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ASPEN IN THE LAKE STATES:
A RESEARCH REVIEW

TECHNICAL BULLETIN NO. 955

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PRESIDENT'S NOTE

Continuous improvement in sustainable forest management is vital to the long-term success of timber production and forest-based manufacturing in a global economy. Research and development are important drivers of continuous improvement. Unfortunately, progress in some key R&D areas has been impeded by industry restructuring and shifting priorities of agencies and universities.

This technical bulletin is the first in a series designed to encourage collaborative research on sustainable forestry systems in timber producing regions of North America. The focus of this report is aspen, a critical component of wood supplies and forest ecosystems in the Lake States, i.e., Michigan, Minnesota, and Wisconsin.

Aspen is the dominant pulpwood species in the Lake States, accounting for 41% of the 9.8 million cords harvested in 2004. Aspen forest types occupy more than 12 million acres in the region and provide high-quality habitat for ruffed grouse and many other species of wildlife.

Aspen timberland area has been decreasing for several decades in Michigan, Minnesota, and Wisconsin. Harvest rates on public forests declined sharply in the 1990s and there has been increasing emphasis on longer rotations and uneven-age management systems. The fraction of aspen timberland in older age classes is large and increasing. There has been no comprehensive analysis of the economic and ecological consequences of these trends.

There are several promising options for improving the productivity of aspen timberlands in the Lake States. For example, hybrids of quaking aspen (*Populous tremuloides*) and European aspen (*P. tremula*) can grow at rates in excess of two cords per acre per year (i.e., more than four times faster than native aspen).

This report was prepared by a team of researchers at the University of Minnesota led by Professor Alan R. Ek, Head of the Department of Forest Resources. The lead author of the report was Grant M. Domke, Research Fellow, with important contributions from Michael A. Kilgore, Associate Professor of Natural Resource Economics and Policy, and Andrew J. David, Associate Professor and Director of the Aspen/Larch Genetics Cooperative and the Minnesota Tree Improvement Cooperative. Dr. Eric Vance served as project manager for NCASI.

Ronald A. Yeske

September 2008

MOT DU PRÉSIDENT

Dans un contexte de globalisation de l'économie, l'amélioration continue de l'aménagement durable des forêts constitue un élément essentiel au succès à long terme de l'industrie de production du bois et de la transformation des produits forestiers. La recherche et le développement (R et D) sont des moteurs importants en matière d'amélioration continue. Malheureusement, les progrès effectués dans certains secteurs clés de la R et D se sont vus ralentis par les restructurations de l'industrie et les changements de priorités des agences gouvernementales et des universités.

Ce bulletin technique est le premier d'une série destinée à encourager la recherche coopérative sur les systèmes d'aménagement durable des forêts dans les régions exploitant la ressource forestière en Amérique du Nord. Ce rapport porte sur le peuplier puisqu'il est une composante cruciale des ressources forestières et des écosystèmes forestiers dans la région des états des Grands Lacs (Michigan, Minnesota et Wisconsin).

Le peuplier est l'essence dominante utilisée pour la préparation de la pâte dans les états des Grands Lacs, puisqu'il représente 41% des 9,8 millions de cordes de bois récoltées en 2004. Les forêts de types peupliers occupent plus de 12 millions d'acres dans cette région et elles fournissent des habitats de grande qualité à la gélinotte huppée et à plusieurs autres espèces fauniques.

Les superficies forestières de peupliers ont diminué dans les dernières décennies dans les états du Michigan, du Minnesota et du Wisconsin. Les taux de récolte dans les forêts publiques ont fléchi brusquement dans les années 1990 et une emphase importante a été apportée aux systèmes d'aménagement caractérisés par des taux de rotations plus longs et par une gestion d'âge des peuplements. La portion de la superficie forestière de peupliers se situant dans les classes d'âge plus avancé est importante et en croissance. Il n'y a toutefois pas eu d'analyse détaillée des conséquences économiques et écologiques associées à ces tendances.

