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PROJECTING MICHIGAN'S ASPEN TIMBER RESOURCE

By

Heidi Ruth Cherry

A THESIS

Submitted to
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ABSTRACT

PROJECTING MICHIGAN'S ASPEN TIMBER RESOURCE

By

Heidi Ruth Cherry

Remeasured plots from 1980 and 1993 Michigan forest inventories were used to develop harvest probability equations based on stand characteristics such as ownership, stocking, and location. Michigan's 1993 inventory plots with aspen were projected thirty years using a modified version of STEMS85 with management based on these equations. Michigan specific diameter growth and mortality correction factors were included. The projected net loss between 1993-2023 in aspen growing stock volume is 60%, from 40 million to 16 million cords. The greatest proportional loss of aspen is projected to occur on private ownerships and in the Upper Peninsula while public lands and the Lower Peninsula increase their proportions. The average annual harvest is projected to increase from a 1983-1993 level of 122 million cubic feet to 128 million cubic feet between 1993-2003. However, projections show a decrease to 97 million cubic feet/year between 2003-2013 and 74 million cubic feet/year from 2013-2023.

ACKNOWLEDGMENTS

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INTRODUCTION

The sustainability of an aspen supply into the twenty-first century has been the subject of research from before the 1970s to the present. The extensive land clearing within Michigan in the late 1800s and early 1900s and subsequent desertion of that land provided an optimum environment for the establishment of an extensive aspen resource that was becoming mature during this time period. As technology improved, a market for the resource was eventually created. However, the maintenance of the resource is highly subject to the management practices applied. As the resource continues to mature and decline, the question of sustaining current output levels is becoming of increasingly critical importance. This research projected the resource as of 1993 for thirty years based on harvesting practices between 1980 and 1993. The goal being to characterize harvest and stocking volume trends during that time period.

I. THE BIOLOGY OF ASPEN

Quaking aspen (*Populus tremuloides* Michx.) and Bigtooth aspen (*Populus grandidentata* Michx.) comprise an early successional or pioneer forest type commonly referred to as aspen. Its natural growth-pattern is to overtake areas that have experienced a large disturbance such as wildfire, tornado or timber harvest. Growth characteristics vary across its natural range which is transcontinental along the northern border of the United States and into Canada. The expected lifetime of aspen increases as the average annual temperature decreases (Perala et. al. 1995, Shields & Bockheim 1981). In the Lake States of Michigan, Minnesota and Wisconsin, it is generally considered a fast-growing and short-lived species that develops on a variety of sites. Good aspen sites are characterized by well-drained loamy soil with a good supply of nutrients to support the fast growing species. While stands in the Rocky Mountains may live for 200 years and allow a rotation age of 125 years, aspen stands in Michigan are often managed on a 35-50 year rotation and will typically begin to break-up after 60 years.

Breaking-up is a process in which small gaps created by mortality in the stand are not replaced by new aspen stems (Perala 1991). The shade of older, more mature trees on the site does not promote successful aspen regeneration. More shade tolerant tree species invade the stand and outcompete any naturally regenerating aspen stems. Contributing factors in stand decay include mean annual temperature, depth to water table and exchangeable potassium (Shields & Bockheim 1981). For modeling purposes, Perala et.

al. (1996) identified the decay triggers to be a threshold stand density of 147 trees per hectare and a stand age equal to 10 plus the site index.

Natural seed regeneration is not considered a reliable or optimal way to fully regenerate an aspen stand. The aspen seed is very fragile, short-lived and specific in its seedbed requirements. However, stand regeneration through root suckers is relatively inexpensive and highly reliable if a few critical conditions are met.

The critical factors in successful aspen regeneration are the parent stand of aspen, the site quality, the amount of direct sunlight, the type of harvest activities, and the season of harvest. Maximum aspen sucker regeneration occurs on well-drained and aerated sites where at least 50 aspen trees or 20 square feet of basal area per acre were cut (Perala 1977). Root suckers originate from dormant buds kept in check during the lifetime of the parent tree through chemical suppression called apical dominance. When the parent tree is cut or top killed, this chemical suppression ceases. Root suckers can initiate growth underneath an overstory of older trees but cannot continue to grow and mature. "As little as 10 to 15 square feet of basal area of residual overstory will slow sucker growth by 35 to 40 percent" (Perala 1977). Direct sunlight allows aspen to take full advantage of its capacity for fast growth when invading newly disturbed areas. On open sites, it can outcompete any later establishing vegetation.

Additional regeneration success factors include the age and health of the parent stand and the type and season of harvest. As the parent stand gets older and more diseased, its regenerative ability decreases. A silvicultural clearcut in which all stems over 1 inch in diameter at 4.5 feet above the ground(dbh) are removed through whole tree harvesting will provide an adequate site preparation through soil scarification and vegetation removal. However, excessive soil compaction by harvesting equipment or extensive disking operations can result in decreased regeneration.

The season of harvest effect is related to the root reserves. Aspen stand regeneration is at a maximum when harvesting occurs from summer through early spring. Harvesting during late spring and early summer decreases initial regeneration capacity. The available food reserves important for sucker growth have been diminished by the parent tree's first growth of the season. A study in Wisconsin showed that the number of root suckers after summer harvesting was only 74 to 78 percent of the number of root suckers after fall and early spring harvesting (Stoeckeler & Macon 1956). Inadequate regeneration can allow competing vegetation to take over the site.

II. THE ASPEN RESOURCE

The aspen covertype is an important natural resource in the state of Michigan. It is valued as a commercial timber species, important wildlife habitat, a resilient pioneer within the ecosystem and an aesthetic part of the landscape. In 1994, there were 154 primary and 148 secondary manufacturers in Michigan using aspen as a raw material (Bertsch & Weatherspoon 1994). All types of aspen production and the proportion of it kept in the state have increased since the 1970s as shown in Figures 1 and 2.[1] Aspen is primarily used as pulpwood by the timber industry (Figure 3). Over half of the sawtimber harvested is either left on the site or used for products other than sawlogs. Figure 4 shows the proportion of harvested aspen sawtimber used for sawlog production. This could indicate a potential for competition between the pulpwood and sawlog industries as the resource matures. Aspen provides the timber industry with a short-rotation fiber supply that can be easily and economically regenerated if the parent stand was healthy, not overmature, and effectively harvested to promote root suckering.

[1] Lake States' timber production estimates by species, product and location are compiled and published periodically by the USDA Forest Service, North Central Forest Experiment Station in cooperation with individual states. The most recent published statistics are presented by May & Pilon (1995) and Piva (1997). 1994 sawtimber statistics are based on preliminary data at the time of this research.

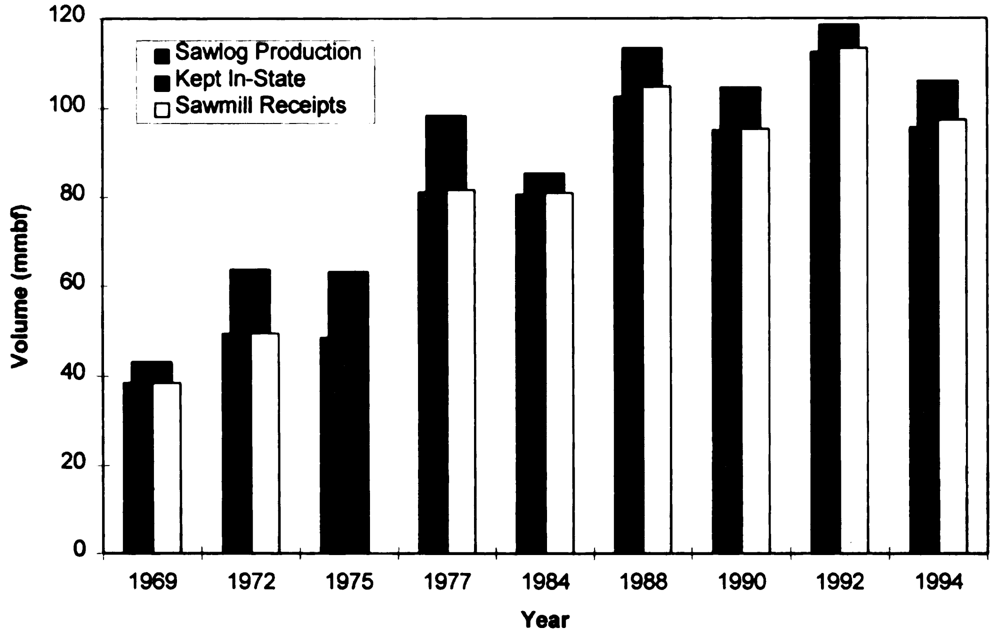

Figure 1: Aspen sawlog production and receipts in Michigan, 1969-1994.

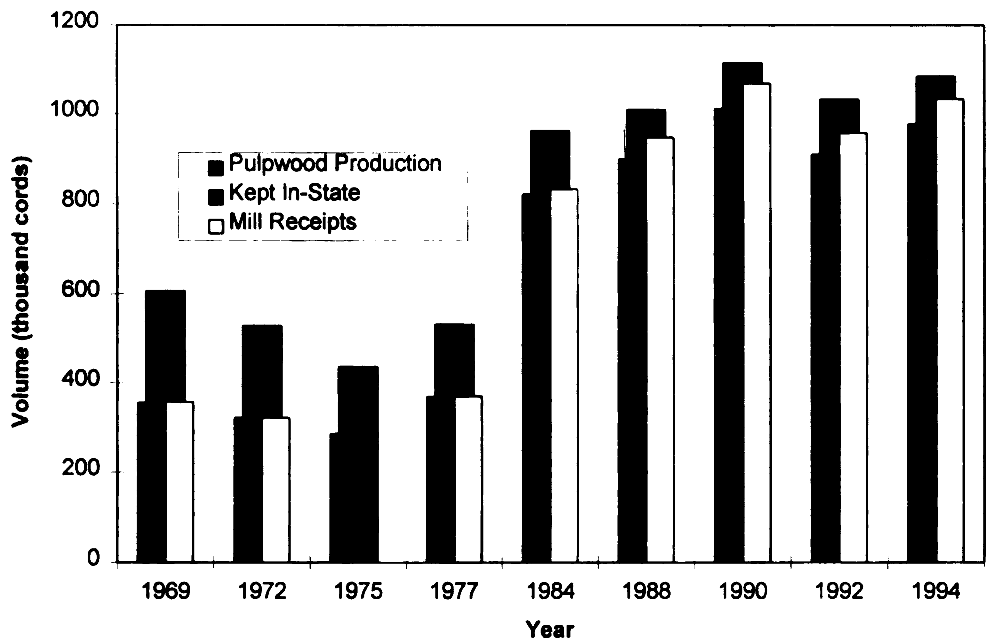

Figure 2: Aspen pulpwood production and receipts in Michigan, 1969-1994.

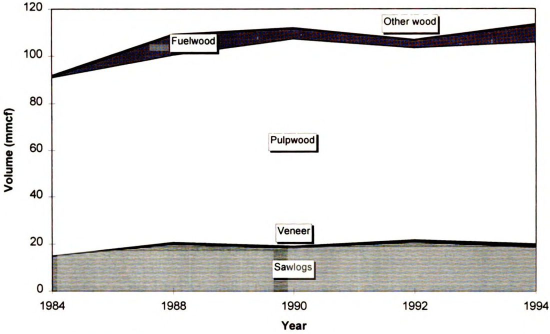

Figure 3: Aspen industrial roundwood production in Michigan by product type, 1984-1994.

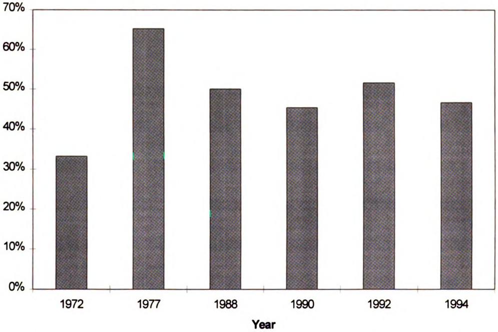

Figure 4: Percent of harvested aspen sawtimber used in sawlog or veneer production, 1972-1994.

Aspen ecosystems also provide habitat to 23 species of mammals, 31 species of birds, 3 species of reptiles and 3 species of amphibians (Ottawa N. F. 1995). These species represent an "important component of the total number of species on the forest" (Ottawa N. F. 1995). In addition, due to the invasive nature of the aspen species in disturbed areas, it helps "stabilize the water regime of streams and lakes" (Brinkman & Roe 1975).

Current Timber Resource

According to the 1993 Michigan forest inventory, there was approximately 3.1 billion cubic feet of live standing aspen timber on 8.4 million acres of timberland (Leatherberry & Spencer 1996).[2] Approximately 5% of the total aspen resource, 173.6 million cubic feet, was standing dead wood. In stands classified as aspen covertype on timberland, there was 1.8 billion cubic feet of aspen timber on 2.6 million acres. Thus, approximately 42% of the aspen timber resource is in stands not typed as aspen.

The 1935 forest inventory reported 5 million acres of aspen-birch covertype and 12 million cords, 948 million cubic feet, of aspen growing stock. The 1955 inventory reported 4.8 million acres of aspen-birch covertype and 22 million cords, 1.8 billion cubic feet, of aspen growing stock. The 1966 inventory reported 4.7 million acres of aspen-birch covertype, of which 4.3 million acres were aspen, and 28.6 million cords, 2.2 billion cubic feet, of aspen growing stock. Thus, for thirty years the aspen acreage remained fairly constant while the aspen stems matured. However, from 1966 to 1980, the aspen

[2] Actual data were summarized from the inventory database developed and maintained by the USDA Forest Service Forest Inventory & Analysis Unit, St. Paul, MN. Survey procedures and data collection are outlined in Field Manual Michigan (1991).

covertype declined by 20% (Potter-Witter & Ramm 1992). The 1980 inventory reported 3.4 million acres of aspen covertype and 32.9 million cords, 2.6 billion cubic feet, of aspen growing stock. The 1993 inventory reported 2.6 million acres of aspen covertype and 40.5 million cords, 3.2 billion cubic feet, of aspen growing stock. This is a net decline of 400 thousand acres, approximately 13% of the 1980 resource. This trend represents the invasion of lands cutover or burned at the turn of this century in Michigan by aspen, and its maturation and successional nature given a decreased level of disturbance. Figures 5 and 6 display this trend by survey unit.[3]

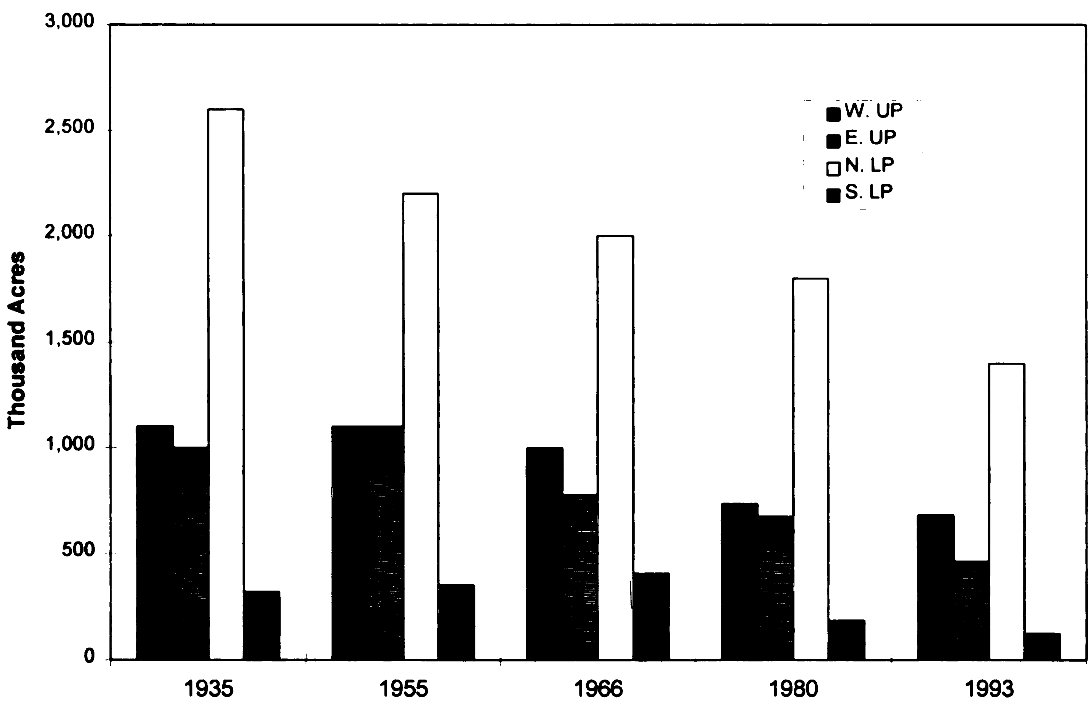

Figure 5: Acreage in aspen covertype by survey and FIA unit, 1935-1993.

[3] The 1935 and 1955 surveys represent acreage in the aspen-birch covertype. The other surveys represent acreage in only the aspen covertype. Lake States' forest statistics are compiled and published periodically by the USDA Forest Service North Central Forest Experiment Station in cooperation with individual states. The most recent statistics for Michigan are presented in Leatherberry & Specner (1996).

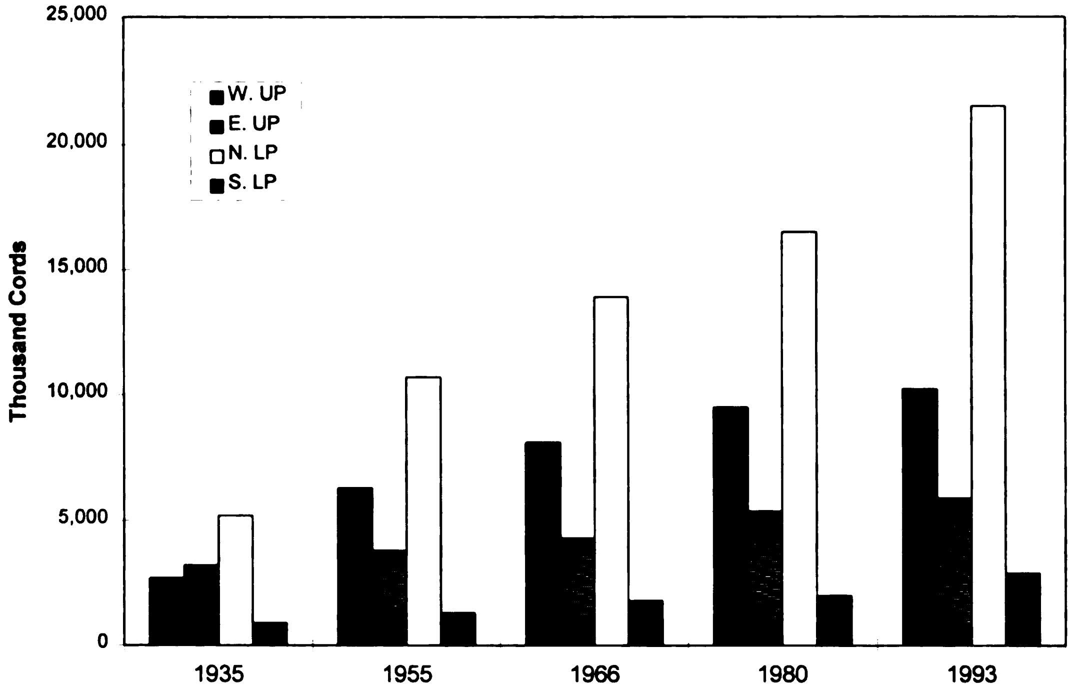

Figure 6: Aspen volume by survey and FIA unit, 1935-1993.

Management Concerns

The silvicultural system used to manage an aspen stand is one of the most important factors in sustaining aspen as a resource. Success in regenerating a vigorous aspen stand is highest with even-aged management practices. With uneven-aged practices such as cutting aspen out of a stand composed predominately of other species limits the opportunity for dense aspen regeneration (Ottawa N. F. 1995). Forty-four percent of the annual net aspen harvest from 1980-1993 occurred in stands not classed as aspen covertype in 1993. These stands supplied 32% of the annual net aspen growth between 1980 and 1993 on stands that incurred harvesting. Of the 956 thousand acres not classed as aspen in 1980 but that did have aspen stems harvested between 1980 and 1993, only 26% or 248 thousand acres were classed as aspen in 1993. Practices such as this contribute to further aspen resource declines.

Another potential loss of aspen occurs in cutting aspen too late in its life cycle or after it has been grossly infected with diseases such as white trunk rot. Overmaturity and decreased vigor and nutritional reserves inhibit the root suckering needed to fully restock the stand with aspen. "Aspen stands begin to deteriorate rapidly when they reach 50 to 60 years of age" (Ottawa N. F. 1995). When disturbance does not occur at an appropriate time, age or scale, aspen will be replaced by later successional covertypes such as shade-tolerant conifers and northern hardwoods.

