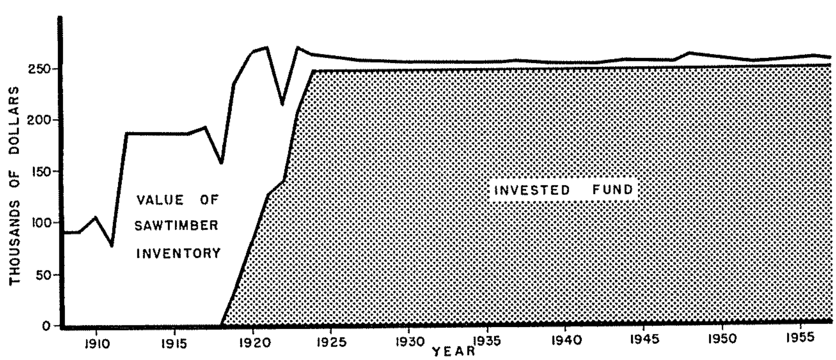
GRAPH 10 WOOD INVENTORY PLUS CUMULATED CUT



GRAPH 11 CUMULATION OF INCOME SPENT



GRAPH 12 CAPITAL VALUES



To recapitulate briefly, the above table indicates that although successful sustained yield management without blowdown might have produced over half again as much sawtimber and about three times more capital value in 1957, it would have brought in only about 12 percent more income. However, there were other programs that could have been used to divert capital into more efficient uses that would have greatly increased and smoothed out the flow of income and the accumulation of capital value. During the last fifty years the net financial gain of management would thereby have been 130 to 320 percent greater than even successful sustained yield without blowdown. It seems clear that, contrary to expectations, the realities of the situation have been such that sustained yield management could not have automatically maximized wood production, income, and capital accumulation over time.

In order to satisfy these three objectives of management equally well, efficient production control and the reduction or elimination of catastrophic losses must be assumed, together with stable demand and prices, and low opportunity costs. In the last fifty years these assumptions have not been realistic. In fact this case history highlights the overwhelming importance that imperfect biological, physical, and economic knowledge (and the resultant uncertainty) has for a manager laying plans for the future use and development of a forest.

At the Harvard Forest this uncertainty has taken several forms:

1. The manipulation of the timber inventory has not been entirely satisfactory. In addition, the response of the forest to management has not been predictable in detail. Reproduction has generally been adequate; but control of its composition during the establishment stage has been costly and uncertain. Better recognition of site effects on reproduction and new techniques to eliminate poor trees are helping reduce this area of uncertainty; but the conditions under which the possible gains are enough to justify the added costs are not entirely clear.

2. The second dimension of uncertainty illustrated by this case history is the effect of natural loss on returns. The most important damage in Petersham has been caused by storm winds, although insect and disease losses have occurred. Fire loss has been very low, but is a much more important factor in some other places.

3. The local demand for primary forest products has changed remarkably during the last half century. Box-quality pine has lost most of its market as the box and cooperage plants have closed one after another in the face of competition from paper and plastic containers. The toy plants have retrenched, and the match factories have ceased altogether. Better quality pine is still in demand as well as high-grade hardwood logs, and new markets for low-grade wood for fiber seem

likely to develop if the necessary plant investment is made. However, the local stumpage market is still largely a matter of "horse-trading", and fails to meet practically every test of the classical competitive market model. These facts, added to the actual changes in utilization that have taken place and may materialize in the future, make the shape of demand in the decades ahead seem uncertain indeed.

4. During its half century of operation, the Harvard Forest has experienced wider fluctuations in stumpage returns than average regional prices would indicate; but this statement is probably true for any specific forest property. In Harvard's experience price fluctuations have been more the rule than the exception. Increases or decreases of more than 10 percent have occurred in 36 out of the 50 years. Six times prices have doubled or better in successive years, and four times they have fallen by one-half or more.

5. Finally, the returns earned by capital invested in growing trees at the Harvard Forest have not been as great as those earned by endowment funds managed by the University. Thus the 50-year experiment in sustained yield has cost the Forest nearly $500,000 of additional financial gain that it could have realized had a different management program been followed during the last half century. This opportunity cost may take different forms in other operating units, but it is practically always present; and more often than not it may be the most important cost of forest management.

The fifty years' experience recorded in this case history have shown that the forest in Petersham is indeed a renewable natural resource that has produced, and will continue to produce, a variety of values. Thus the core premise of forestry, agreed upon from the beginning by both Fernow and Pinchot, seems sound. However, the perpetuation of values by "wise use" has been so narrowly interpreted in the past that many opportunities for financial gain have been lost without any clear benefit to forest production in the long run. The facts of the case suggest that the Forest's managers had much more silvicultural latitude for varying their management program than they originally supposed. Their capacity to adjust cutting schedules and methods is most important in view of the tremendous impact that catastrophic events have had on growth and on the flow of forest values during the last five decades.

Perhaps the most important highlight of Harvard's experience is the fact that events have turned out so differently from those on which plans were based fifty years ago. The demand and price of forest products has varied greatly, silvicultural control has been less effective than anticipated, and natural catastrophies have upset the best laid plans. These forces seem likely to continue, making our knowledge of future events so imperfect that flexibility to meet uncertainty and risk should be a central consideration of any theory devised to guide the prudent management of forest resources. To be most useful, production concepts should release the imaginations of foresters to analyse the full range of possibilities and project bands of probable results. Such activities will not eliminate the final subjective evaluation of risk that must be made by financially responsible management, but they will define and reduce the areas of uncertainty as much as possible in the light of existing knowledge (Johnson, 1953). Finally, the Harvard Forest case history suggests that both natural and social scientists have a great deal to contribute to the job of perfecting new and more realistic forest management concepts.

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