Il existe un certain nombre d'options prometteuses pour améliorer la productivité des superficies forestières de peupliers dans la région des états des Grands Lacs. Par exemple, les variétés hybrides de peuplier faux-tremble (*Populous tremuloides*) et du peuplier européen (*P. tremula*) peuvent atteindre des taux de croissance en excès de deux cordes par acre par année (c'est à dire une croissance plus de quatre fois plus rapide que celle du peuplier indigène).

Une équipe de chercheurs de l'université du Minnesota, dirigée par le professeur Alan R. Ek, chef du département des Ressources forestières, a préparé ce rapport ; Grant M. Domke, professeur agrégé en est l'auteur principal. Michael A. Kilgore, professeur associé du *Natural Resource Economics and Policy* ainsi que Andrew J. David, professeur associé et directeur de *Aspen/Larch Genetics Cooperative* et *Minnesota Tree Improvement Cooperative* ont aussi contribué de manière significative à ce rapport. Dr Eric Vance a agi comme gestionnaire de projet pour NCASI.

Ronald A. Yeske

Septembre 2008

ASPEN IN THE LAKE STATES: A RESEARCH REVIEW

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ABSTRACT

Trembling aspen is a critical component of forests in the Lake States, with important economic and environmental contributions to the region. There is a modest ongoing investment in aspen research, but the research is fragmented and not always closely linked to industry information needs. Closer communication and collaboration between the forest research scientists and industrial forest managers is needed to ensure that limited research funding is allocated to priority topics and that research outputs are relevant to industry managers and can be used to develop strategies to best utilize and sustain this resource. This is particularly important given the changing nature of the forest products industry in the region and for larger-scale issues related to fiber supply, global competitiveness, and the role of forests in carbon sequestration and bioenergy production. This research assessment summarizes the status and trends of aspen in the Lake States, including its economic and environmental contributions, and characterizes current research on management, productivity, and environmental considerations for aspen. It also suggests strategies to help meet industry needs for information and technology transfer and identifies research gaps and areas for potential collaboration.

KEYWORDS

aspen, ecology, economics, forest management, Lake States, *Populus*, resource trends, silviculture

LE PEUPLIER DES ETATS DE LA REGION DES GRANDS LACS : REVUE DE L'AVANCEMENT DES RECHERCHES

BULLETIN TECHNIQUE N[O] 955
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RÉSUMÉ

Par ses contributions économique et environnementale à la région, le peuplier faux-tremble est une composante cruciale des forêts des états de la région des Grands Lacs. La région investit modestement, mais de façon continue, dans la recherche concernant le peuplier mais cette dernière demeure fragmentée et n'est pas toujours étroitement reliée aux besoins d'information de l'industrie. Une communication et une collaboration plus étroites entre les chercheurs du domaine forestier et les gestionnaires forestiers de l'industrie est nécessaire afin de s'assurer que les fonds de recherche limités soient dirigés vers les thèmes de recherche prioritaires. Il importe également que les résultats de ces recherches soient pertinents pour les gestionnaires de l'industrie afin qu'ils servent au développement des stratégies d'utilisation et de développement durable de la ressource. Ceci revêt une importance particulière étant donné la nature changeante de l'industrie des produits du bois dans la région et les grands enjeux reliés à l'approvisionnement en fibres, la compétitivité globale et le rôle des forêts dans la séquestration du carbone et la production de biocarburant. Cette revue de l'avancement des recherches fait la synthèse de l'état actuel et des tendances associés à l'exploitation des forêts de peupliers dans les états de la région des Grands Lacs (incluant leurs contributions économique et écologique) et présente les travaux de recherche en cours sur l'aménagement, la production et les questions environnementales entourant le peuplier. Ce rapport présente également des suggestions de stratégies pour répondre aux besoins de l'industrie en matière d'information et de transfert de technologies de même qu'il identifie les secteurs pour lesquels la recherche est nécessaire ainsi que ceux pour lesquels la collaboration entre les partenaires est envisageable.