The Michigan forest inventory indicates that over 600,000 acres lost classification as aspen covertype between 1980 and 1993. Across ownerships, only 4% was converted by planting or seeding, most on public lands. The remaining 96% is classified as natural conversion. Forty-four percent of the converted lands is now predominately maple-beech-birch, a late successional covertype.

Demand Concerns

Overutilization is a concern reflected by a 1.02 aspen growth to removal ratio in 1992. The net annual aspen growth was 111.5 million cubic feet while timber production output was 108.9 million cubic feet (Leatherberry & Spencer 1996). "Removals did exceed projected growth for the northern Lower Peninsula for the 7-year period between 1980-1987" (Potter-Witter & Ramm 1992). Figure 7 shows an increasing trend in aspen removals.

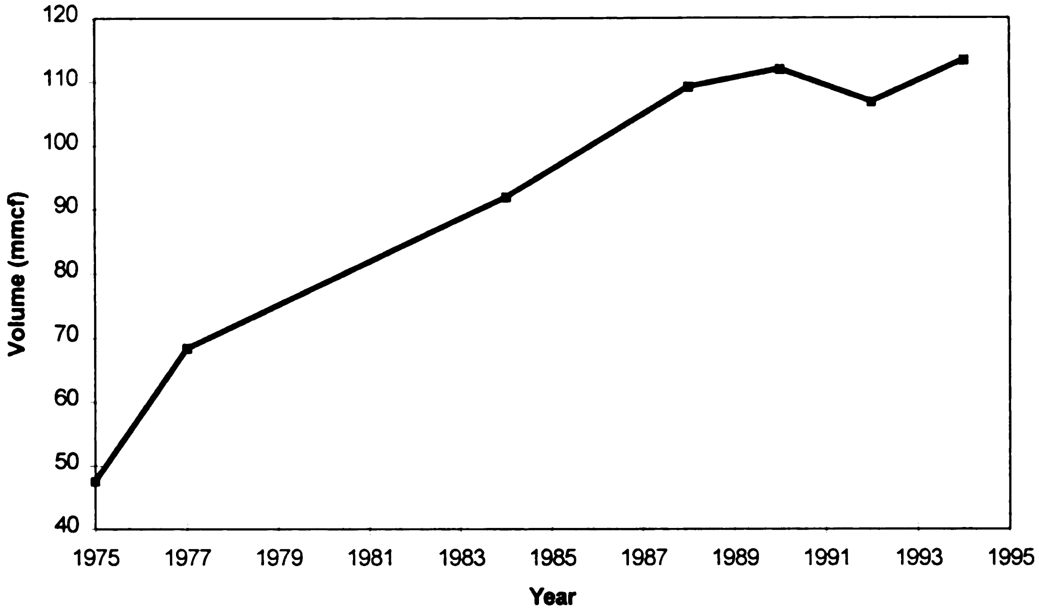

Figure 7: Aspen growing stock & non-growing stock volume production (Removals minus residuals & slash), 1975-1995.[4]

The price per cord for aspen has increased sharply from 1987 to 1994. A 1995 USFS aspen ecosystem report states that the stumpage price in constant 1994 dollars has gone from $3.76 to $20.48 per cord. Figures 8 and 9 show this increasing price trend based on stumpage price data collected on Michigan State Forest sales and data reported by TimberMart North. This increase reflects both a rising demand for the resource and uncertainty about its future supply from national forests (Ottawa N. F. 1995).

[4] Growing stock volume is the central stem volume ofpoletimber and sawtimber size trees. Non-growing stock volume is limbwood, saplings, cull and dead volumes. Logging residual ismerchantable volume not used for roundwood production. Logging slash is theunmerchantable volume not used.

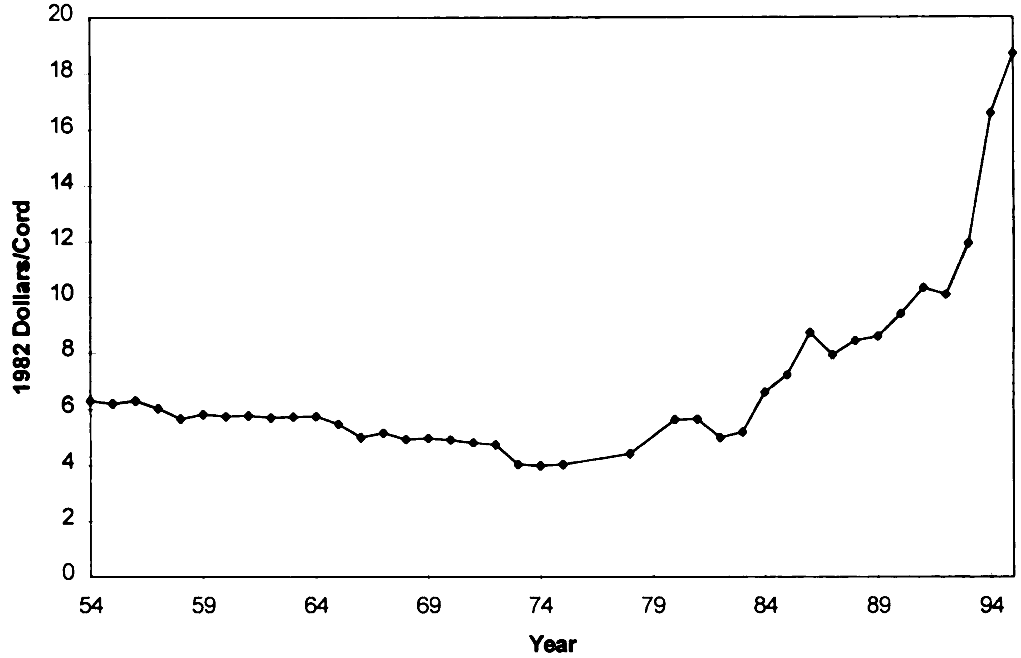

Figure 8: Average aspen pulpwood stumpage price per cord in constant 1982 dollars, 1954-1994.

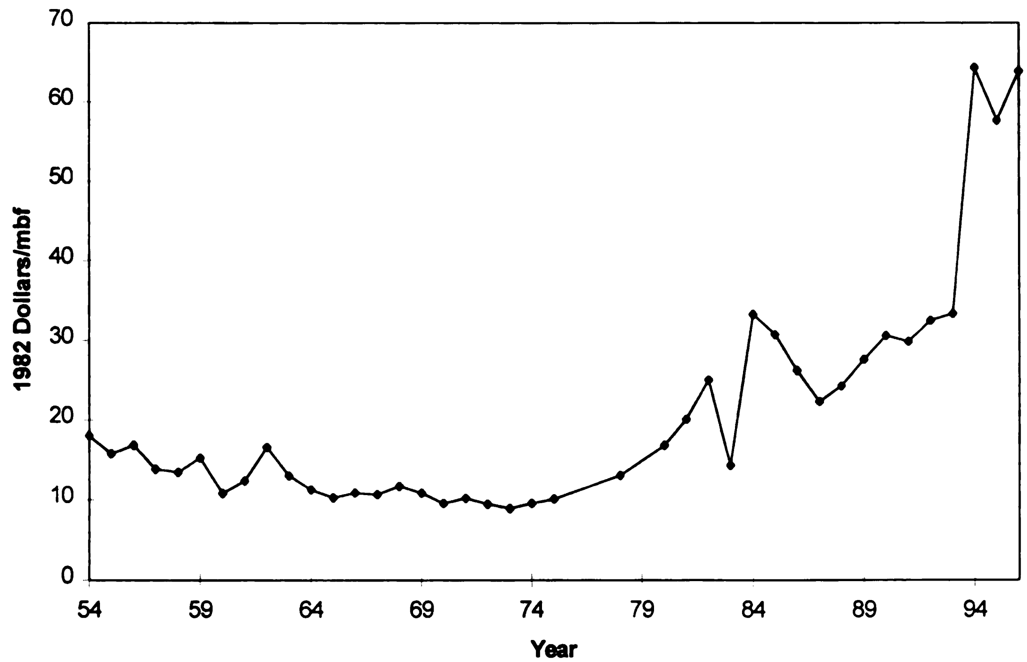

Figure 9: Average aspen sawtimber stumpage price per mbf in constant 1982 dollars, 1954-1994.

Structure Concerns

Another concern about the aspen resource is an imbalance in the age classes. A supply shortage is predicted when the current 35 year age-class aspen matures. This shortage is related to the imbalanced aspen age-class structure shown in Figure 10. Relating to this, Potter-Witter and Ramm 1992 stated that under current conditions, the price for aspen will continue to rise steadily until 2000 and then it will rise "dramatically." However, because much of the aspen resource is in mixed species and multi-story stands, the stand age collected during the inventory may not be representative of the aspen resource.

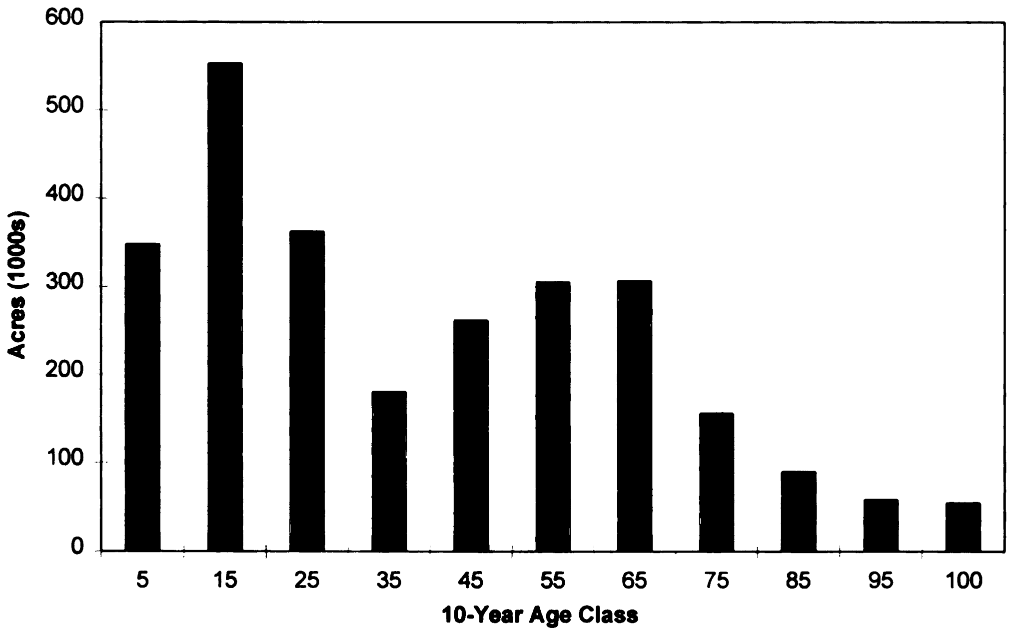

Figure 10: Area of aspen covertype on timberland by age-class in MI, 1993.

The younger age classes are presently more abundant than the current mature age classes. If these lands aren't converted or lost, early harvesting may supplement a shortage if they are productive enough.

Ownership Concerns

A critical factor in future availability of an aspen timber resource is ownership. Landowners have a variety of management goals and take a variety of actions to achieve them. These management actions may not be directed at providing for a future aspen resource. Therefore, the aspen resource distribution across ownerships should be considered in projections. Currently, 57% of Michigan's timberland acreage in aspen type, 1.5 million acres, is held by non-industrial private landowners. Forest industry owns only 5% of the current aspen timberland acreage, 123 thousand acres, in Michigan. Approximately 38% of the aspen timberland acreage, 990 thousand acres, is in public ownership. As seen in Figure 11, the privately held lands have a greater amount of aspen in aspen typed stands that are either better stocked with aspen or more mature.

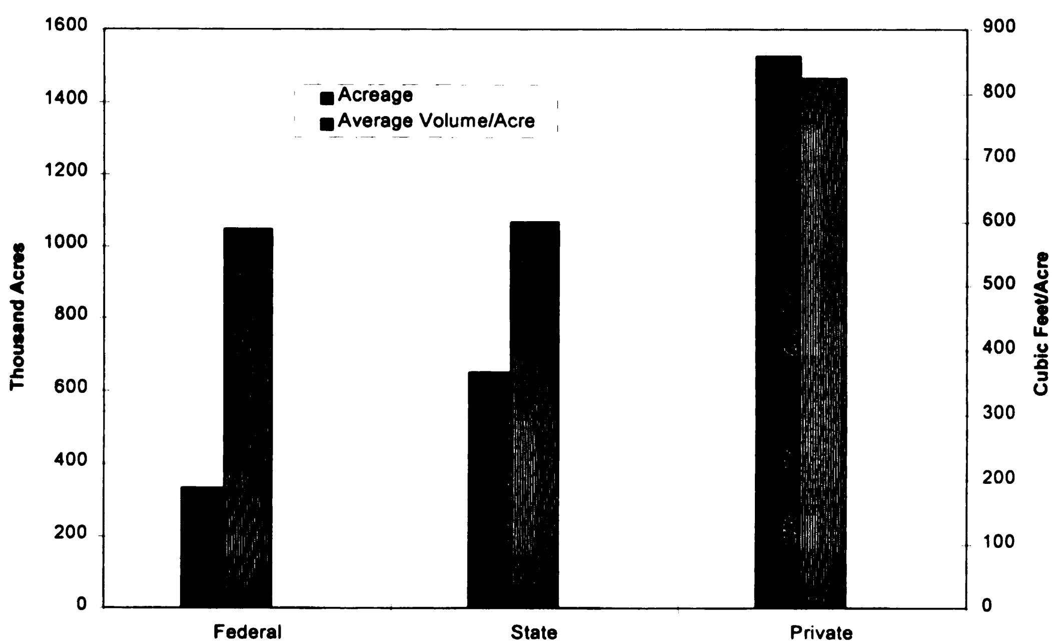

Figure 11: Aspen covertype acreage and aspen volume on timberland by ownership.

Management goals may place wildlife management, old-growth preservation, aesthetics and recreation above maintaining aspen as a timber resource. Additionally, the value of the aspen as a timber resource may not be recognized due to historically lower aspen prices. It may take time for the market supply to adjust to the increasing demand level and for an equilibrium point to be established. Considering these factors, there is a potential for approximately 95% of the current aspen resource not to receive the specific management practices needed to sustain it. Individual ownerships should be aware of the contribution they can have in their area. A landscape view of what and where the future aspen resource will be can facilitate stand management decisions and is important in making public forest planning responsive to all.

III. BACKGROUND

There has been increasing concern within the forest products industry and other organizations about maintaining an aspen timber resource and sustaining harvest levels. In the past, this need for timber supply projections has resulted in studies that project available resource data under developed assumptions or identify and analyze changes in the resource over time.

Past Projections

Leuschner (1972) projected the Lake State's aspen resource thirty years using the forest inventory data collected in the 1960s and updated to a base year, 1968. His model incorporated changes in commercial forest area, cut allocations and shifts, growth and in-growth in three regions. These regions were northern Wisconsin and Michigan's upper peninsula, Michigan's northern lower peninsula, and northern Minnesota. Growth was based on trends in net annual growth. Total cut was an estimate of industry demand adjusted for availability. Each survey unit was allocated a portion of the total cut based on past production.

Projection assumptions included past resource trends, loss due to overmaturity and succession, and positive, pro-active management practices. The trend assumption was based on the previous inventory cycle. Overmaturity and succession were modeled by controlling resource availability and in-growth. Positive practices were modeled by controlling harvest type, allocation and in-growth.

This study is an update of Leuschner's aspen projections based on recent trends. Data for the past two survey cycles are available in electronic format which facilitates the modeling process. This projection focuses on the entire state of Michigan. As Leuschner did, the recent trends assumption is based on an inventory cycle, 1980 to 1993.

Leuschner projected that the cut would diminish in Michigan's upper peninsula by 1990 or by 1995 if industry accepted smaller material. By 1998, the cut was projected to be coming from the 6-8 inch dbh classes. In 1990, the projected cut for the Upper Peninsula totaled 67.2 million cubic feet—26.9 million cubic feet from the eastern half and 40.3 million cubic feet from the western half. The actual 1992 harvest levels were 16.8 and 31.7 million cubic feet respectively. The overestimate could be related to industry increasing their proportional use of other species. Leuschner projected a continuous decline in growing stock throughout the projection but more sharply in the western half than in the eastern half. The projected growing stock levels were 340 million cubic feet in the eastern half and 350 million cubic feet in the western half of the Upper Peninsula. The growing stock volumes in 1992 were 469 and 803 million cubic feet respectively.

In the northern Lower Peninsula, the projected cut increased until after 1995 and was projected to come from the 6-8 inch dbh classes. A sharp downward trend in growing stock was projected due to a perceived lower level of growth capacity. The projected cut and growing stock level for the northern Lower Peninsula in 1990 was 59.5 and 550 million cubic feet respectively. In 1992, the actual cut level was 53.6 million cubic feet and growing stock was at 1.7 billion cubic feet. This large discrepancy may be related to the assumption of lower growth levels in the northern Lower Peninsula, lower levels of harvesting than assumed, or the structure of the analysis regions.

Leuschner projected that most of the available resource in 2000 would be in the 12 inch dbh and smaller classes. In fact, 97% or more of northern Michigan's aspen stems in 1992 were in this range. Across Leuschner's projection assumptions, the projected total cut ranged from 104 to 127 million cubic feet for Michigan in 1990. In 1992, aspen production was at 102.7 million cubic feet. Leuschner's projected growing stock in 1990 ranged from 730 to 1,270 million cubic feet. In 1992, aspen growing stock was close to 3 billion cubic feet according to the inventory data.

Recent Projections

Liggett and Leefers (1990) modeled Michigan's aspen resource from the 1980 forest inventory data and projected a significant decline in the aspen resource over the next 50 years due to its early successional nature. They analyzed current management plans and recent trends in the resource to develop their model assumptions. The National Forest management scenario was derived from the 1986 forest plans. The State Forest management regime was extrapolated from draft plans for two of the forests. They cited a 1985 study by Carpenter and Hanson that estimated 23% of non-industrial private landowners would harvest in the next 10 years, and 21% would never harvest. Using these numbers, they modeled the area of the resource that would likely be available for harvest.

Liggett and Leefers also stated that natural succession should be modeled and is dependent on the "extent and tolerance of other species." They referred to a study by

Shields and Bockheim (1981) which reported 37% mortality in declining aspen stands with a mean age of 54. The Hiawatha National Forest Plan assumed aspen would convert to other forest types at age 90 unless harvested. Liggett and Leefers assumed significant deterioration at ages greater than 70--aspen regeneration was not assured when these stands were harvested, and natural succession at age 90.

Liggett and Leefers used FORSOM to project the managed resource. This model requires that expected yields for the projection period be entered by the user. The total aspen acreage in the year 2030 was projected to range from 2.7 million acres to 2.4 million acres depending on harvesting intensities on private land. This is down 634 to 924 thousand acres from the 3.4 million acres reported in the 1980 forest inventory. According to the 1993 inventory data, this benchmark has already been reached with 2.6 million acres reported. The authors felt that decreased logging and interference in natural fire cycles has opened the door to a continuing loss of acreage for the pioneering aspen species.

A Generic Environmental Impact Statement (GEIS) was done in 1992 on maintaining productivity and the forest resource base for Minnesota (Jaakko Poyry Consulting, Inc. 1992). The study was based on the 1990 forest inventory data collected in Minnesota. The scope of the GEIS is more expansive and all-encompassing than this proposed study and applies only to Minnesota. However, the techniques used to model the resource provide a good framework.

The GEIS used the GROW program--a scaled-down version of STEMS much more dependent on user programming. The GEIS formulated three harvesting levels: a base level related to current demand, a medium level related to increased demand by proposed industry expansion and a high level which took advantage of all available but unharvested land in the medium harvest scenario.

Management scenarios used a treatment option model and a harvest scheduling model. The harvest model projected the resource for 50 years with the goal of optimizing the marginal cost of production. Prices included harvesting costs based on quality, stocking and distance from designated market centers. Optimal solutions were found for each harvest target level.

The GEIS modeled regeneration by adding a typical tree list into the growth model 15 years after harvest. This tree list was derived from FIA data for regenerated stands ranging in age from 10 to 20 years. These stands were screened from the database based on age, visual verification, commercial forest use and seedling/sapling classification. Stands were aggregated by site quality, dbh and crown ratio. More precise models were not found and researchers such as Belli and Ek (1988) suggest a precise model "is still very distant." All trees greater than 1-inch dbh on the FIA plots were included to provide for in-growth.

The study analysts assumed that lower competition levels would favor lower mortality and larger trees and compensate for lack of in-growth in the model. Studies showed that over 50 years, the difference between projected and measured aspen stands could range from -61 to -51 trees per acre, -15 to -5 square feet per acre, and -1.2 to 1.4 cubic feet per acre for aspen less than 5 inches dbh.

The GEIS authors felt STEMS85 construction underrepresented Minnesota stands, didn't account for catastrophic losses and overestimated growth. Concerns relevant in Michigan as well. The authors studied stands undisturbed by human actions to try to correct for catastrophic events but did not find a universal solution. The authors were also concerned that some FIA stand data may actually represent two different stands, but no solution was found to correct this problem.

In the first model run, ownership was not a consideration in projecting the resource. The second runs included updates on growth and yield coefficients, changes in forest area, changes in covertype, and timberland availability based on ownership constraints. Other factors affecting timber production included policy, silviculture, rotation length, management alternatives, old-growth, best management practices, buffers and sensitive areas. Allowable cut for long-term sustained yields was modeled using the ACES (Rose 1992) model and the 1990 and projected 2040 age class distribution. The growth model in ACES is very conservative so the allowable cuts derived were considered to represent the lower bounds.

In the first model run, all three harvest levels were met in all market centers. The aspen covertype experienced the heaviest level of cutting and represented 40-60% of the harvested area across the state. Rotation age ranged from 40 to 90 years. High increases in demand could only be met if privately held aspen was available. Long-term trends suggested a “slight decline” in aspen acreage over the projection period. It also showed a short-term deficit in 20-30 years because of an imbalanced age class distribution—a similar concern in Michigan.

The second runs showed infeasibilities in meeting target harvest levels for species such as aspen due to constraints such as longer rotation lengths and restrictions on clearcutting. The only solution for the GEIS was to lower the base target level for aspen or to relax some of the constraints. The rising marginal price for aspen confirmed concerns for its future availability.

Potter-Witter and Ramm (1992) analyzed the aspen supply in Michigan based on forest inventory data, Michigan Department of Natural Resources data, stumpage prices and industry data. Through comparison and trend analysis of the data from past decades, they reported a declining aspen acreage. They referred to a study by Spencer et al.(1990) that looked at the aspen resource from the mid 1960's to 1987 for the Lake States. It reported that Michigan had the greatest decline in aspen acreage, 19.9%. Annual growth also declined by 6.7 million cubic feet from 1980-1986. Scarcity is reflected in the 4-5% real rate of increase for stumpage prices between 1980 and 1987. Potter-Witter and Ramm projected that by the year 2000, there would be only 143,000 acres or less of mature aspen.

Einspahr and Wyckoff (1990) found shortages in the 11-20, 21-30 and 31-40 aspen age classes with large volumes of overmature aspen. They predicted shortages in 2000-2020 related to increased demand and age class imbalances.

Study Objectives

The timber industry in Michigan currently relies on the future availability of the aspen timber resource for pulp, manufactured panel and saw mills. While industry is capable of changing to other timber species to supply mills, this can be costly. It would also require the existence of an alternative supply equal to aspen's growth potential and economically efficient regenerative capacity. Industry needs reliable estimates of future timber supplies to plan manufacturing operations. A decrease in species diversity and current resource status due to changing harvest practices and attitudes about timber harvest is also of interest to ecologists, wildlife and biodiversity proponents.

The objective of this study is to project the current Michigan aspen resource for thirty years. This projection is based on past harvesting trends developed from an analysis of the 1980 and 1993 remeasured forest inventory plots. The goal is to describe the potential aspen resource distribution across the state of Michigan as characterized by ownership, age class, standing timber volume, and harvest yields assuming current management trends continue.

Timber production is not the only consideration related to the outputs from an aspen forest ecosystem. However, it is beyond the scope of this study to analyze the interrelationships between the various market and non-market forest values and the tradeoffs for the aspen timber resource. This study is not a prediction. There are many assumptions inherent in this type of projection. It is meant to present a generalized base description of one potential future resource status. From which, one can decide upon alternative management strategies related to how they might wish to alter this potential result.

IV. STUDY METHODS

Data Collection and Resource Characterization

The initial step was the compilation of aspen resource data from the 1980 and 1993 forest inventories. These forest inventories were conducted by the USDA Forest Service, North Central Forest Experiment Station, Forest Inventory & Analysis Unit (FIA). A description of the survey procedures used in the inventory can be found in Hansen et. al. (1992) and the Field Manual Michigan (1992). The inventory data were screened for plots containing any stems of aspen qualifying as live growing stock and greater than or equal to 1 inch dbh. The procedures used for determining stocking and covertype on the plots can be found in Hansen & Hahn (1992).

Individual FIA survey plots were mapped, and areas related to ownership, stocking and harvest levels were delineated in each county. This characterization and mapping provides a good overview of the current resource, possibly identifying areas of highest impact due to changes in the resource status, and providing a good base level from which to work. Figures 12 and 13 show that the greatest aspen growth per acre occurs in counties where the majority of the aspen resource is in stands typed as aspen. They also show that this growth is occurring across all ownerships. Additional maps are in Appendix A. The size of the circles on the maps are representative of the proportion of the statewide resource within each county. The subdivision of these circles represent proportions of the county resource. Depictions of the survey data at the county level are subject to high levels of error. However, they are useful in generalizing resource characteristics.

The individual tree records on these plots were used as input into the projection model. Each survey plot represented a separate stand with its own characteristics. Each measured tree on the plot has an expansion factor to a trees per acre basis. In addition, each plot has an expansion factor to acres of land within the respective county. A computer program was developed to facilitate the organization of the survey data into properly formatted tree lists with appropriate stand information header lines.

Data from plots measured in 1980 and remeasured in 1993 were used to develop the past trends management scenario. The selected plots had measured aspen stems in 1980, were classified as timberland in 1993, and did not change ownership between 1980 and 1993. Ownership was classified as federal, state or private. Private ownership includes industrial, non-industrial and Indian stands. These criteria allowed an analysis of available timber lands, with an aspen component, that included ownership and stocking as possible factors in predicting future management actions.

There were 3,730 remeasured plots. Four hundred and thirty-six plots were deleted due to a change in ownership. Of the remaining plots, 1,547 plots had at least one live and measured aspen stem. Those 1,547 plots had 66,787 measured trees in the 1980 survey, 9,350 of which were aspen. There were 89 plots with evidence of harvest activity prior to the 1980 survey. Between the 1980 and 1993 survey, there were 30,673 remeasured trees and 481 plots with evidence of cutting. On those 481 plots, 10,770 trees were measured in 1993, 4,929 of which were cut.

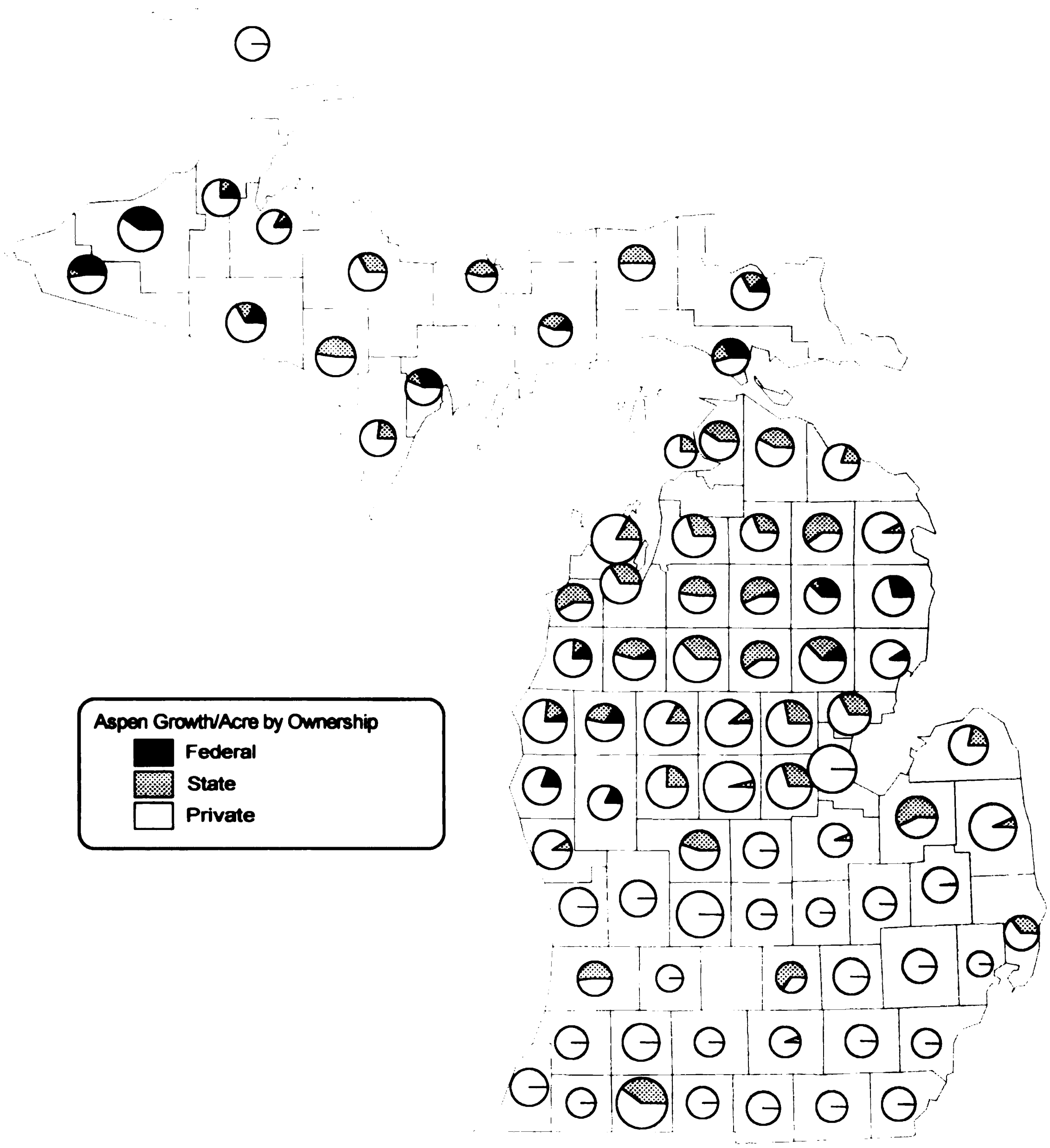

Figure 12: Michigan county aspen growth per acre by ownership class, 1993.

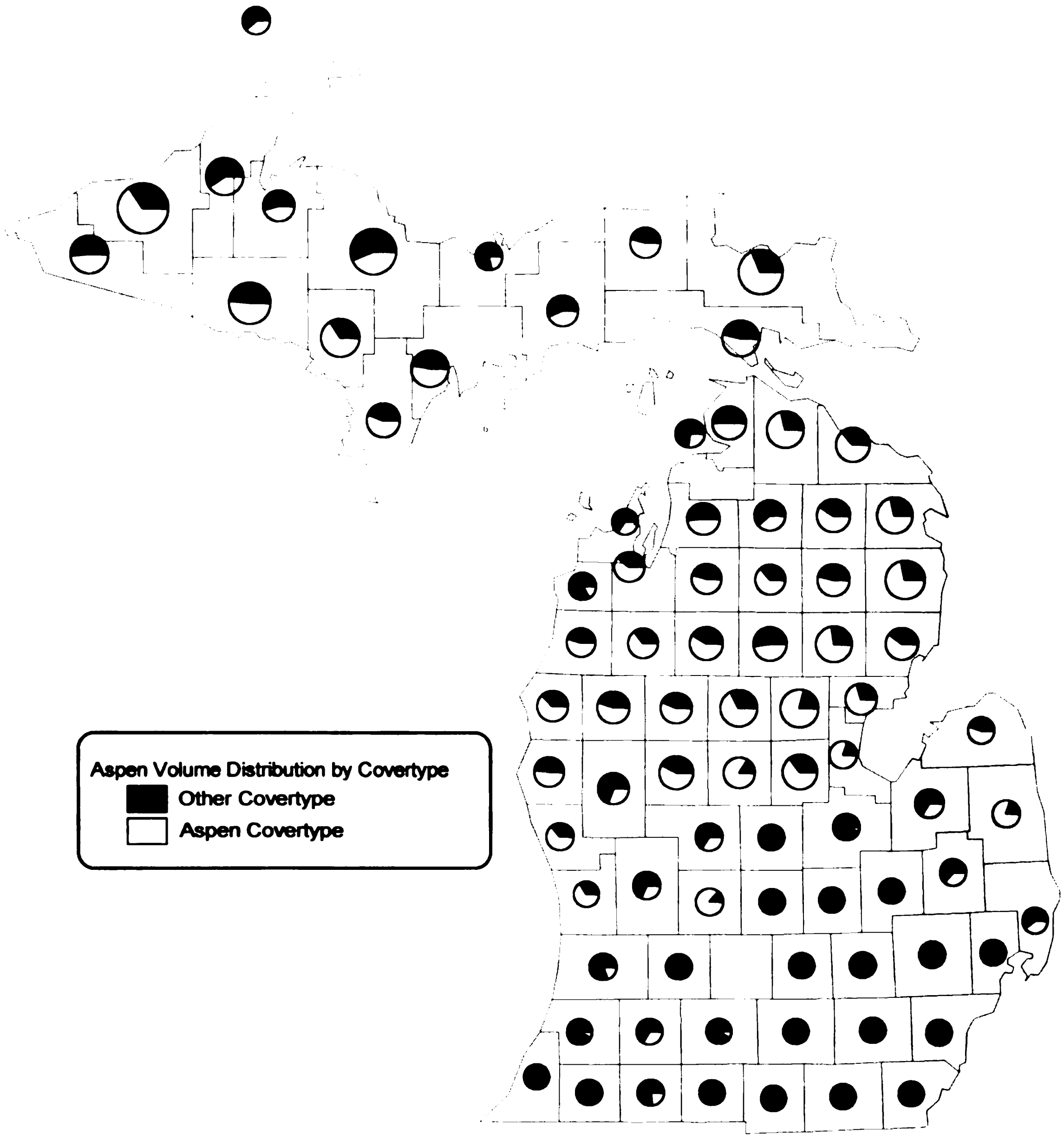

Figure 13: Michigan county aspen volume distribution by stand covertype, 1993.

The 1993 survey data to be projected was collected from stands with at least one live, measurable aspen stem with a dbh of at least 1 inch. The stand information required for the projections includes the state, plot name, forest type, stand age, site index species, stand site index, survey date, stand origin (planted/natural), plot area expansion factor, FIA unit in Michigan, distance from nearest road in chains, and ownership group. The individual tree information includes species, dbh, crown ratio, tree expansion factor to a per acre basis, tree site index, tree history of 1 if alive, 2 if cut, and 3 if dead, and tree classification as acceptable, rough or rotten. All tree site indexes were entered into STEMS85 as 0. This prompts STEMS85 to calculate the individual tree site index based on the stand site index.

Growth Model

The Stand and Tree Evaluation and Modeling System or STEMS85 was used for the projections (Brand et. al. 1988). This is an individual-tree, distance-independent growth and yield model developed for the Lake States. Growth and mortality were projected on a yearly basis for 30 years with potential management actions applied at 10 year intervals. STEMS85 allows the user to modify management decision trees or select management options, perform batch or interactive processing, modify output reports, and provides a regeneration algorithm for clearcuts. STEMS85 incorporates a diameter adjustment to the growth component and a modified mortality model as compared to the original STEMS (Holdaway & Brand 1986). STEMS85 was originally in FORTRAN computing language. The program was compiled into an MS-DOS executable application with Microsoft Fortran Powerstation Version 4.0. This facilitated easier alteration to the programming code and more control over the program elements.

A model validation was done by Holdaway & Brand (1986). Mean dbh errors over a 10 year period showed an average overprediction of 0.09 inches for bigtooth and quaking aspen. Mean number of trees error for aspen was +5 trees/acre. Mean basal area error for aspen was +4 sq.ft./acre. Caution is recommended in utilizing the model beyond 30 years (Holdaway & Brand 1986).

STEMS85 Modifications

Extensive modifications were made to STEMS85 to facilitate this study. The Lake States' growth and mortality equations were modified; the individual tree survival rates were modified; the harvest methods were modified; the model outputs were modified.

Michigan specific correction factors were added to modify the diameter growth and mortality equations. These correction factors are applied according to tree species, dbh and location within either the upper or lower peninsula of Michigan. They were developed by the FIA Unit of the North Central Forest Experiment Station using data collected on remeasured plots in the 1993 survey. The correction factors were calculated based on the procedure outlined by Smith (1983). The diameter growth factors are multiplicative coefficients that are used to modify the annual growth projected by STEMS85. The mortality factors are multiplicative coefficients that are used to modify the probability that a tree will die over the course of a year.

There were 1,635 trees remeasured on plots that were classified as undisturbed between 1980 and 1993 with a remeasurement period of 9 to 10 years. After projecting the 1980 tree data using the corrective growth and mortality coefficients, the projected and remeasured survey data were compared. When all remeasured trees were considered, the average difference between remeasured and projected diameters for some species such as quaking aspen were high. However, there were 1,387 trees that survived the remeasurement period. The average differences between projected and remeasured diameters for these trees are more accurate, especially for aspen, as shown in Table 1. Thus, the corrected mortality equations still did not fit well and were introducing a high degree of error into the projections.

Table 1: Average DBH differences in inches between remeasured data and projections including the modified growth and mortality equations in STEMS85.

SPECIES	**Number of Trees**	**AVG. DBH DIF (in.) (Observed-Projected)**	**AVG. DBH DIF (in.) (Mortality Removed)**
ALL	1635	-.20	-.10
Jack pine	333	-.29	-.13
Balsam fir	35	-.23	.01
Red pine	289	-.24	-.22
E. white pine	36	.19	.25
N. white cedar	175	-.03	-.03
Red maple	316	-.10	-.09
Sugar maple	318	-.08	-.08
Paper birch	375	-.10	-.01
Bigtooth aspen	161	-.08	.03
Quaking aspen	130	-.40	.01
White oak	26	.09	.09
N. red oak	90	-.01	.03
Black oak	149	-.44	-.40

Additional mortality correction factors were developed. For each species on all remeasured and undisturbed plots, the annual survival rate was calculated for both the remeasured 1993 data and the data projections of the 1980 survey. These calculations were based on the methods outlined in Buchman (1983). The survival rates were calculated for 4 dbh classes. The classes were Class 1: <5 inch, Class 2: >4.9 and <10 inch, Class 3 :>9.9 and <15 inch, and Class 4 :>14.9 inch dbh. The mean and standard deviation of the difference between the projected survival rate and the remeasured survival rate were determined for each species and dbh class with at least 50 observations. The means and standard deviations are shown in Table 2. The number of trees on which the distributions are based is shown in parentheses. Correction factors randomly selected from a normal dataset based on these distributions were applied to the appropriate trees in STEMS85 according to species and dbh class.

After the annual probability of mortality is calculated by STEMS85 for each tree, two random variates are drawn from a uniform distribution (0,1). These variates are then used to calculate a normal deviate using the Box-Muller transformation. The deviate is then transformed to be representative of a distribution with a mean and variance equal to that above for a specific species and dbh class combination. This value modifies the annual probability of mortality for the tree. With this correction in place, the projected volumes become more precise and accurate as compared to the remeasured volumes. This is shown in Table 3 with the difference representing remeasured volume minus projected volume.

Table 2: Distributions of survival rate differences in proportion of trees. [Mean, Standard Dev.] (number of observations).

SPECIES	CLASS 1	CLASS 2	CLASS 3	CLASS 4
Jack pine	[-.026,.013] (294)	[-.01,.005] (845)	[-.007,.01] (159)	
Red pine	[-.004,.004] (153)	[-.001,.00003] (713)	[-.002,.9E-6] (204)	[-.001,.0001] (105)
White pine	[-.006,.003] (54)	[-.005,.0002] (119)	[-.003,.0003] (127)	[-.009,.005] (231)
White spruce	[.025,.071] (52)	[-.012,.010] (137)	[-.010,.018] (114)	[-.015,.031] (62)
Balsam fir	[-.019,.013] (678)	[-.035,.016] (782)	[-.068,.029] (136)	
Black spruce	[.006,.016] (231)	[.009,.019] (481)		
N. white cedar	[.13E-3,.020] (532)	[-.003,.002] (1529)	[-.004,.002] (533)	[.005,.018] (105)
Hemlock	[.0001,.005] (46)	[-.003,.0007] (133)	[-.003,.001] (208)	[-.0004,.002] (179)
Black-Green ash	[-.007,.012] (307)	[.002,.014] (311)	[.007,.015] (120)	
Red maple	[.040,.056] (710)	[.0009,.005] (1201)	[.0005,.003] (634)	[-.003,.001] (336)
Elm	[.014,.040] (200)	[-.084,.003] (201)	[-.144,.004] (84)	
Yellow birch	[-.011,.013] (62)	[-.005,.009] (239)	[-.002,.007] (199)	[.005,.025] (234)
Basswood	[.057,.068] (58)	[-.004,.002] (255)	[-.004,.0006] (190)	[-.012,.002] (77)
Hard maple	[.003,.020] (718)	[.0002,.001] (956)	[-.001,.001] (484)	[-.003,.0007] (326)
White ash	[.046,.060] (71)	[-.005,.004] (150)	[-.006,.003] (84)	[.024,.071] (79)
White oak	[-.026,.0009] (86)	[-.004,.0001] (219)	[-.002,.0001] (185)	[-.0004,2E-6] (193)
N. red oak	[.156,.10] (333)	[.008,.017] (357)	[-.0005,.001] (224)	[.002,.003] (224)
Other red oak		[.014,.032] (222)	[.0003,.001] (199)	[.008,.028] (121)
Bigtooth aspen	[.11,.126] (183)	[-.006,.004] (322)	[-.004,.003] (264)	[.005,.005] (74)
Quaking aspen	[-.009,.045] (530)	[-.023,.008] (791)	[-.016,.015] (646)	[-.011,.012] (189)
Paper birch	[-.044,.005] (111)	[-.017,.003] (461)	[-.017,.005] (223)	

Table 3: Remeasured minus projected volume before and after mortality correction.