MOTS CLÉS

Peuplier, écologie, aspects économiques, aménagement forestier, Grands Lacs, *Populus*, tendances des ressources, tremble, sylviculture

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1.0 INTRODUCTION

Quaking and bigtooth aspen (*Populus trembuloides* Michx. and *P. grandidentata* Michx.) and balsam poplar (*P. balsamifera* L.) are classic examples of early successional pioneer tree species (Perala 1990). They are disturbance-dependent, fast growing, short lived, and require high light environments for establishment and rapid growth (Brinkman and Roe 1975; Perala 1990; Alban et al. 1991; Shepperd 2001). Despite sharing many of the same life history traits and coexisting throughout the Great Lakes region, their overall geographic distributions differ (Little 1971; Burns and Honkala 1990). Quaking aspen is the most widely distributed tree species in North America with a transcontinental range (Little 1971; Burns and Honkala 1990) extending from the tree line in northwestern Alaska south to the mountains of Mexico. Balsam poplar also has a transcontinental range, but is restricted to Canada and Alaska and the northernmost parts of the eastern U.S. (Burns and Honkala 1990). Bigtooth aspen has the smallest native range of the three species, and is found throughout the Northeastern and North Central U.S. and adjacent Canada (Burns and Honkala 1990).

The aspens and balsam poplar have important economic value and provide many ecosystem services across their respective ranges. They provide erosion control, groundwater recharge, habitat and forage for wildlife, insects, and pathogens, and aesthetic value (Alban et al. 1991; Burns and Honkala 1990; Potter-Witter and Ramm 1992; David et al. 2001). Their economic importance has evolved over the last one hundred years, particularly in the North Central region (Minnesota, Wisconsin, and Michigan) of the United States where turn-of-the-century logging and fires created ideal conditions for disturbance-dependent species (Graham, Harrison, and Westell 1963; Cleland, Leefers, and Dickman 2003). The aspens and balsam poplar (hereafter referred to collectively as aspen) have gone from weed tree to one of the most highly sought after commercial species in the Lake States (Einspahr and Wykoff 1990; Alban et al. 1991; Balatinecz and Kretschmann 2001; David et al. 2001; Piva 2006). Today, aspen is a premier pulp and paper species and is used heavily in engineered wood products in the region (Burns and Honkala 1990; Piva 2006). The demand for these wood products, along with fire suppression, natural succession, early dieback, land conversion, forest management practices, and pests and pathogens, has led to declines in these species across North America and particularly the Lake States (Cleland, Leefers, and Dickman 2003; Frey et al. 2004). These declines, along with the importance of maintaining ecological function in managed forests, have led to changes in how aspen is managed across the region. Traditional aspen silviculture has been augmented by silvicultural systems and associated practices which increase biodiversity, capture early mortality, and improve tree growth and form (David et al. 2001; Cleland, Leefers, and Dickman 2003; Ostry et al. 2004).

Over the last four decades, several reviews have documented and described the biology, ecology, economics, and silviculture of aspen throughout the United States and Canada (Perala 1977, 1990; DeByle and Winokur 1985; Peterson and Peterson 1992; David et al. 2001; Cleland, Leefers, and Dickman 2003; Frey et al. 2004). However, in the last decade, new markets and technologies have emerged, mill expansions have increased fiber demand, total aspen acreage has continued to decline, and ecosystem management concepts have evolved to shape how these forests are managed, particularly on public lands.

This report describes the current status and knowledge of aspen in the Lake States and reviews the literature, highlighting recent findings and identifying critical gaps in our understanding of the species across the region. It also suggests strategies for linking research and emerging technologies to management.