	Volume Difference Before	Volume Difference After
Total Growing Stock	-1%	+4%
Total Growing Stock-Aspen	-9%	+6%
Total Aspen Sawtimber	-4%	+9%
Total Aspen Pulpwood	-13%	+5%

The volume equations used in STEMS85 are based on data collected in the upper peninsula of Michigan as described in Raile et. al. (1982). However, the equations used to calculate volumes in the forest inventory database are based on data collected across the Lake States as described in Hahn (1984). Additionally, there are three modifications incorporated into these equations by the forest inventory unit. If stand basal area is less than 50 square feet per acre, stand basal area is set equal to 50 square feet per acre. If the tree site index is less than 20 feet or greater than 120 feet, the tree site index is set equal to 50 feet. Finally, if the current basal area is less than the previously measured basal area, the stand basal area used in the volume equations is set equal to the greater of the two (Miles 1997). Calculation of the total cubic foot volume for the 1993 inventory trees shows an average 10% difference between the results of these two sets of volume equations. Consideration should be given to this difference when comparing base STEMS85 projected volumes and remeasured volumes from the survey data.

STEMS85 was modified to allow the input of additional stand information variables such as plot location in the upper or lower peninsula of Michigan, distance of the plot from the nearest road, stand expansion factor, stand ownership classification and history of previous cutting on the stand. The original random number generator relied on the user to specify a new seed value for each run. This was replaced with a seed value generator tied into the computer's internal time clock. For each stand projection, a new set of uniform random numbers between 0 and 1 were generated. These random numbers were used in correcting the annual probability of mortality for each tree, in determining probabilistic mortality, and in determining stand harvesting during the projection.

Mortality can be modeled in a deterministic or probabilistic nature. For large datasets, the differences should be minimized. For these projections, mortality was probabilistic. Annual mortality was determined by comparing a random number and calculated annual probability of mortality in STEMS85. If the calculated probability is greater than the random number, the measured tree and all those it represents are killed during that year's simulation. The use of random numbers in determining stand harvesting is described in a later section.

The STEMS85 batchrun capability was modified so that the user can set the number of simulations a group of stands will go through. The subsequent output values can be averaged, and the effects of the stochastic elements in the projection can be determined by examining the distribution of the outputs.

The program output of STEMS85 was also modified in order to facilitate its use. This required the addition of tracking and summary variables in the program code. A subroutine to calculate mortality volume was also added.

STEMS85 requires several assumptions: no change in tree quality such as cull status over the length of the projection; no undetected disturbance in the survey plots affects the projection; no catastrophic events or insect or disease outbreaks occur; high variability occurs in the projection of seedling/sapling size stands. Management activities occurred in the middle of the projection cycle so that variations in growth and mortality from cutting stands early in the cycle or late in the cycle would be offset.

Regeneration

The possibility that incorporation of a more accurate representation of those 1993 stands that were regenerating aspen would enhance the declining values was explored. The regenerating stands were identified as 1993 stands less than 20 years old with an overstory of less than 40 square feet/acre and either greater than 20 square feet/acre of aspen basal area cut between 1980 and 1993 or seedling sized aspen less than 1 inch dbh recorded on the plot. For the first decade, all stands were projected with the modified

STEMS85 based on the plot data taken from the 1993 inventory. Aspen regeneration stocking levels were generated for the regenerating stands using the equations described in Ek and Brodie (1975).

For those stands that met the minimum aspen harvest requirement, the stocking level was calculated for a stand age of two and then projected for an additional eight years. For the sucker/seedling stands, each recorded seedling size aspen was given a plot expansion factor of 30 based on ten 30ft. radius plots. The sum of these stems was set as the age two stocking and projected for eight years using the Ek and Brodie equations.

After the first decade of the modified STEMS85 projections, the Ek and Brodie regeneration was added to the respective stand tree lists. These individual tree entries were determined by the application of the integral of Gaussian probability function from Bevington (1969) to the number of seedlings and their average dbh from the regeneration projections. This process develops a tree list based on a normal distribution. Each regenerating stand was given an age of 10. The compiled tree lists were then projected for the remaining twenty years using the modified STEMS85. Because the regeneration was added to tree lists that had already been projected for 10 years, it was not possible to model mortality probabilistically. Therefore, the tree lists at the end of the first 10 years were the result of a single simulation with deterministic mortality. It is possible that this approach biased the status of these regenerating stands at 10 years. However, there were only 202 regenerating plots identified, and so any bias should have minimal impact on the overall projections.

Past Trends Management Scenario

Equations to calculate the probability that a stand and then a single tree within that stand will be harvested were developed using the logistic regression routine in *SAS*. Logistic regression models the association between a binary dependent variable and a set of binary and/or continuous independent variables. Because of the binary explanatory variables, discriminatory analysis could not be used. Logistic regression analysis provides coefficients for the independent variables to calculate the probability of an event, designated by the binary variable. This type of analysis has been used in predicting timber harvest and supply and postfire mortality (Ryan & Reinhardt 1988, Jamnick & Beckett 1988, Connaughton & Campbell 1991, Bell & Eriksson 1991). The regression results are easy to apply and not biased by the variables' distributions.

For this study, a two-fold approach to harvesting was used. The first logistic regression was to determine the probability that a stand will incur some degree of harvesting over a 10 year period. The second logistic regression was to determine the probability that an individual tree would be cut. Although the surveys are classified as 1980 and 1993, the remeasurement period for the stands actually ranged from 6 to 17 years. The stands were not adjusted to one base year. Therefore, the logistic regression results represent the probability of harvest for a varying cycle length. Most of the remeasurement periods were between 9 and 13 years. So, for these projections, the logistic regression results will be used to determine the probability of harvest for a 10-year interval.

The independent variables considered for this regression included ownership, cubic foot and board foot volume (stand, aspen, hardwood, softwood, cull), trees per acre (live, greater than 5 inch dbh), basal area per acre (live, cull, dead, aspen), age, site index, stand distance from nearest road, location in Michigan, and past history of harvesting. These variables were selected because they are indicative of the stand's life stage, potential growth, timber value, availability, and possible management intentions and possible conflicts. Correlation matrices were developed so regression results would not be biased by the inclusion of highly correlated variables. If two variables had a Pearson Correlation Coefficient greater than .4, only one was included in the regression.

Stand variable information was taken from the 1980 survey data for plots remeasured in the 1993 survey. The history of cut was a binary variable of 0 if the 1980 plot record indicated no harvested trees, and 1 if it did. The ownership factor was included with two binary variables. If the ownership was federal, the first variable was 1 and the second variable was 0. If the ownership was state or local government, the opposite applied. If the ownership was private, both variables were 0. The 1993 plot data were used to determine the value of the dependent variable. If any remeasured tree on the plot was harvested, the dependent harvest variable was 1. If not, the variable was 0.

The total dataset was subdivided into two subdatasets. After randomly ordering the observations, approximately the first two-thirds were put into a model dataset. The remaining observations were put into a validation dataset. The model dataset was used in the regression. An alpha-value of 0.1 was used to determine the significance of each variable included in the regression.

The variables that were significant in the regression are shown in Table 4. Own1 designates federal ownership, Unit designates the upper peninsula of Michigan, DRFT is the distance from the road in chains, Live5 is the number of trees per acre greater than 5 inch dbh, GSBDVH is the board foot volume per acre of hardwood species, Numlive is the number of live trees per acre, Aspvol is the cubic foot volume per acre in aspen, and Volratio is a ratio of board foot volume per acre to cubic foot volume per acre. The odds ratio represents the increase in the odds of an event given a one unit increase in the respective variable. The r-square value, rescaled to account for the number of observations, was .143. The probability of harvest is calculated by 1/(1+exp(-b - BX) where b is the intercept parameter estimate, B is the vector of slope parameter estimates, and X is the vector of explanatory variables (SAS Institute Inc. 1995).

Table 4: Logistic regression estimates for stand level harvesting.

Variable	Estimate	Std. Error	Pr > Chi-square	Std.Estimate	Odds Ratio
Intercept	-1.6127	.2166	.0001		
Own1	-.8477	.2745	.0020	-.145431	.428
Unit	.3549	.1520	.0196	.097870	1.426
DRFT	-.0327	.0125	.0086	-.150315	.968
Live5	.00438	.000943	.0001	.216829	1.004
GSBDVH	.000112	.000056	.0454	.099986	1.000
Numlive	-.00032	.000142	.0242	-.110384	1.000
Aspvol	.000654	.000255	.0103	.119195	1.001
Volratio	.123	.0674	.0677	.089934	1.131

The individual tree harvest probability regression was performed in a similar manner. The data were collected from remeasured stands that incurred harvesting between 1980 and 1993 and had at least one live, measurable aspen stem during the 1980 survey. Again, the dataset was subdivided similar to the stand level dataset. This model calculated the probability that each tree on the plot, and the trees it represents, would be cut during each 10 year period. Some independent variables to be considered were dbh, net cubic foot volume, relative basal area of the trees within the stand, and some of the same stand characteristics used in the stand level logistic regression. Variables considered in addition to those for the stand level regression were the binary variables SW-- equal to 1 if the tree was a softwood, Aspen-- equal to 1 if the tree was an aspen, and Own2—equal to 1 if the plot was owned by state or local government. Netcuvl is the cubic foot volume of the measured tree times 10. BA is the square foot per acre of the measured tree plus the trees it represents. Volasp is a ratio of the total aspen cubic foot volume on the acre to the total cubic foot volume on the acre. Those variables in the model dataset found to be significant are shown in Table 5. The rescaled r-square value was .159.

Table 5: Logistic regression estimates for tree level harvest.

Variable	Estimate	Std. Error	Pr>Chi-square	Std. Estimate	Odds Ratio
Intercept	-.9868	.1086	.0001		
Own2	.4933	.0578	.0001	.114072	1.638
Unit	.4754	.0517	.0001	.129908	1.609
SW	.3052	.0640	.0001	.067543	1.357
Numlive	-.00065	.000053	.0001	-.177494	.999
Volratio	-.1599	.0243	.0001	-.098227	.852
DRFT	.0227	.00391	.0001	.078371	1.023
Aspen	.8364	.0614	.0001	.209024	2.308
BA	.1083	.0154	.0001	.093798	1.114
Netcuvl	.00211	.000173	.0001	.190083	1.002
Volasp	.7898	.1022	.0001	.120238	2.203

The accuracy and precision of the logistic regression results were evaluated in three ways. The Hosmer and Lemeshow goodness-of-fit test was applied to the model dataset. This test is considered conservative, biased towards specific types of lack of fit and dependent on the grouping of the observations (SAS Institute Inc. 1995). This statistic compares a value based on observed and expected event frequencies in each group to a chi-square distribution. It was significant for the stand level regression but not for the tree level regression as shown in Table 6.

Table 6: Hosmer and Lemeshow Goodness-of-Fit Test

Logistic Regression	Goodness-of-Fit Statistic	Degrees of Freedom	p-value
Stand Level	1.6082	8	.9908
Tree Level	46.99	8	.0001

The second test was development of a classification table. The logistic procedure in *SAS* uses a one-step approximation of a typical jackknifing method. The model is fit using all observations but one. The resulting coefficients are applied to this one observation to calculate its event probability. The event probability is then compared to a predetermined cutoff point that ranges from 0 to 1. If the calculated event probability is greater than the cutoff point, then an event occurs. If not, the event does not occur.

For this study, the cutoff point was determined by examining a table of all possible cutoff points and their resulting sensitivity and specificity. Sensitivity is a ratio of the number of correctly classified events over the total number of events (SAS Institute Inc. 1995). Specificity is a ratio of the number of correctly classified nonevents over the total number of nonevents (SAS Institute Inc. 1995). The cutoff point was set where these two ratios were approximately equal. This assures that the regression results are not biased toward more accurately predicting events or non-events. There is an equal probability that an event or non-event is accurately predicted.

For the stand level regression, this cutoff point was .3 and produced the classification table shown in Table 7. Approximately 66% of the observations were correctly classified. For the tree level regression, this cutoff point was .44 and produced the classification table shown in Table 8. Approximately 64% of the observations were correctly classified.

Table 7: Stand level harvest event classification table for model dataset with cutoff point of .3.

	Predicted		
Actual	**NOT HARVEST**	**HARVEST**	Total
NOT HARVEST	**451**	234	685
HARVEST	106	**195**	301
Total	557	429	986

Table 8: Tree level harvest event classification table for model dataset with cutoff point of .44.

	Predicted		
Actual	**NOT HARVEST**	**HARVEST**	Total
NOT HARVEST	**2661**	1629	4290
HARVEST	1266	**2430**	3696
Total	3927	4059	7986

The final test was the application of the regression results to the independent validation datasets. Only the model dataset was used to determine the coefficients for the independent variables. These coefficients were then used with the validation dataset to calculate the event probabilities. The same cutoff point from the model dataset classification table was used to develop a classification table for the validation dataset. The percent of accurately predicted events and non-events was examined. The classification table for the stand level validation dataset is shown in Table 9 Approximately 67% of the observations were correctly classified. The classification table for the tree level validation dataset is shown in Table 10. Approximately 66% of the observations were correctly classified.

Table 9: Stand level harvest event classification table for validation dataset with cutoff point of .3.

	Predicted		
Actual	**NOT HARVEST**	**HARVEST**	Total
NOT HARVEST	**249**	119	368
HARVEST	59	**119**	178
Total	308	238	546

Table 10: Tree level harvest event classification table for validation dataset with cutoff point of .44.

	Predicted		
Actual	**NOT HARVEST**	**HARVEST**	Total
NOT HARVEST	**994**	557	1551
HARVEST	377	**856**	1233
Total	1371	1413	2784

The stand level model was selected because of its significant goodness-of-fit test and its approximately equal classification error rate for both the model and validation datasets. The tree level model was selected because of its approximately equal classification error rate for both datasets, and it outperformed any other combination of variables in respect to all three tests.

These harvest probability models were incorporated into the STEMS85 management routine. During each management activity, the stand and tree data values from the beginning of the projection period were used as input into the harvest probability equations. The cutoff probability values set above were compared with the calculated harvest probability for each stand and each tree. If the cutoff probability was less than the calculated harvest probability, the stand or the tree was harvested. Figure 14 illustrates this procedure.

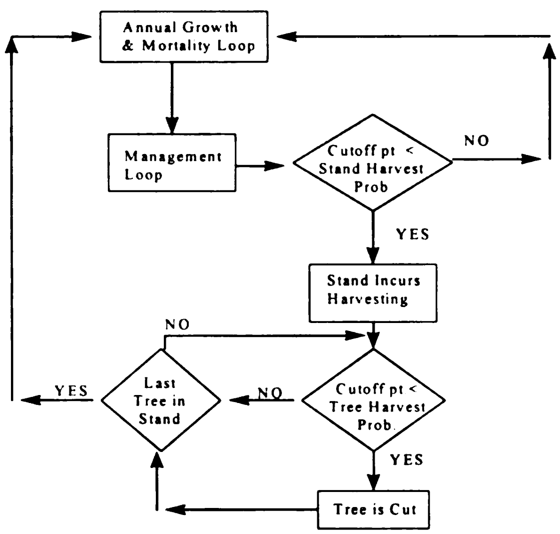

Figure 14: Stand and tree harvest flowchart

The assumptions necessary for this model are that all survey plots on timberland are available and accessible for harvest; harvesting can be modeled at an individual tree level; there are no constraints on supply; there are no effects due to stumpage price; the FIA survey plots are representative of the actual resource.

A discrepancy between volume equations used by STEMS85 and by the FIA unit was described earlier. The logistic regression coefficients were based on tree volumes calculated by the FIA unit's equations. In addition, the survey database only includes tree volumes for live, acceptable growing stock trees. The volume equations in STEMS85 calculate volume for all trees of all classes. In order to accurately utilize the regression models, STEMS85 was modified so that the volumes used as independent variables in the harvest probability equations are calculated using the FIA unit's equations. In addition, the stand and individual tree volumes were based on only those trees with a tree class of 20 or acceptable.

This modified version of STEMS85 was tested by projecting the 1980 plots with aspen that were remeasured in 1993. Mortality was deterministic. Management was implemented according to the logistic regression equations. The projection consisted of 12 one year periods with management in year 6. More than twice as much volume was harvested by STEMS85 than was measured as harvested in the 1993 survey. This discrepancy can be explained by the classification tables developed in testing the stand level model. The cutoff point was chosen so that the probability of misclassifying an event was equal to that of misclassifying a non-event. This allows for a more realistic representation of the projected timber flow and resource status across the state and ownerships. However, it results in a 59% false positive rate and a 20% false negative rate. Thus, 59% of the plots harvested by the modified STEMS85 were not remeasured as having had any cutting by the 1993 survey, and 20% of the plots not harvested by the modified STEMS85 were remeasured as having had some cutting by the 1993 survey. This discrepancy could be a function of the variables selected for the regression, the exclusion of other factors such as markets and accessibility, and possible missed harvest events on plots classified as undisturbed in the survey data. Variations in the cutoff point from .36 to .4 and inclusion of an age limit for harvesting a stand only slightly improved the results.

An analysis of the plots that were correctly and incorrectly classified showed no significant difference between the two groups in the distribution of stand values such as aspen volume, quality, size and species mix, etc.. Only stand stocking characteristics such as total cubic foot volume and basal area showed a clear variation between the two groups. As Figure 15 shows, the stands that were wrongly cut by the modified STEMS85 tended to have lower stocking levels than those correctly cut. Additional comparisons are in Appendix B.

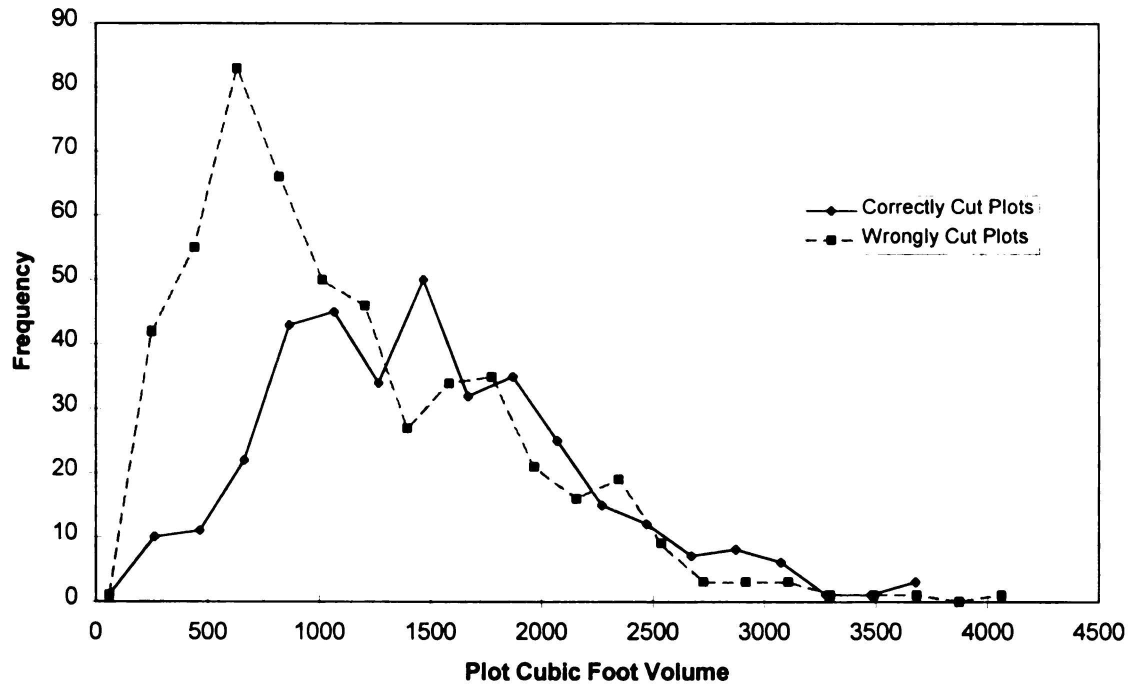

Figure 15: Comparison of 1980-1993 projected cut plots' cubic foot volume/acre, 1980.