2.0 RESOURCE STATUS AND TRENDS

2.1 Forest Type History

Prior to European settlement, the aspens played an important, though minor, role in the forests of the Great Lakes region (Finley 1976; Comer et al. 1995; Almendinger 1997). Land survey information from the General Land Office in each of the three Lake States has been used to reconstruct pre-settlement forestland conditions (Finley 1976; Comer et al. 1995; Almendinger 1997). In northern Minnesota, an estimated 30% of the forest was composed of mixed conifer-aspen, aspen-birch, and aspen-oak. In northern Michigan and Wisconsin, aspen was a much smaller component of pre-settlement forests, with approximately 300,000 acres in each state (Comer et al. 1995; Finley 1976).

Beginning around 1850 in central Michigan, settlers began clearing forestland to make way for farms and homesteads. By the 1930s, most of the virgin timber in the Lake States had been removed. During the 80-year cutover period, wildfires burned throughout the region, creating ecologically ideal conditions for aspen by reducing tree competition, creating an optimal seedbed, and stimulating vegetative reproduction (Graham, Harrison, and Westell 1963; Haines and Sando 1969; Cleland, Leefers, and Dickman 2003). The result was a massive forest type conversion across the Lake States (Cleland, Leefers, and Dickman 2003; Friedman and Reich 2005).

Today, aspen/birch and the northern hardwoods (maple/beech/birch) are the two most dominant forest types in the North Central states, each occupying more than 12.6 million acres of timberland (Table 2.1). Note these figures and subsequent figures are based on USDA Forest Service Forest Inventory and Analysis (FIA) inventories corresponding to the three most recent inventories.[1] Minnesota has the largest proportion of that total aspen/birch timberland with more than 6 million acres (Table 2.1). Michigan and Wisconsin each have more than 3 million acres of aspen/birch timberland despite being dominated by the maple/beech/birch forest type (Table 2.1).

Following the extensive cutover at the turn of the last century, aspen was considered a useless weed (Holcomb and Jones 1938; Spencer and Thorne 1972; Graham, Harrison, and Westell 1963; Balatinecz and Kretschmann 2001; Stone 2001). As the supply of more favorable timber species diminished and aspen reached merchantable size, several industries began using it (Holcomb and Jones 1938).

It was quickly realized that the wood of this early successional, disturbance-dependent species could be pulped and was well suited for a variety of other forest products (Holcomb and Jones 1938; Lamb 1967, Einspahr and Wyckoff 1990, Balatinecz and Kretschmann 2001). The level of aspen pulpwood production across the region has increased substantially over the last 40 years and the aspens are now the dominant species harvested for pulpwood in the Lakes States, accounting for 41% of the 9.8 million cords harvested in 2004 (Piva 2006).

Since the recorded peak of the aspen/birch acreage in the 1930s, this forest type has declined in each of the three Lake States (Cleland, Leefers, and Dickman 2003). In Michigan and Wisconsin, acreage declined more than 36% from 1935 to 2004. The aspen/birch acreage declined by 6% over the same 69-year period in Minnesota (Cleland, Leefers, and Dickman 2003). These trends continue across the Lake States, although the declines have slowed over the last three decades (Table 2.1). Today,

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[1] The inventory reporting dates are:

Michigan 2006, 1993, and 1980
Minnesota 2006, 1990, and 1977
Wisconsin 2006, 1996, and 1983

aspen/birch remains one of the two most dominant forest types, representing 25% of the 50 million acres of timberland in the region (Table 2.1). Only the maple/beech/birch forest type compares across the Lake States, representing approximately the same percentage of the region's timberland (Table 2.1).

Table 2.1 Area of Timberland in the Lake States by Forest Type Group and Inventory Period

Forest Type Group	Michigan			Minnesota			Wisconsin		
	1980	1993	2006	1977	1990	2006	1986	1996	2006
White/red/jack pine	1,647,730	1,862,200	1,922,952	759,100	891,100	808,420	1,250,300	1,169,409	1,502,283
Spruce/fir	2,583,384	2,673,400	2,438,925	2,957,000	3,555,500	3,371,179	1,347,200	1,341,458	1,335,898
Oak/hickory	1,761,999	1,981,800	2,738,329	928,700	1,166,200	1,142,949	2,858,700	2,885,157	3,407,198
Elm/ash/cottonwood	1,420,801	1,626,900	1,426,394	1,006,800	1,289,900	1,295,271	1,240,600	1,528,139	1,337,184
Maple/beech/birch	6,243,239	7,161,300	6,466,349	1,202,400	1,393,100	1,735,777	3,996,900	5,299,822	4,461,895
Aspen/birch	3,643,936	3,156,900	3,117,508	6,697,000	6,317,200	6,246,467	3,903,100	3,407,714	3,236,521
Other	105,077	114,900	785,595	3,800	6,000	273,644	2,200	12,624	610,141
Nonstock	86,755	38,500	126,782	58,300	104,200	239,019	160,400	56,561	151,502
Total	17,492,921	18,615,900	19,022,834	13,613,100	14,723,200	15,112,726	14,759,400	15,700,884	16,042,622

Ownership patterns are important to understanding management options. In the Lake States, 60% of the 50 million acres of timberland are privately owned, with 51% of the aspen timberland in private ownership (Figure 2.1). Since most of that is in non-industrial private forest (NIPF) ownership, such landowners are clearly crucial to aspen availability in the future. Public ownership is also important across the region and has evolved somewhat differently in each of the Lake States (Cleland, Leefers, and Dickman 2003). Minnesota's public lands are, in descending order of magnitude, state, local (county and municipal), and federal for both aspen and total timberlands (Figure 2.1). Wisconsin's public timberlands are primarily local, followed by federal and state lands (Figure 2.1). In Michigan, state and federal lands are the principal public ownerships, with a few local forests (Figure 2.1). Additionally, most of these public timberlands are in the northern portions of the respective states.

2.2 Usage, Supply and Demand

Aspen is used for a wide variety of products (Lamb 1967; Einspahr and Wyckoff 1990; Balatinecz and Kretschmann 2001). Its light weight and color, as well as the fiber length, make it a desirable paper species because it can be pulped by most of the commercially important processes (Lamb 1967; Einspahr and Wyckoff 1990; Balatinecz and Kretschmann 2001). It is also well suited for use in building products such as hardboard, insulation board, particle board, and structural flake board (waferboard and oriented strand board) (Einspahr and Wyckoff 1990; Balatinecz and Kretschmann 2001). In addition, aspen wood is being used in paneling, matches, chopsticks, toys, core stock, containers, pallets, framing lumber, and interior trim (Lamb 1967; Einspahr and Wyckoff 1990; Balatinecz and Kretschmann 2001).

Aspen has long been used for fuelwood locally. That market has potential for considerable expansion with reemerging interest in biomass energy and new technologies for harvesting, such as portable chipping and grinding equipment that can utilize small sized trees, tops, and slash (Balatinecz and Kretschmann 2001). In addition, new technologies for converting wood to liquid fuels may lead to new value-added opportunities. Many forest products manufacturing facilities are already highly self-sufficient in terms of energy and are exploring options for increasing biomass energy production for internal use and/or sales to others. Increasing demand for biomass energy could affect competition for aspen and other wood resources.