Since there was no bias in terms of levels of aspen stocking on the plots, 59% of the plots projected to be harvested were randomly uncut, and 20% of the plots projected to not be harvested were randomly cut. After the harvest probability for each stand was calculated in the modified STEMS85, a random number was selected from a uniform distribution (0,1). For those stands whose calculated harvest probability was greater than or equal to 0.3 and the random number was less than 0.59, the stand would not be cut and would return to the growth and mortality loop. If the harvest probability was less than 0.3 and the random number was less than 0.2, the stand would be cut. The total volume cut between 1980 and 1993 with and without the random harvest correction were then compared. Tables 11 and 12 show a comparison between the 1993 remeasured data, the base projection data and the corrected projection data. The harvest correction produces more accurate projections of the remeasured plots while still maintaining an approximately equal distribution of harvest values across ownerships and units.

Table 11: Comparison of 1980-1993 projected and measured harvest and stocking volumes.

	Remeasured Data	Base Projection	Corrected Projection
Cubic feet aspen cut, 1980-1993	183.8	456.3	216.7
Cubic feet aspen stocking, 1993	465.6	187.6	399.8

Table 12: Comparison of 1980-1993 projected and measured harvest levels by proportional distribution across ownership and location.

1980-1993 percent total cut	Remeasured Data	Corrected Projection
Federal aspen cut	11%	12%
State aspen cut	28%	26%
Private aspen cut	61%	61%
Upper Peninsula aspen cut	55%	51%
Lower Peninsula aspen cut	45%	49%

In projecting the 1993 data, the modified STEMS85 was run 55 times for each plot in order to provide data to estimate the variance in the projected outcomes. No provision was made for regenerating stands harvested during the projection. I did not feel that the simulations accurately reflected harvest activities on an individual tree basis, and so it would be difficult to estimate the possible effect of residual overstory on any regenerating aspen.

Successional processes are not specifically addressed in the model because the age data for the projected plots is unreliable. The stands continue to grow and die throughout the projection period. Because aspen is intolerant, it was assumed that the ingrowth on these plots did not consist of a large aspen component. Those stands that did incur harvesting were tracked and summarized by acreage and residual volume in order to provide a generalization of the standing resource at the end of the projection.

V. RESULTS AND DISCUSSION

Michigan's aspen resource continued to increase in volume prior to 1993 as the lands cleared and abandoned at the turn of the century reverted to forestland and the pioneering aspen became established and matured. However, these projections indicate this trend is likely to reverse given continued harvest levels, management practices and natural succession. From 1935 to 1993, the acreage in aspen covertype decreased by 48% as natural succession, development and aging processes continued and harvest rates increased 139% between 1975 and 1994. Possible shortages in aspen inventories have been the subject of much research since the 1970s (Leuschner 1972, Liggett & Leefers 1990, Potter-Witter & Ramm 1992). This potential shortage has been linked to increased harvest levels, imbalanced age classes, natural succession due to lower levels of disturbance, increasing resource maturity, and management practices that don't promote natural aspen regeneration. These projections suggest that aspen volumes will start to decline between 1993-2003 as the average annual harvest rate is almost sustained at 1994 levels. After 2003, recent harvest rates cannot be maintained by the projected aspen inventory.

Findings

These results represent the average of 55 projections of Michigan's aspen resource from 1993-2023 simulated with a modified version of STEMS85. This program projected growth, mortality and harvest of Michigan's aspen resource based on the 1993 statewide forest inventory. The growth, mortality and harvest probability equations were fit to data collected in Michigan on remeasured plots from the 1980 and 1993 inventories. These results represent one possible future condition based on the assumption that recent trends in growth, mortality and harvesting continue. All error bars represent 3 standard deviations from the mean based on the averaging of the simulations.

Projections show that standing aspen volume declines by approximately 25% over each of the first two decades from 1993-2013 and 30% over the third decade from 2013-2023. Figure 16 demonstrates the projection of an overmature resource that has been significantly influenced by past and current harvesting patterns, natural successional losses, and acreage conversions. The projected net loss between 1993-2023 in the aspen growing stock volume is 60%, from a 1993 level of 40 million cords to a 2023 level of 16 million cords. This decline occurs across all ownerships and both peninsulas in Michigan as shown in Figure 17.

The greatest proportional loss of aspen from 1993-2023 is projected to occur on private ownerships (67%) and in the Upper Peninsula (64%). Federal and state/local ownerships and the Lower Peninsula increase their proportion of the total state aspen resource while private ownerships and the Upper Peninsula decrease their proportions by 2023 as compared to 1993. This decline in the aspen resource is related to the continuation of increased aspen harvest levels from the past two decades into the first decade of the projections, and the effect of minimal acres and stocking in younger age classes due to the increasing proportion of the resource progressing undisturbed into overmaturity.

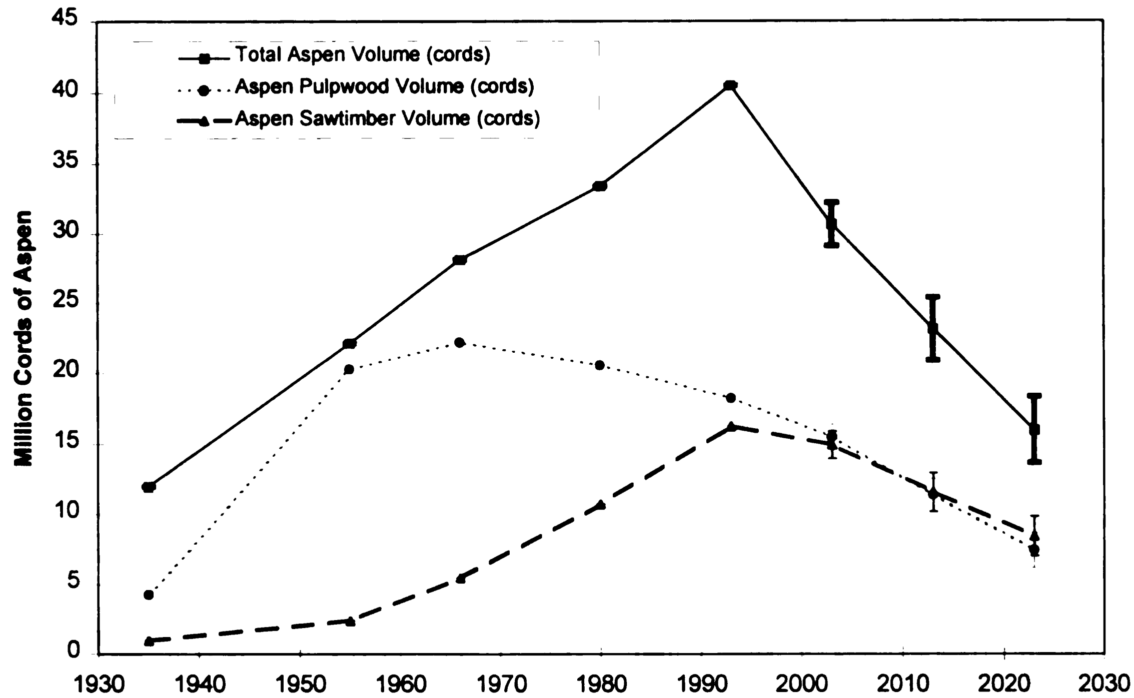

Figure 16: Michigan's aspen resource from 1935-2023 based on published inventories (1935-1993) and study projections (2003-2023).[5]

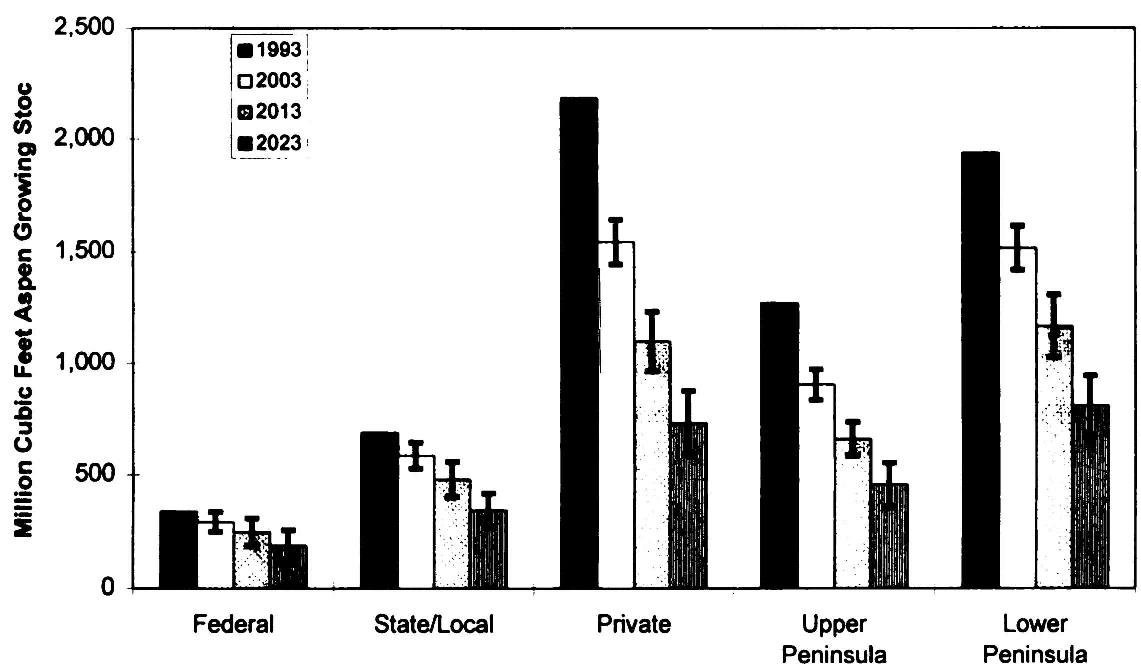

Figure 17: Michigan's aspen growing stock volume by ownership and peninsula, 1993-2023 from published 1993 inventory and study projections (2003-2023).

[5] Sawtimber volumes were converted using 1 mbf=160 cubic feet and 79 cubic feet=1 cord.

Total projected aspen removals for 1993-2003 were only 63 million cubic feet greater than removals for 1983-1993, an increase of 5%. However, the period of 1993-2003 had the greatest amount of mortality within the time frame of the projections as shown in Figure 18. This could be related to a large portion of the aspen resource in 1993 being mature to overmature and subsequent decades' mortality coming from a decreasing aspen base.

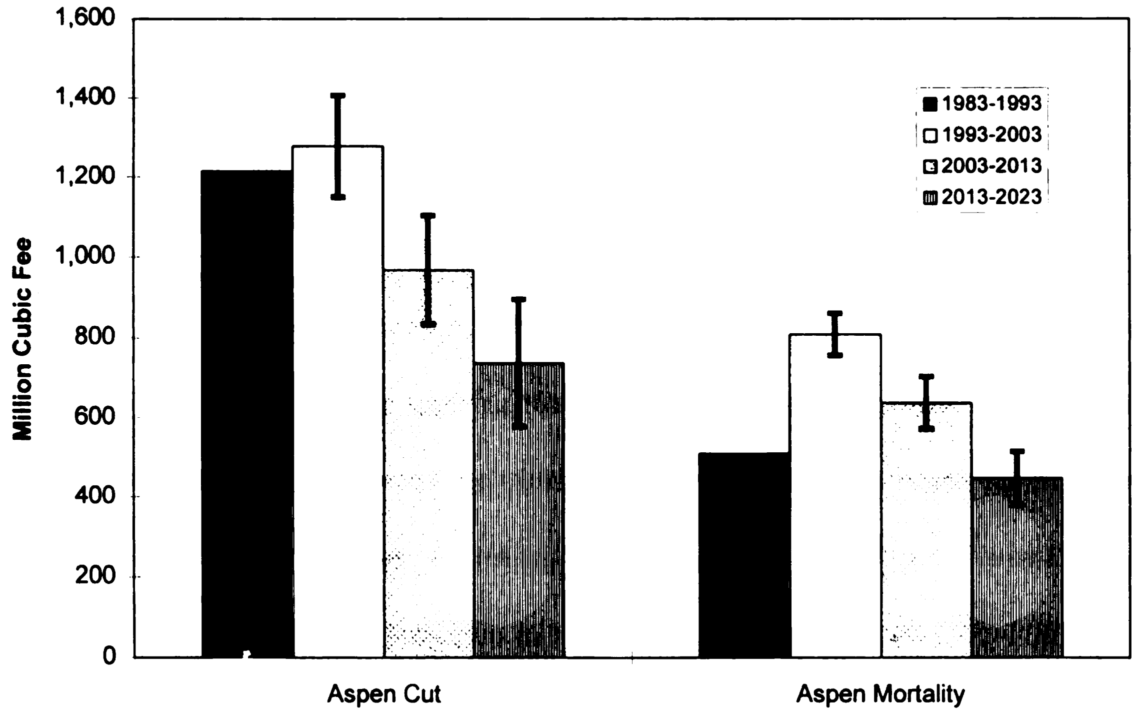

Figure 18: Michigan's aspen resource cut and mortality from published reports (1983-1993) and study projections (1993-2023).[6]

Based on these projections, this increased aspen harvest level is not sustainable. The resource becomes overmature as the increased mortality indicates, and the maturing

[6] Aspen removals for the period 1983-1993 (Blyth et. Al. 1988, Smith et. Al. 1990, Hackett & Pilon 1993, May & Pilon 1995). Aspen mortality for the period 1983-1993 is based on average annual mortality (Leatherberry & Spencer 1996).

resource volumes are not sufficient to maintain the 1994 harvest level. The average annual harvest level between 1983-1993 was 122 million cubic feet. This is projected to increase to 128 million cubic feet between 1993-2003. The projected average annual harvest then falls to 97 million cubic feet between 2003-2013 and 74 million cubic feet between 2013-2023. Based on the timber product output publications referenced in Figure 18, approximately 16% of the harvested volume does not make it into production. Assuming this continues to apply to the projections, only 108 million cubic feet per year between 1993-2003 will be available for industrial roundwood production. This is 5% less than the 1994 industrial roundwood production level of 114 million cubic feet.

Despite a decreasing harvest level on federal and state/local ownerships, the 1983-1993 harvest level is projected to be maintained between 1993-2003 by an increased harvest level on private ownerships. The 1983-1993 ownership and geographic harvest distribution was calculated by applying the respective removal proportion based on the 1993 Michigan inventory remeasured plots to the aspen volume cut based on the timber production output publications. Private aspen harvest volumes go from 708 million cubic feet between 1983-1993 to a projected 881 million cubic feet between 1993-2003, an increase of 24%. The projected harvest levels by ownership and peninsula are shown in Figure 19.

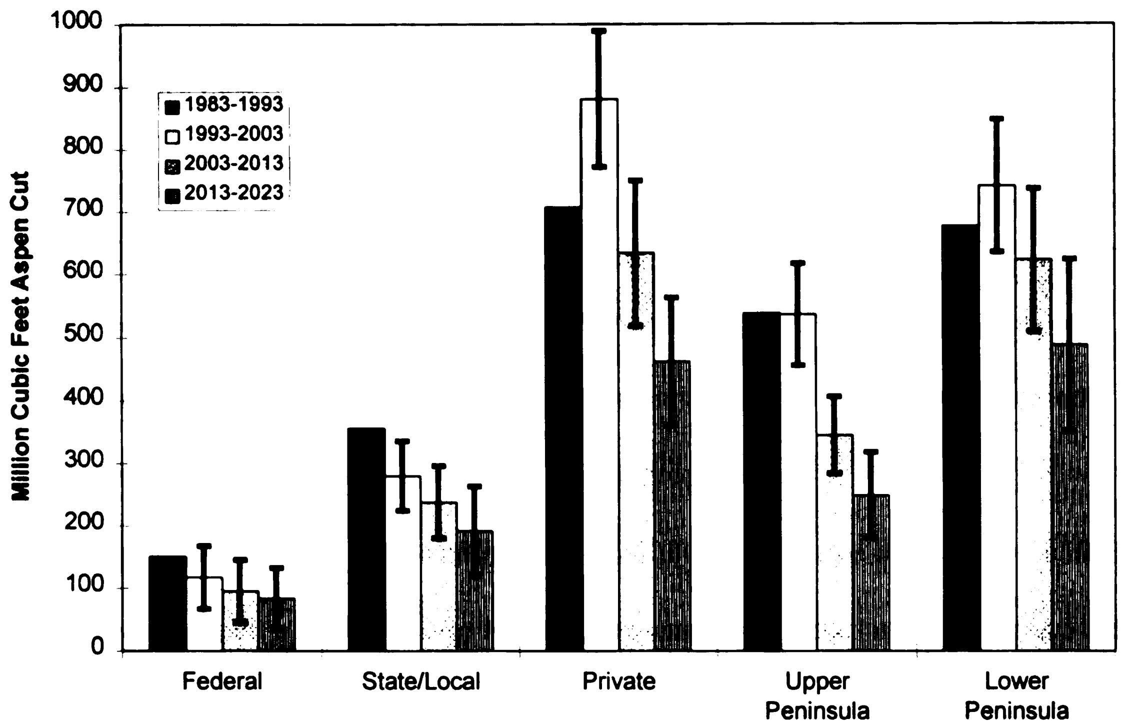

Figure 19: Michigan's aspen harvest volume by ownership and peninsula from published inventory and timber product output reports (1983-1993) and study projections (1993-2023).

After the initial projection period of 1993-2003, the private ownership and the Upper Peninsula show the greatest decrease in aspen harvest levels which coincide with the large decreases in aspen growing stock shown in Figure 17. These projected 27%-28% volume reductions result from maintaining the harvest level during the first decade from a resource not capable of replacing that volume in its current status. From 1983-1993, aspen harvests on federal and state/local ownerships and in the Upper Peninsula were proportionally greater than their share of the state's aspen growing stock. While the federal and state/local ownerships and the Upper Peninsula had 10.5%, 21.5% and 39.6% of the state's aspen growing stock, the harvest levels were 12.4%, 29.3% and 44.3% of the state's aspen harvest, respectively. After 1993, the federal and state/local ownerships' harvest proportions are projected to be less than their statewide growing stock proportions which increase by 4% and 6%, respectively, between 1993-2023. Private ownerships are projected to increase their 1993-2003 proportional harvest levels by almost 11% more than their 1983-1993 proportion. The Lower Peninsula is projected to increase both its proportional harvest level and standing aspen volume between 1993-2003. This may indicate better growing sites in the Lower Peninsula and/or the effect that increased harvest/disturbance levels can have in terms of future production.

The age class distribution projected for 2023 shows a large increase from 1993 in the number of aspen covertype acres in the overmature age classes of 75 years and older. This acreage does not necessarily represent aspen stands. It represents aspen stands in 1993 in which the aspen is not harvested during the projections to 2023. However, it is unlikely this aspen will survive into these older age classes. Perala et al. (1996) identified one of the decay triggers to be a stand age equal to 10 plus the site index. It is likely that these stands represent aspen acreage lost through conversion to a different forest type if ingrowth and natural successional processes were incorporated into the projections. The projected acreage in the mature age classes of 55 and 65 is 32% and 65% less than the acreage in 1993, respectively. The age classes of 35 and 45 do contain a greater number of acres in 2023 than in 1993. It is possible that these maturing acres could provide for an increased aspen harvest level in succeeding periods. However, these periods are beyond the scope of these projections due to the time period and the fact that regeneration on stands cut during the projection was not included. Figure 20 shows the acreage distribution by age class.

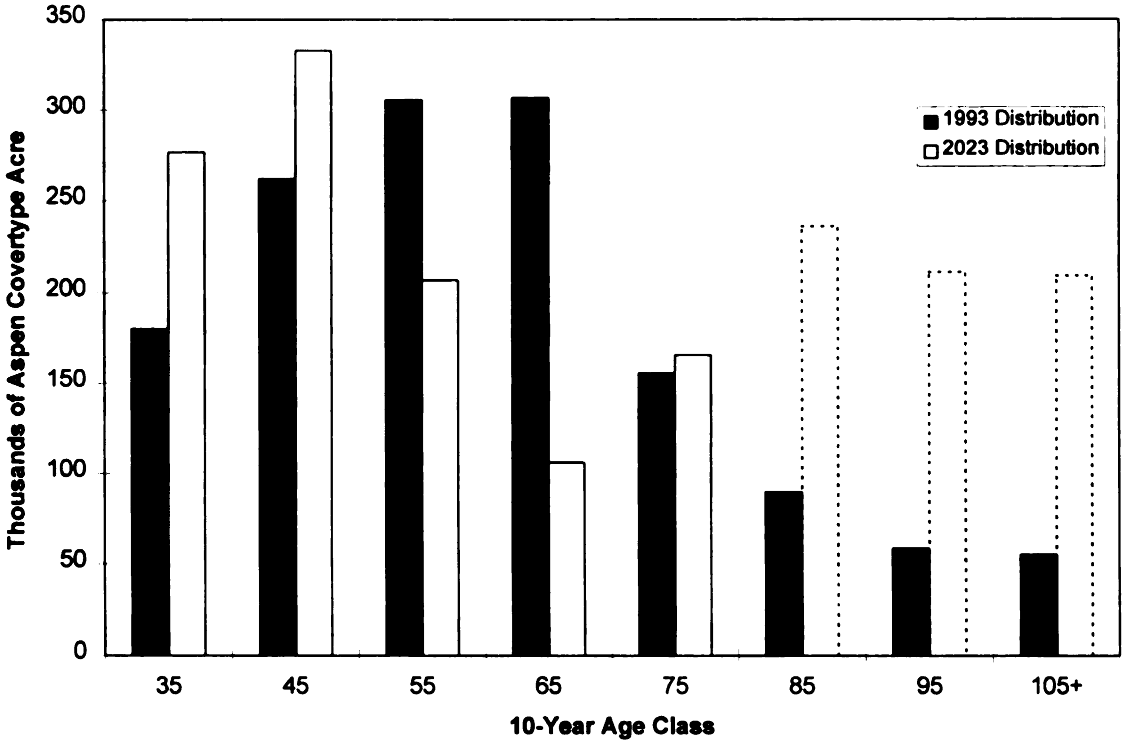

Figure 20: Comparison of Michigan's 1993 and 2023 aspen covertype age class distributions from 1993 inventory and study projections for 2023.[7]

Analysis and Future Research

Aspen regeneration will have a large impact on future resource levels, and there is significant need to consider the success of aspen regeneration in any long-term resource projection. However, within the short time span of these projections, the additional regeneration is not successful in preventing a loss of the current resource.