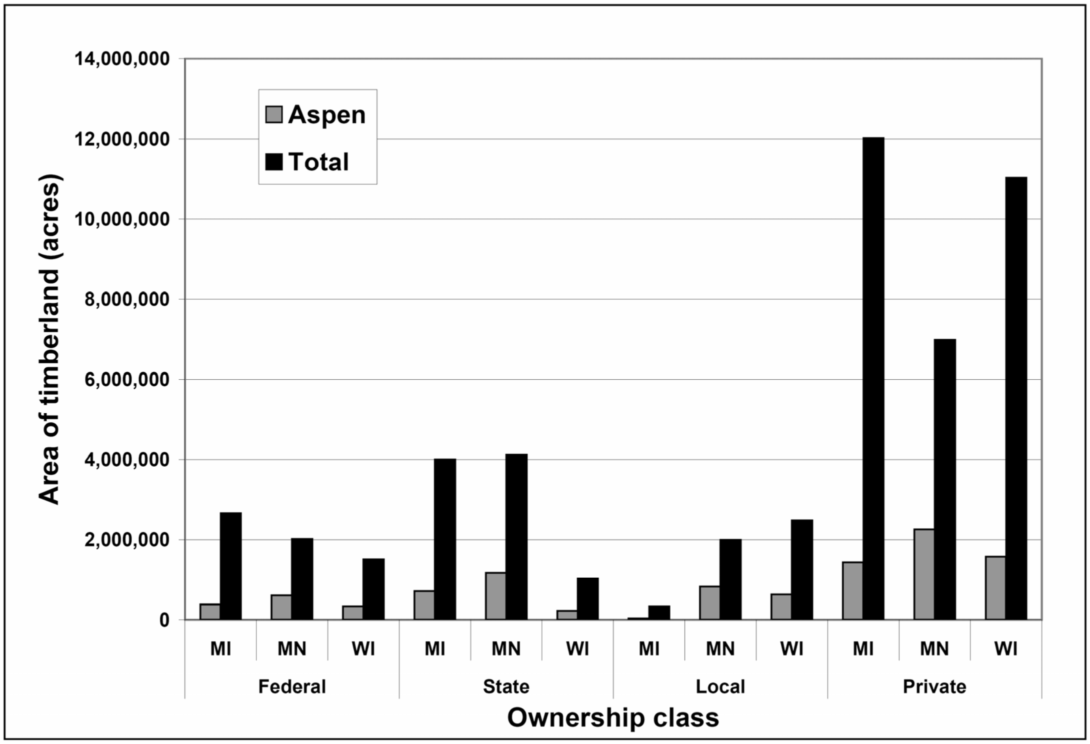

Figure 2.1 Aspen and Total Timberland Area by State and Ownership for the 2006 Inventory Period

Trends in aspen timberland acreage over the last three decades are summarized by state in Figure 2.2. Declines are evident in all three states. These changes are likely the result of natural succession and forestry practices that favor other species, e.g., favoring longer lived hardwoods by thinnings that remove aspen and leave hardwoods; or clearcutting and leaving hardwood residuals that shade and otherwise inhibit the regeneration of aspen. A role for natural succession is suggested by the fact that substantial areas of aspen timberland are in older age classes (Table 2.2). However, any interpretation is partly speculation as there has been no comprehensive analysis of factors that are leading to the decline of aspen acreage.

Aspen net volume per acre on timberland by age class is shown in Table 2.3. For Minnesota and Wisconsin, the data are sufficient to suggest that aspen volumes per acre are similar across inventories and thus time, but there may be differences for higher site classes or levels of species composition. The net volume per acre steadily increases in each state and inventory period until age 70 and thereafter fluctuates (Table 2.3). This suggests that extended rotations are unlikely to improve yields on some sites and that mortality and declining tree quality impact net yield accumulation for long rotation ages. However, the FIA aspen covertype definition is very broad (from 100 to as low as 30% aspen); thus, there is reason to investigate potential effects further, perhaps by species composition, site quality, and stand treatment history. Yet stand treatment history impacts should be modest, as there has been minimal thinning or other intermediate treatments applied to aspen to date.