There were 202 plots in the 1993 inventory that could be considered to be in the process of regenerating at the time measurements were taken. These plots were less than 20 years old with an overstory of less than 40 square feet of basal area per acre and either

[7] Dashed borders represent aspen acreage in 1993 with aspen volume not projected to be harvested by 2023. These acres in 2023 are not likely to still be in aspen but rather, converted to another forest type.

greater than 20 square feet of basal area per acre of aspen cut between 1980 and 1993 or aspen seedlings/suckers measured on the plot. These parameters identify plots with potential future aspen volume resulting from regeneration not overly suppressed by a more mature overstory.

The effect of these stands with enhanced aspen stocking on both the projected harvest and residual stocking levels was minimal due to the short-term nature of the modified STEMS85 projections and the proportionately small number of these stands. The average projected output and growing stock values were within the range of the original projections that did not include the enhanced regeneration. At most, the projections with the regenerating aspen stocking increased average period ending stocking levels by less than 1%.

A large portion of the aspen resource is projected to progress undisturbed into the overmature age classes given the past, and projected, harvesting patterns. Over 612,000 acres of aspen covertype are projected to be over 75 years old in 2023. This is 23% of the acreage in aspen covertype in 1993. The possibility of salvaging some of the aspen stands that progressed into overmature age classes or were lost to mortality is highly dependent on the age and quality of the resource being harvested in the projections. If the harvests are coming from newly mature stands in which volume would not be lost by delaying harvests a decade, perhaps harvests could be shifted to older, overmature stands during the first decade and inventory sustained for harvest in succeeding decades. This could possibly maintain 1994 harvest levels into the succeeding decades. Because the mortality level is at its highest during the first decade, much of the resource may be too overmature and diseased to be utilized. If it isn't, it may not be possible to fully utilize the older timber resource without increasing overall harvest levels in the initial projection period. Since the first decade projections are relatively close to meeting a continuation of the 1994 demand level, the market may not provide an opportunity for salvage of the older resource.

The possibility of salvaging the older aspen resource would require a more detailed examination of the resource being harvested in each decade in terms of the mortality and growth rates, distribution across ownerships and where changes in harvest potentials could occur. A more sensitive modeling approach would be required to estimate any potential effects of specific management strategies to maintain the aspen resource. This would require a shorter projection cycle and more specific models of harvest probabilities.

The projected harvest does not maintain the 1994 harvest level throughout the next thirty years. Maintaining 1994 harvest levels would require an unparalleled effort at statewide management of the aspen resource. It is possible that harvest levels could rise after the initial lull between 2003-2023, but this is highly dependent on the management practices implemented over the next thirty years. It may require the clearcutting of older stands not past their prime but that are not necessarily marketable or stands with a minimal aspen component that are in later successional stages. Maintaining an aspen timber resource will require a concerted effort to facilitate active regeneration in management practices and avoid further successional losses on large ownership blocks such as publicly held lands or to increase industry's aspen holdings.

It appears the Lower Peninsula and publicly held lands are potential sources for increased resource output in the future. After 1993, their projected proportion of standing resource and timber supply increase. It is possible that an increase in their output levels could offset some of the harvest volume decline in the next thirty years without impairing future contributions. A closer look at the resource on these ownerships in terms of maturity, stocking, and availability would be required to determine if these lands could contribute greater volumes over the next thirty years. However, this possibility could be negated if the management practice of clearcutting is legally restricted from being applied. The effect of restricting clearcutting on federal lands is not easily determined in this analysis. It would likely decrease harvest levels over the next thirty years. The degree to which it would decrease would depend on the amount of aspen harvested using a selection management approach. If no aspen harvesting occurred on federal lands between 1993-2003, Michigan's projected average annual harvest level would be 116 million cubic feet, 2% greater than the 1994 harvest level of 114 million cubic feet if the total harvest volume was utilized for roundwood. The greater effect of not allowing clearcutting of aspen would come into play beyond the time period of these projections as the lack of regeneration in these stands decreased the possible future mature aspen resource growing stock levels.

A closer examination of the aspen resource being harvested would be required to determine if shifts in harvesting practices could increase aspen inventories and sustain harvests. While private and Upper Peninsula aspen resources are projected to have a proportionately greater drain over the next 30 years as compared to that on public and Lower Peninsula lands, this might be a factor of the aspen resource age and quality distribution across these ownerships and peninsulas. Further classification of the aspen resource status and outputs on these ownerships and peninsulas at shorter projection cycles could provide a clearer picture of the options available to aspen resource managers. It might facilitate the development of management alternatives that could alter the projected outcomes for the resource.

Limitations

There are five main factors limiting this modeling approach. These include assumptions related to the inclusion and application of regeneration, natural succession, harvest probabilities based on logistic regressions, 10 year projection periods, and survey data as representative of the aspen resource. Each is addressed below.

It is possible that modeling the first period mortality for the 202 regenerating stands deterministically biased the status of these stands at 10 years. With only 202 regenerating plots identified out of over 4500, any specific bias should have limited effects on projection results. Any possible regeneration from stands harvested during the projections would not produce measurable aspen volume before 2023. So, the exclusion of this regeneration process is not likely to affect projected inventory volumes.

Another potential source for error in describing the future aspen resource is that plots converting to aspen through disturbance or natural successional processes were not modeled. Between 1980 and 1993, there was a net loss of approximately 400,000 aspen acres. Included in this net loss were approximately 200,000 acres which changed classification to aspen covertype. It would be reasonable to expect that some acres would gain an aspen component during the projections. These new aspen components could be added to the projections if the parameters capable of defining the probability of their future occurrence were identified and an average tree list was defined.

Natural succession and stand breakup were not specifically modeled. These processes were generally included through the modified mortality rates, harvest probability equations, and recalculation of the stand covertype after each projection cycle. A more specific approach would be to remove any stands that reach a specific age from harvest consideration and inclusion in standing volume totals. However, the age of the aspen resource would have to be more accurately determined. Modeling natural succession would require the addition of ingrowth tree lists over the course of the projection and a more accurate model for determining the specific plot harvest patterns. Natural succession is likely to affect the growth of aspen originally in a stand but not add new aspen stems due to the shade intolerance of aspen.

The reason for the logistic regression resulting in overcutting stands with lower stocking levels than the plots actually harvested between 1980 and 1993 has not been specifically defined. It is possible that refinement of the harvesting equations could result in different harvest volume projections. The choice to assume harvests occur in the middle of the projection period may bias the projections. Mid-cycle harvesting was chosen in order to balance the volume lost on stands cut early with the volume gained on stands cut late. More specific knowledge of harvest timing and conditions at that time are necessary to improve the modeling of harvest patterns.

The use of data collected in 1980 and 1993 to develop the harvest probability equations limits this analysis by locking the projections into a 10 year cycle. This limits its usefulness for those who plan on a shorter time horizon. However, it was not possible to calculate probabilities for a shorter projection cycle without knowing when the stands were cut between 1980 and 1993. It is possible that the total harvest level over a decade could be the result of a widely varying annual harvest rate. The average annual harvest levels were calculated by dividing the period harvest by 10 years.

A more comprehensive harvesting model might be developed with more detailed knowledge of financial considerations, mill location, specific harvest levels and timing, bidding and contract considerations, and market fluctuations. Harvest probabilities were based on past management related to stand-specific variables. It may be possible to include additional variables to increase the efficacy of the regressions. Additional research is required to improve understanding of harvesting patterns and to implement harvesting behavior models within a projection framework.

These results are meant to provide information to those interested in the status of the aspen resource and its outputs, and those who are in a position to affect the outcomes. Improvements in projection methods and especially models of harvesting patterns would likely produce more detailed insights into the dynamics of this important forest resource.

Conclusion

Unless recent management practices change, the aspen resource is projected to continually decline over the period of 1993-2023. The 1994 harvest level cannot be maintained throughout the first decade, and subsequent decade harvest levels are projected to continue declining. Public ownerships increase their statewide proportional aspen resource due to their decreasing harvest levels from 1993-2023 and an increased harvest level on private ownerships which greatly reduces their standing aspen volume. In addition, a large portion of the aspen resource is projected to progress into overmature age classes which decreases its utility and ability to regenerate and represents losses through natural successional processes. Increased harvesting of the aspen resource in mature age classes in 1993 would be required to salvage this loss, possibly increase harvest levels before 2023, and provide a potential future aspen resource stemming from the regeneration on these stands. It is clear that if recent management practices continue, the current aspen inventory and harvest levels cannot be maintained between 1993-2023.

APPENDICES

APPENDIX A

APPENDIX A

Distribution of Michigan's Aspen Resource According to 1993 Survey Data

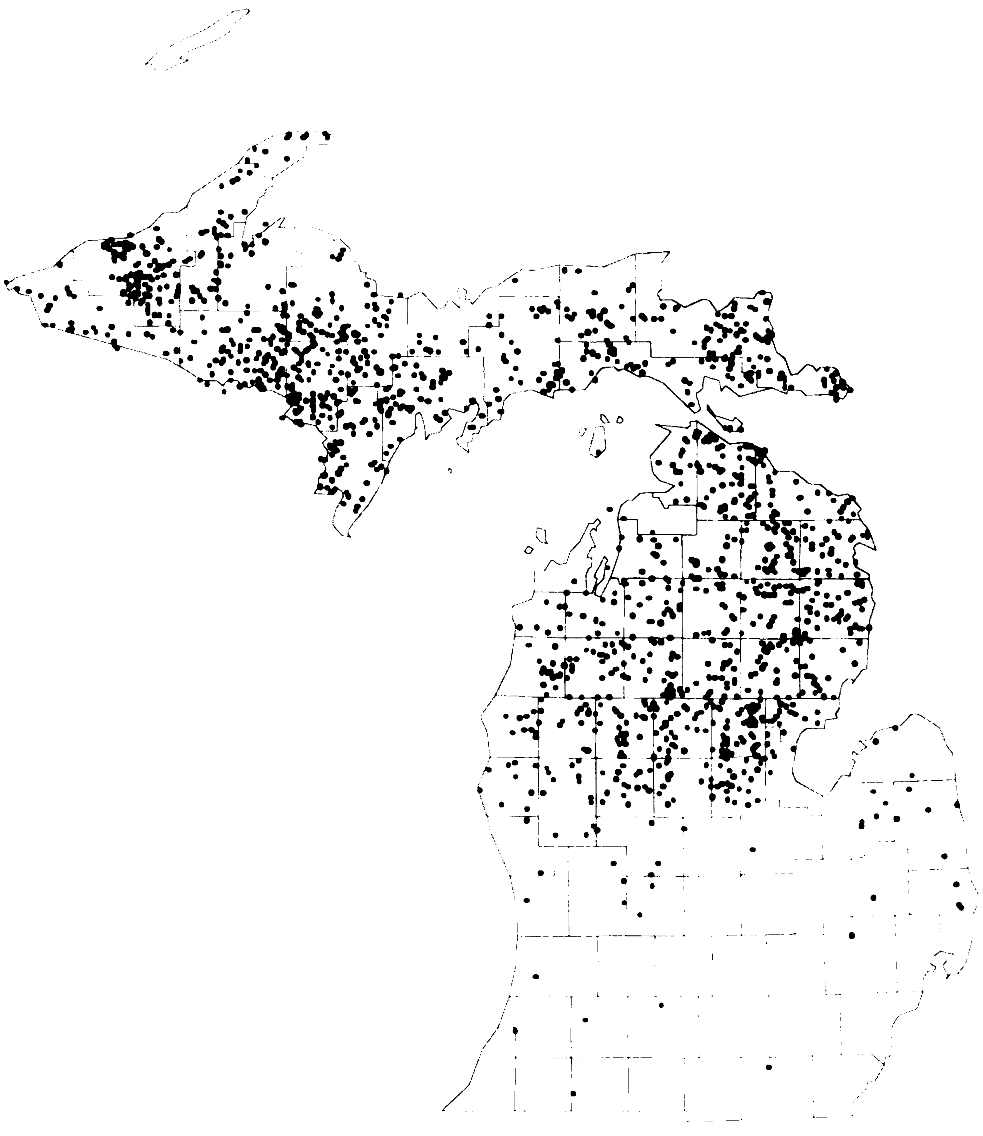

Figure 21: 1993 surveyed aspen covertype plot locations.

Figure 22: Distribution of aspen cubic foot volume cut, 1980-1993.

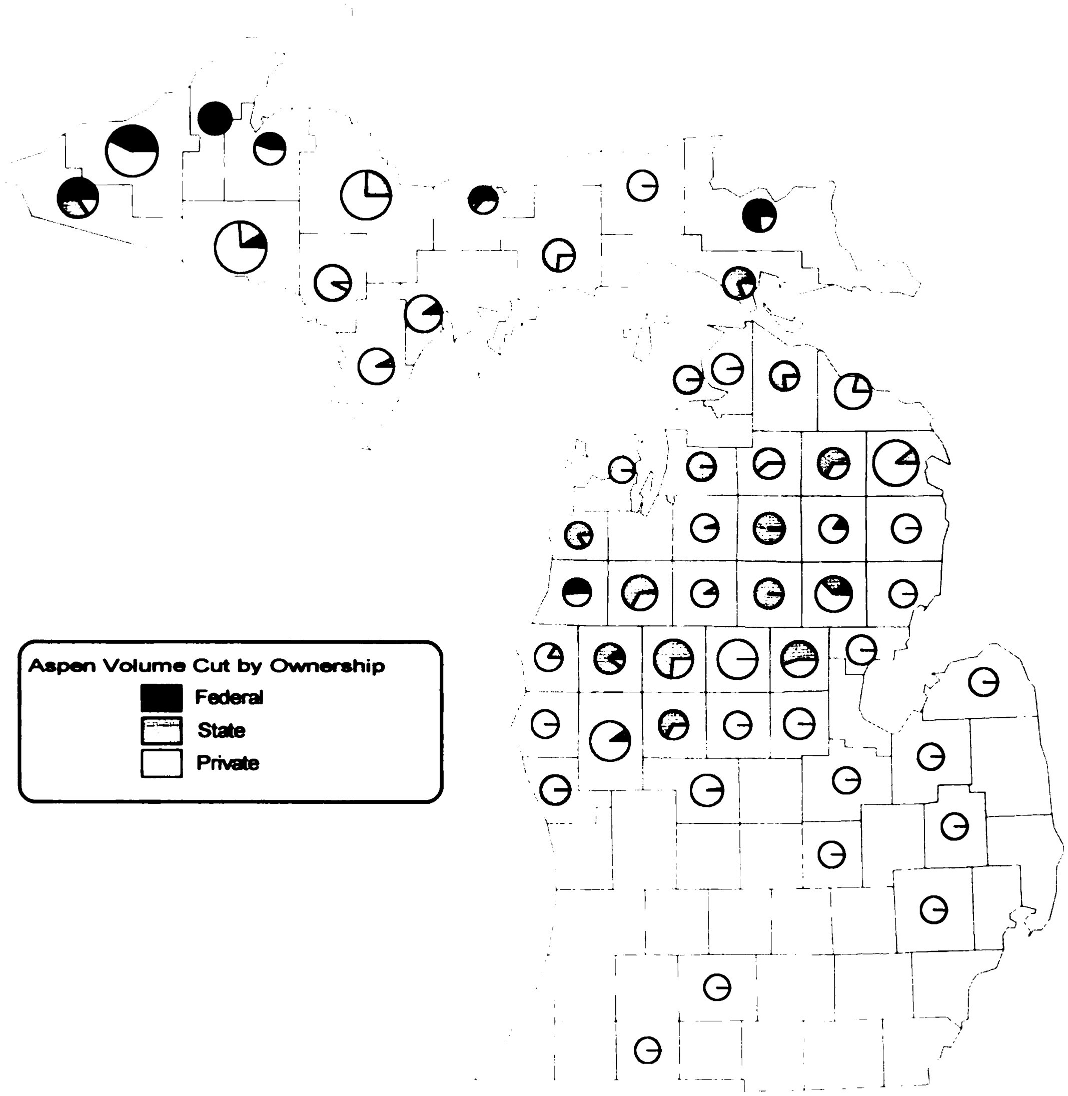

Figure 23: Distribution of aspen cubic foot volume cut by ownership, 1980-1993.

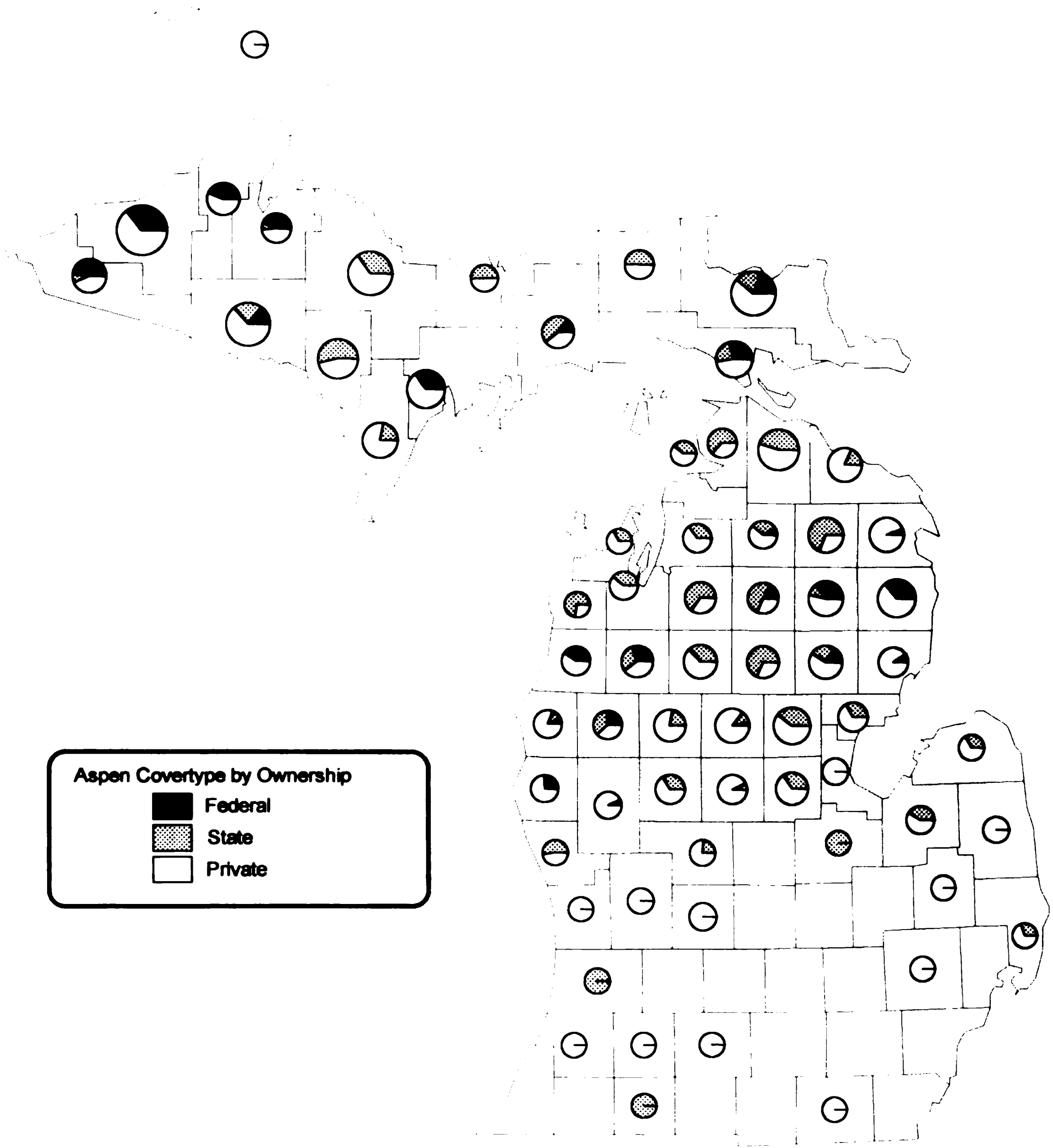

Figure 24: Distribution of aspen covertype acreage by ownership class, 1993.

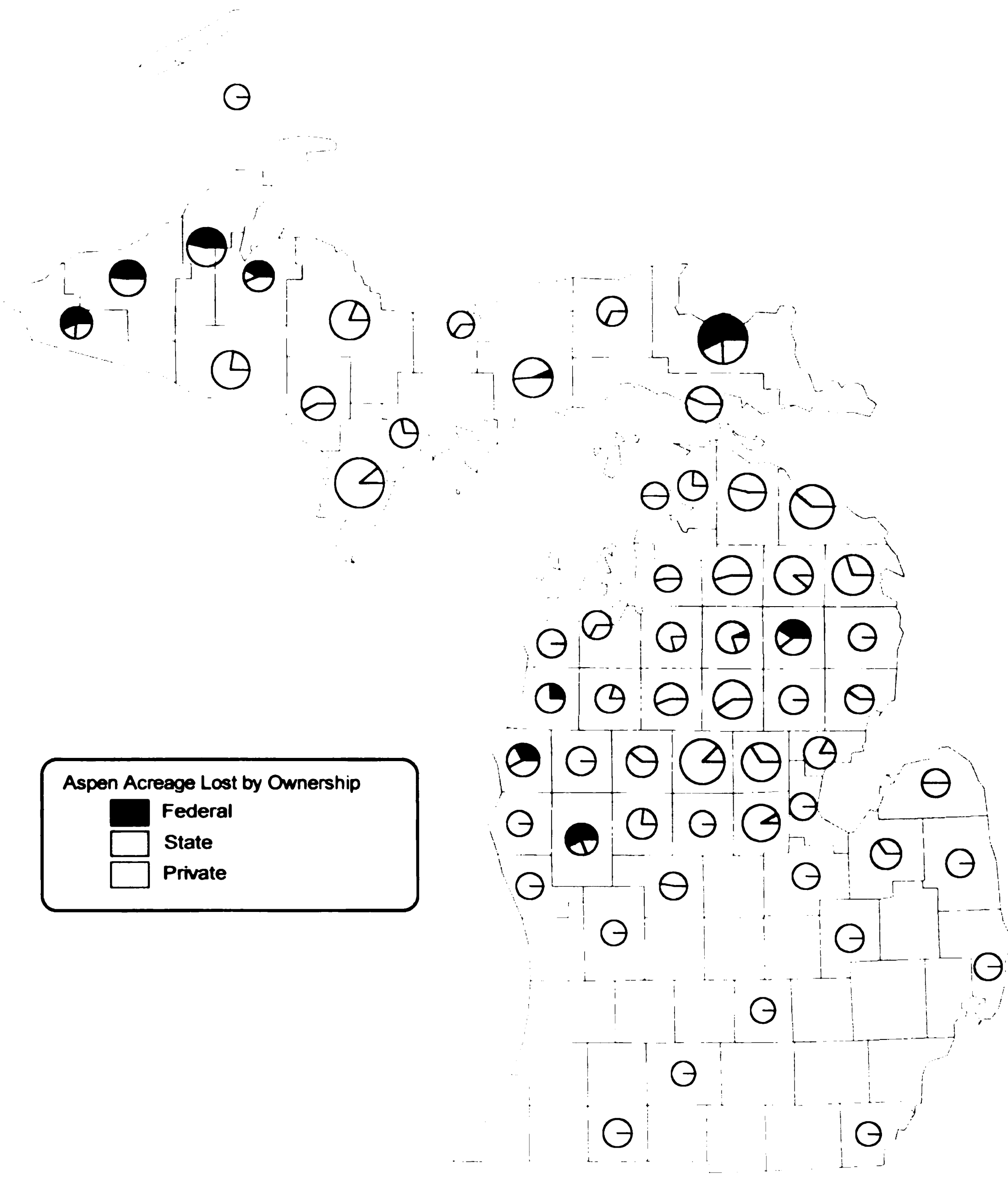

Figure 25: Distribution of aspen covertype acreage lost by ownership, 1980-1993.

Figure 26: Distribution of standing aspen cubic foot volume, 1993.

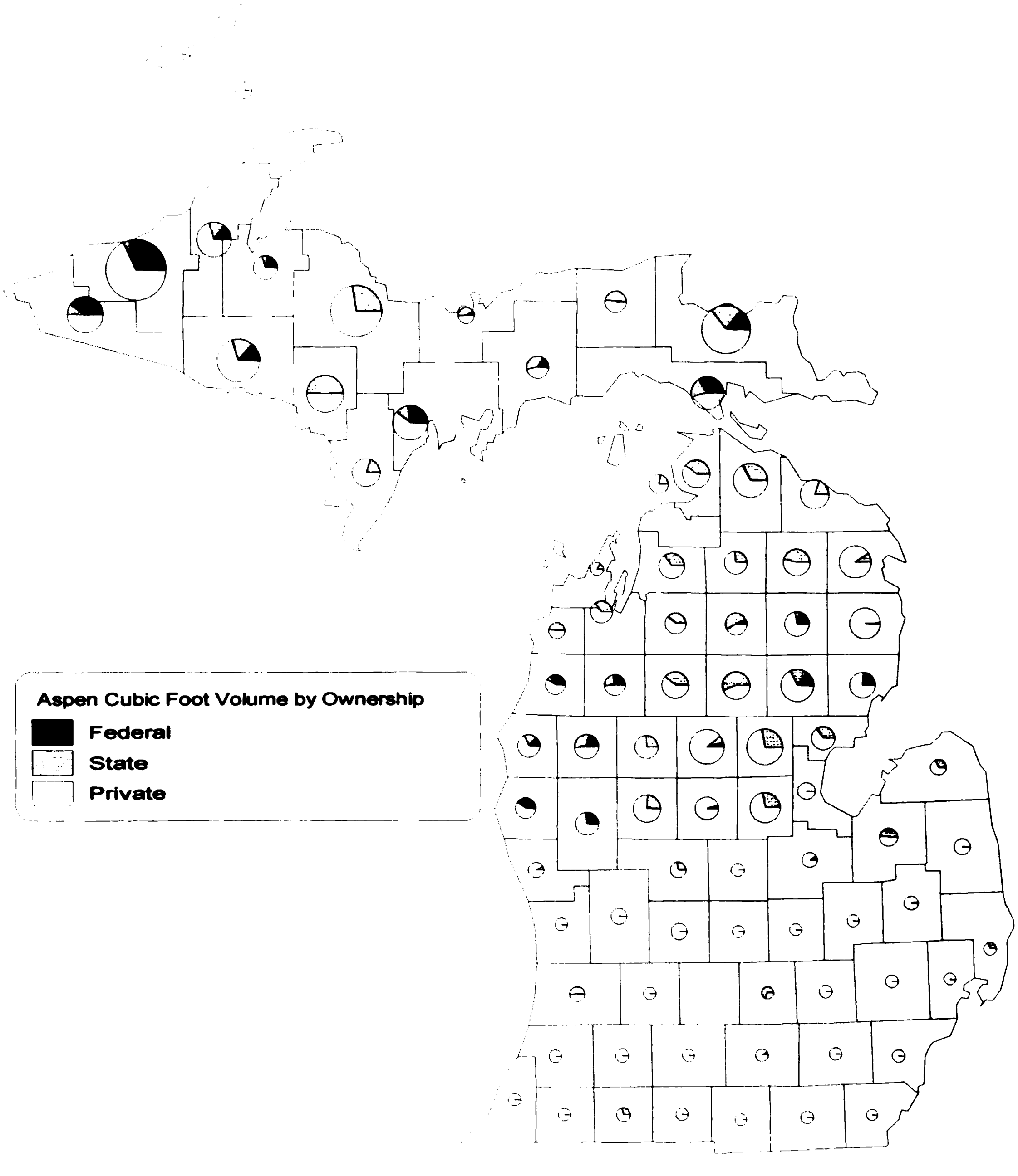

Figure 27: Distribution of aspen cubic foot volume by ownership, 1993.

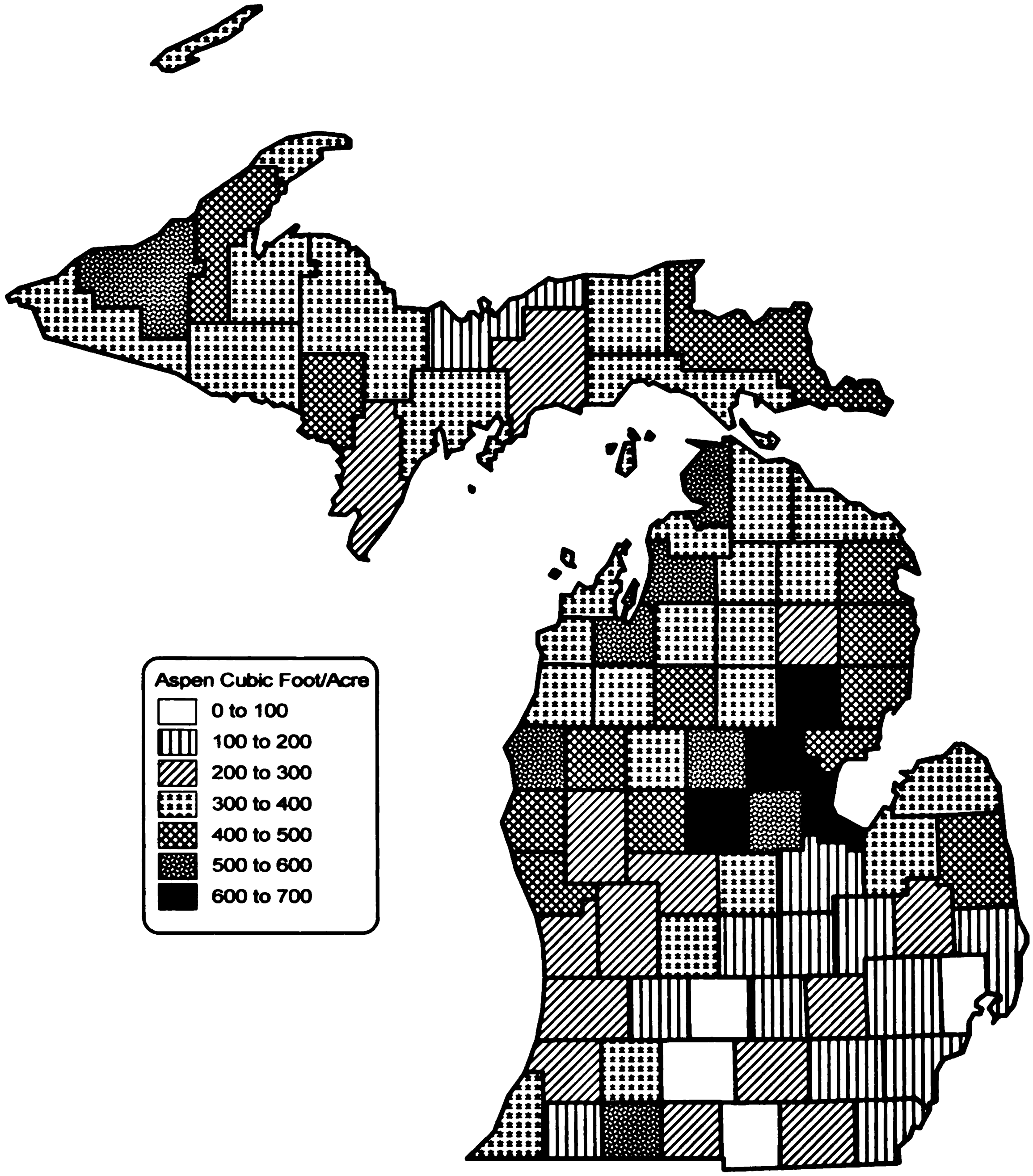

Figure 28: Distribution of average aspen cubic foot volume/acre on all acreage with aspen volume, 1993.

Figure 29: Distribution of aspen cubic foot volume by stand covertype classification, 1993.

APPENDIX B

APPENDIX B

Comparisons of 1980 Survey Plots Projected Using the Initial Logistic Regression Results to be Correctly and Incorrectly Cut as Determined by 1993 Survey Remeasurements

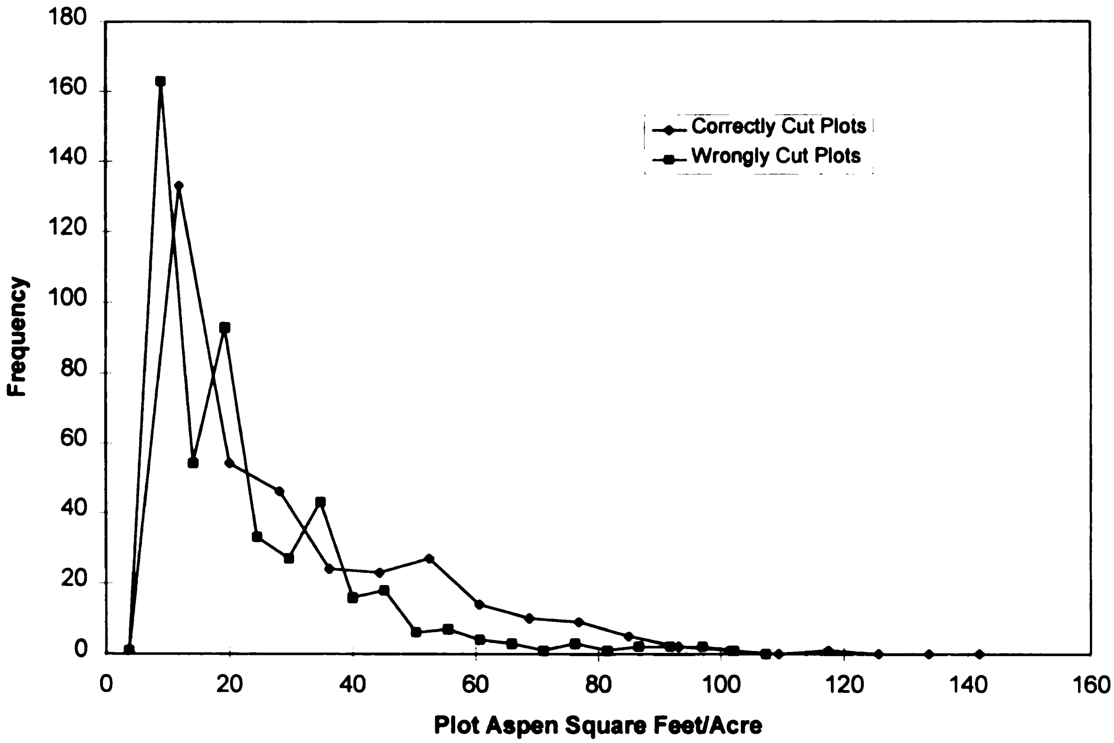

Figure 30: Comparison of 1980-1993 projected cut plots' aspen square feet/acre, 1980.

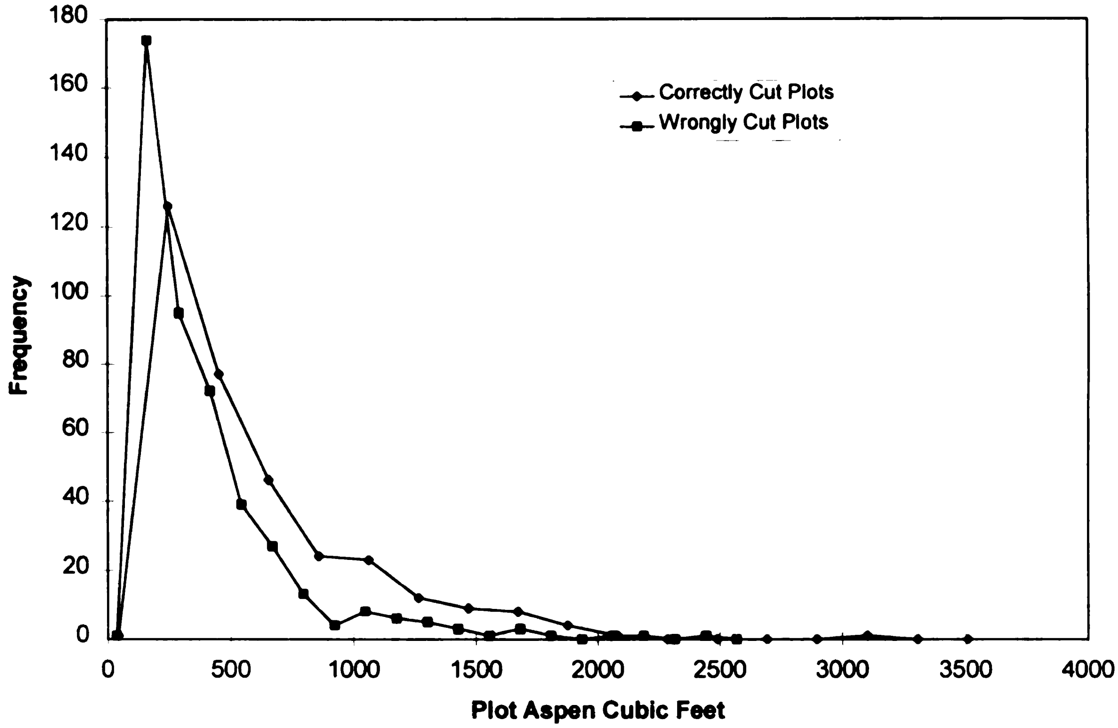

Figure 31: Comparison of 1980-1993 projected cut plots' aspen cubic foot volume, 1980.

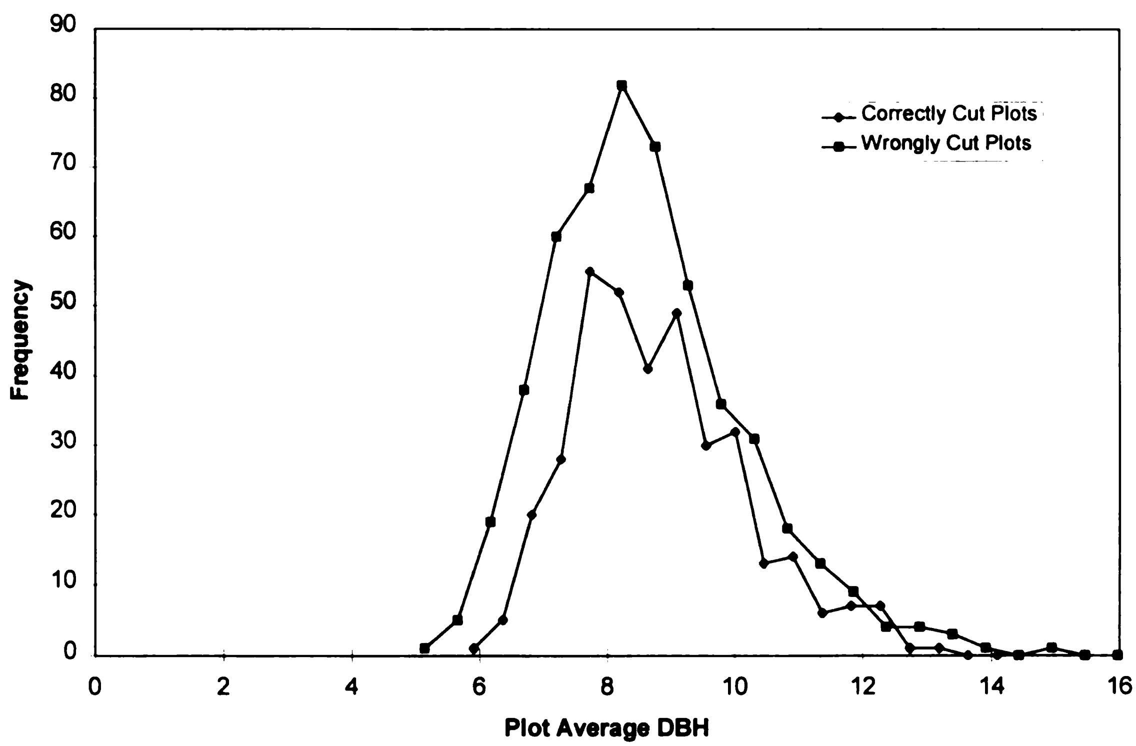

Figure 32: Comparison of 1980-1993 projected cut plots' average dbh, 1980.

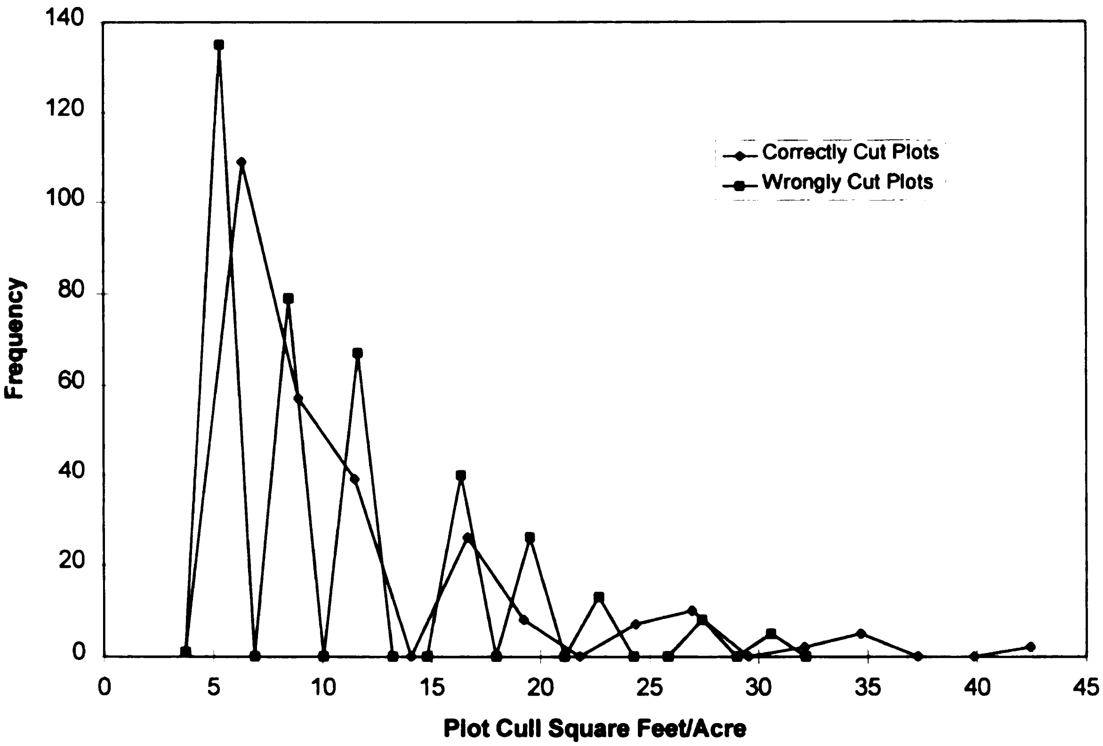

Figure 33: Comparison of 1980-1993 projected cut plots' cull in square feet/acre, 1980.

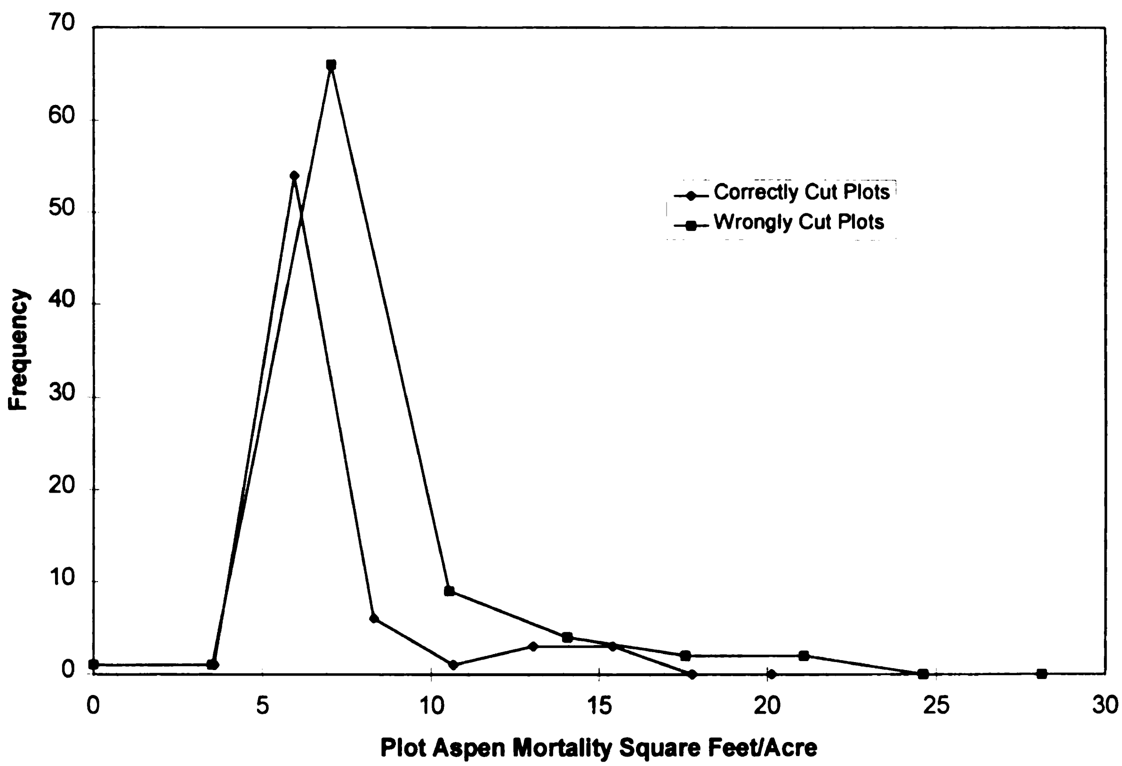

Figure 34: Comparison of 1980-1993 projected cut plots' aspen mortality in square feet/acre, 1980.

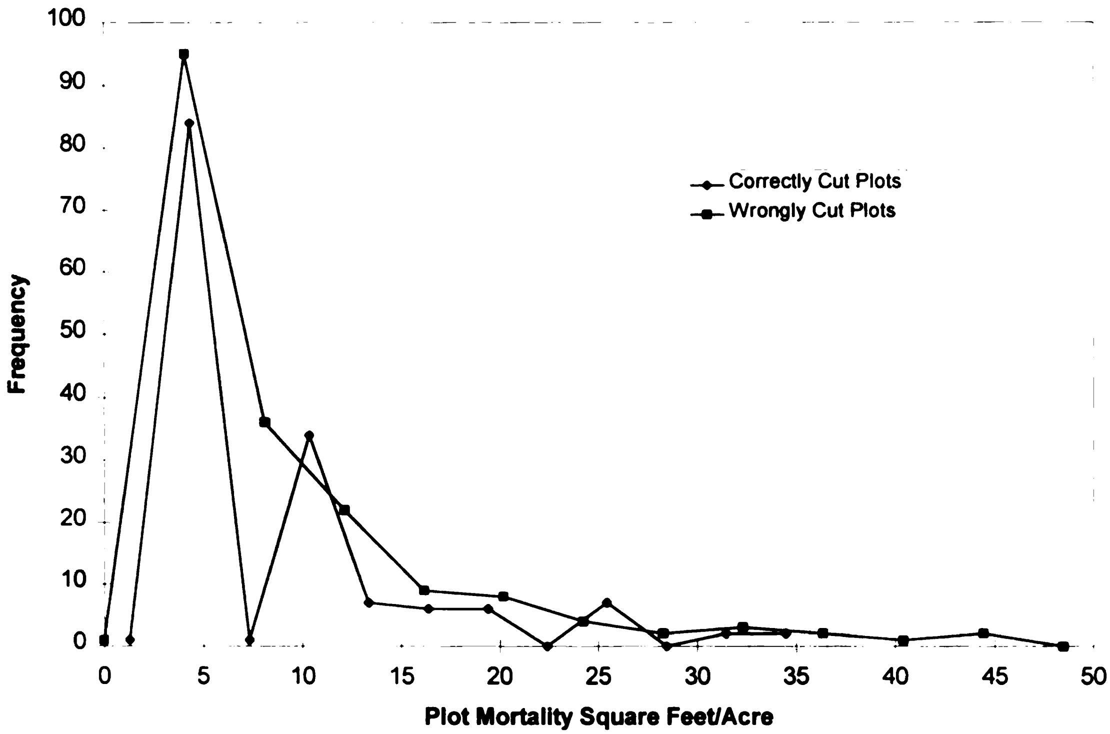

Figure 35: Comparison of 1980-1993 projected cut plots' mortality in square feet/acre, 1980.

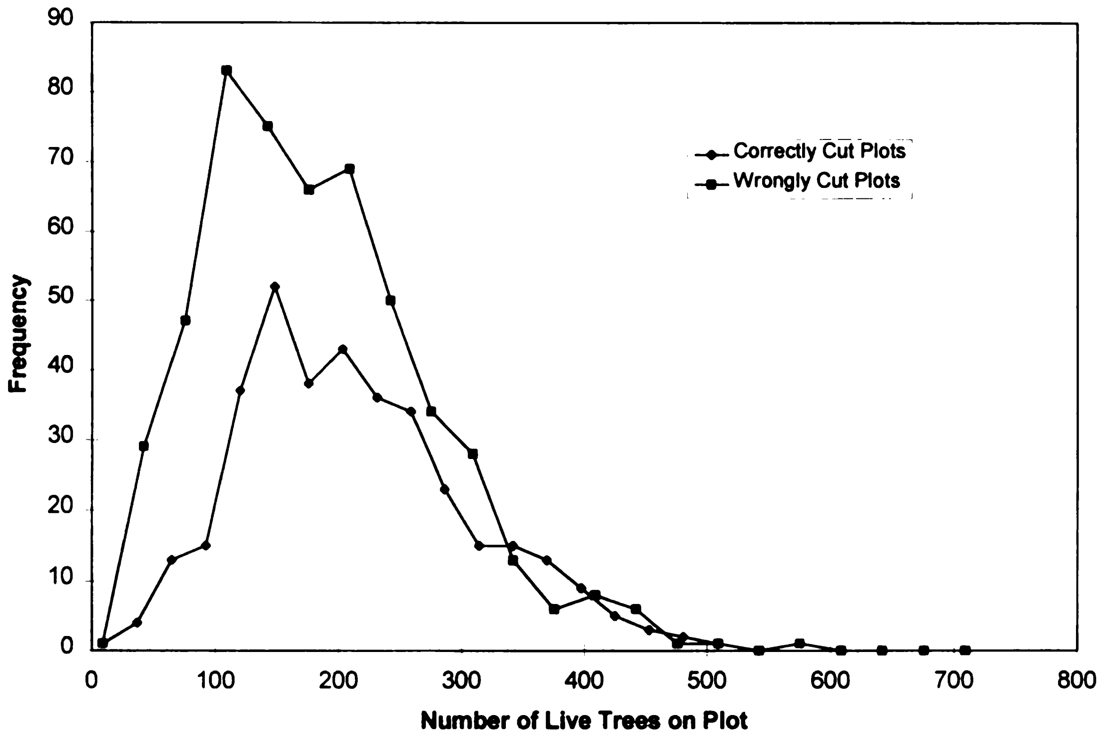

Figure 36: Comparison of 1980-1993 projected cut plots' number of live trees per acre, 1980.

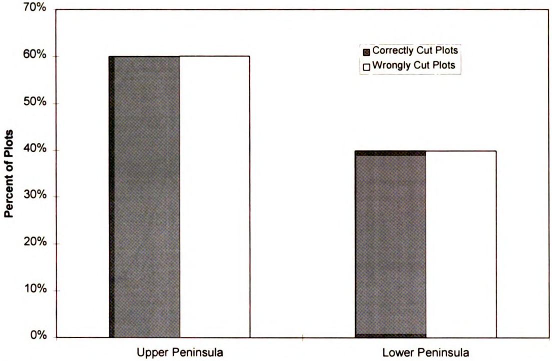

Figure 37: Comparison of 1980-1993 projected cut plots' location, 1980.

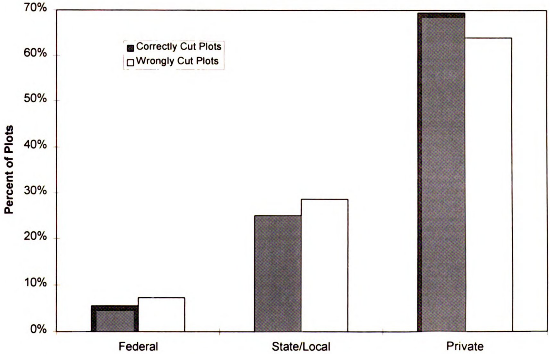

Figure 38: Comparison of 1980-1993 projected cut plots' ownership class, 1980.

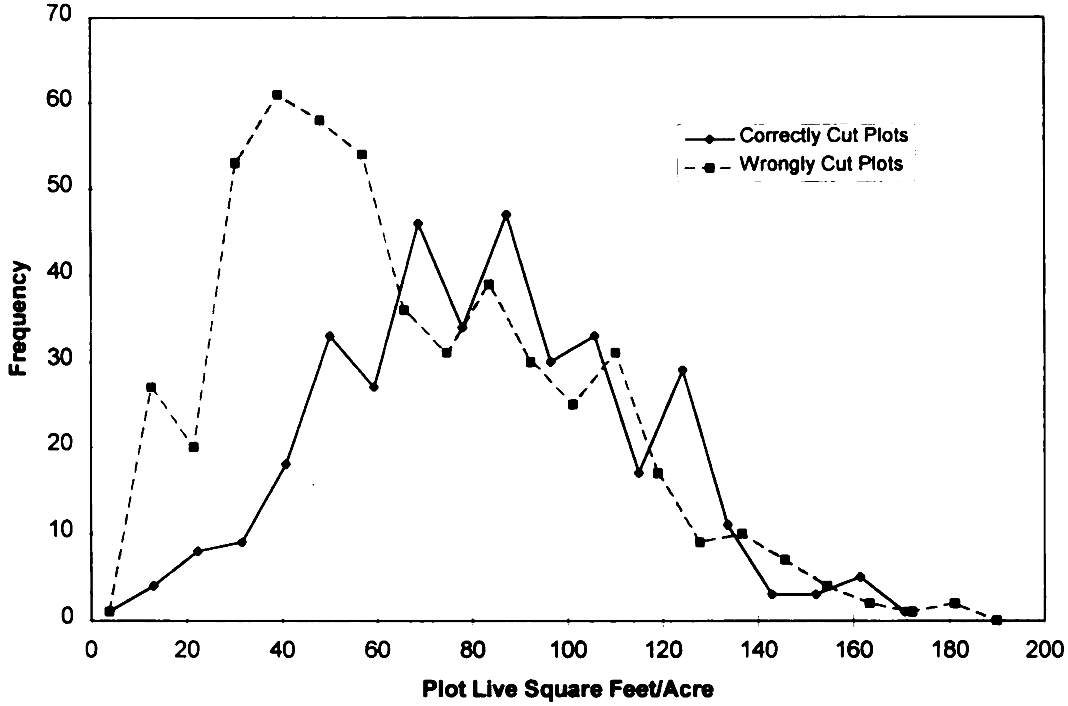

Figure 39: Comparison of 1980-1993 projected cut plots' live square feet/acre, 1980.

APPENDIX C

APPENDIX C

Study Projection Data for 1993-2023

Table 13: Averages for projections of Michigan's aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	1225213 [23892]	897820 [31174]	588306 [33089]
Aspen Sawtimber (mbf)	7376350 [158239]	5723956 [227207]	4170660 [231465]
Aspen Pulpwood Cut (mcf)	622764 [24805]	462645 [28711]	347317 [28454]
Aspen Sawtimber Cut (mbf)	4042981 [170760]	3114614 [164452]	2398906 [189717]
Aspen Pulpwood Mortality (mcf)	441198 [10471]	351562 [14291]	247970 [15038]
Aspen Sawtimber Mortality (mbf)	2274411 [75414]	1765008 [80406]	1232581 [79660]

Table 14: Averages for projections of Michigan's aspen resource, 1993-2023 [min,max].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen (mcf)	2421244 [2325587,2504435]	1826542 [1725180,1956163]	1264725 [1138522,1443844]
Aspen Cut (mcf)	1278201 [1198083,1366514]	968373 [869337,1058887]	736936 [598829,874747]
Aspen Mortality (mcf)	808284 [766965,841711]	636916 [582156,673399]	447261 [402660,505149]
Federal Aspen (mcf)	292500 [255719,322958]	247831 [199079,288487]	188356 [141162,268568]
Federal Aspen Cut (mcf)	117101 [83656,165360]	95609 [61694,143420]	83186 [54102,118142]
Federal Aspen Mortality (mcf)	112389 [96470,132224]	94048 [68884,114265]	74651 [55358,101330]
Lower Pen. Aspen (mcf)	1517478 [1459690,1587256]	1167774 [1066958,1246004]	809097 [730255,885204]
Lower Pen. Aspen Cut (mcf)	741874 [666846,811629]	622952 [555450,719307]	487747 [361886,585788]
Lower Pen. Aspen Mortality (mcf)	435786 [397664,461910]	366872 [334685,397873]	262906 [227193,300997]
Private Aspen (mcf)	1544063 [1468254,1607938]	1098602 [1014200,1183137]	730982 [629976,821201]
Private Aspen Cut (mcf)	881142 [817006,987490]	634625 [539781,709345]	462018 [394598,521467]
Private Aspen Mortality (mcf)	514449 [474860,539391]	383847 [350596,422406]	251597 [216407,287167]
State Aspen (mcf)	584681 [544643,622326]	480109 [424496,529304]	345388 [292033,411072]
State Aspen Cut (mcf)	279957 [238575,320711]	238139 [197383,277869]	191733 [137992,249513]
State Aspen Mortality (mcf)	181447 [167289,197945]	159021 [135819,180093]	121012 [95948,145561]
Upper Pen. Aspen (mcf)	903767 [853667,970351]	658768 [601038,729984]	455628 [381321,558641]
Upper Pen. Aspen Cut (mcf)	536326 [456547,598388]	345420 [305438,396190]	249189 [206607,304835]
Upper Pen. Aspen Mortality (mcf)	372499 [347984,401995]	270044 [241111,302079]	184354 [156906,216507]

Table 15: Averages for projections of Michigan's Federal aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	171838 [10116]	148175 [13481]	107931 [16162]
Aspen Sawtimber (mbf)	745651 [43821]	615719 [63446]	496981 [66540]
Aspen Pulpwood Cut (mcf)	65058 [10353]	54664 [11090]	49626 [13003]
Aspen Sawtimber Cut (mbf)	321557 [55273]	252470 [48260]	207099 [42339]
Aspen Pulpwood Mortality (mcf)	64442 [4046]	58852 [7259]	47942 [7852]
Aspen Sawtimber Mortality (mbf)	297540 [31194]	217960 [26269]	165480 [26679]

Table 16: Averages for projections of Michigan's Private aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	731754 [18068]	476211 [20150]	291689 [21700]
Aspen Sawtimber (mbf)	5005983 [126648]	3832065 [202107]	2705435 [194726]
Aspen Pulpwood Cut (mcf)	414916 [20920]	277971 [22861]	189116 [15362]
Aspen Sawtimber Cut (mbf)	2874294 [130254]	2195269 [145076]	1678578 [147039]
Aspen Pulpwood Mortality (mcf)	274082 [9435]	195788 [8693]	124083 [9215]
Aspen Sawtimber Mortality (mbf)	1488205 [59610]	1162336 [60069]	787810 [64979]

Table 17: Averages for projections of Michigan's State/Local aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	321621 [11052]	273435 [15717]	188686 [14728]
Aspen Sawtimber (mbf)	1624714 [78045]	1276173 [94396]	968244 [89857]
Aspen Pulpwood Cut (mcf)	142790 [10512]	130010 [14238]	108575 [15090]
Aspen Sawtimber Cut (mbf)	847131 [76623]	666874 [71288]	513228 [76590]
Aspen Pulpwood Mortality (mcf)	102673 [4735]	96923 [6686]	75945 [7493]
Aspen Sawtimber Mortality (mbf)	488666 [25580]	384712 [33296]	279290 [27694]

Table 18: Averages for projections of Michigan's Upper Peninsula aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	440291 [12985]	327490 [15680]	221521 [20250]
Aspen Sawtimber (mbf)	2868791 [84057]	2049576 [87151]	1449515 [96340]
Aspen Pulpwood Cut (mcf)	254848 [14044]	159773 [11726]	121177 [16502]
Aspen Sawtimber Cut (mbf)	1742375 [96038]	1147354 [79115]	791587 [67187]
Aspen Pulpwood Mortality (mcf)	194132 [6457]	146087 [8335]	104239 [9946]
Aspen Sawtimber Mortality (mbf)	1108094 [49769]	768731 [40515]	496836 [38427]

Table 19: Averages for projections of Michigan's Lower Peninsula aspen resource by timber class, 1993-2023 [std].

OUTPUT	Period 1 1993-2003	Period 2 2003-2013	Period 3 2013-2023
Aspen Pulpwood (mcf)	784922 [20125]	570330 [24956]	366785 [21648]
Aspen Sawtimber (mbf)	4507558 [132819]	3674381 [187001]	2721144 [190599]
Aspen Pulpwood Cut (mcf)	367917 [21188]	302873 [24288]	226140 [24105]
Aspen Sawtimber Cut (mbf)	2300608 [139472]	1967260 [136682]	1607319 [163539]
Aspen Pulpwood Mortality (mcf)	247066 [9329]	205475 [9847]	143731 [11262]
Aspen Sawtimber Mortality (mbf)	1166317 [57607]	996277 [61780]	735745 [64926]

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