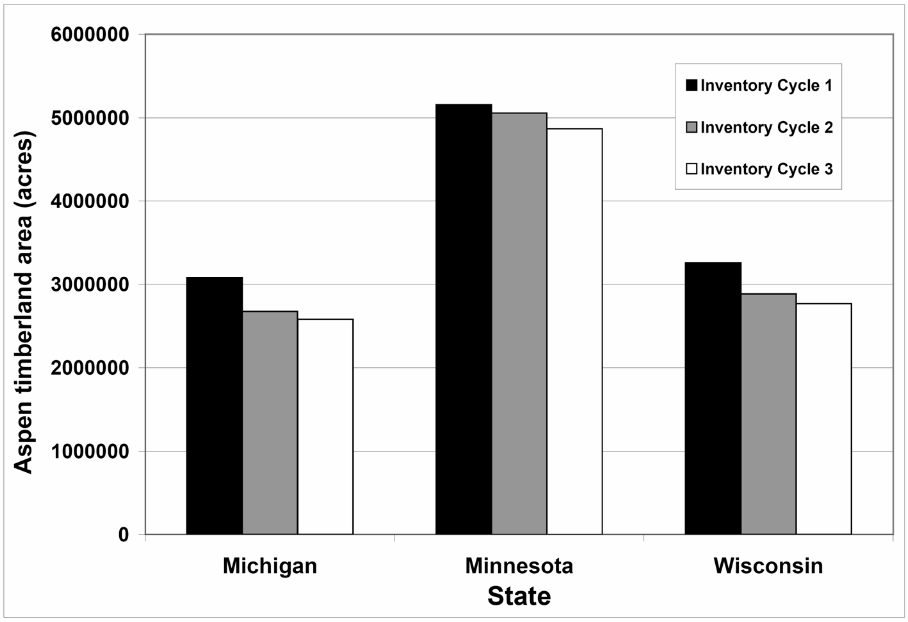

Figure 2.2 Aspen Timberland by State and Inventory Period [Inventory 1 = 1980 (MI), 1977 (MN), and 1983 (WI), Inventory 2 = 1993 (MI), 1990 (MN), and 1996 (WI), and inventory 3 = 2006]

Table 2.2 Area of Aspen Timberland by State, Ownership, and Age Class for the 2006 Inventory Period

Age class	Michigan				Minnesota				Wisconsin			
	Federal	State	Local	Private	Federal	State	Local	Private	Federal	State	Local	Private
0-10	17,723	104,745	2,042	138,689	85,392	228,850	156,439	373,992	31,389	25,586	125,150	232,240
11-20	46,375	92,382	3,909	133,453	80,380	169,524	133,364	268,607	42,309	37,870	110,410	193,720
21-30	46,113	112,876	668	184,292	84,520	141,209	87,730	295,639	47,397	40,103	130,431	226,739
31-40	59,002	146,508	8,368	221,375	70,256	118,844	77,928	268,933	66,292	34,004	124,628	301,955
41-50	56,553	96,382	9,984	288,009	45,303	179,398	103,526	316,567	58,359	32,370	67,579	229,744
51-60	73,070	76,954	2,122	188,672	78,475	143,258	92,181	324,429	37,775	26,717	33,506	194,726
61-70	51,558	31,569	3,551	160,377	102,092	119,807	102,030	222,140	20,885	17,701	32,310	110,138
71-80	23,162	28,134	2,975	79,693	32,347	52,635	56,883	138,321	20,783	2,542	8,939	68,999
81-90	4,169	19,233	2,291	34,387	15,419	11,317	9,889	32,129	4,132	6,850	0	20,538
91-100	0	2,604	0	8,252	12,211	5,954	3,146	4,468	1,397	0	0	682
100+	2,604	3,825	0	4,118	2,896	8,481	865	8,388	0	0	0	1,383

The decline in aspen covertype acreage is a concern. Table 2.4 indicates changes in the aspen forest type acreage by site productivity class over the last three inventory periods. The loss of aspen acreage is occurring on the moderately productive sites. This may be due to natural succession with aging and/or conversion following harvesting. Conversely, aspen appears to be holding its own on poor sites. This may also be due to natural succession, where previously abandoned sites (e.g., fields or mines) are now dominated by aspen. It may also be due to active aspen management on public lands which have historically been considered the low productivity areas that settlers did not want (Shands and Healy 1977; Cleland, Leefers, and Dickman 2003).

Table 2.3 Aspen Timberland Volume (cuft/ac) by Age Class, State, and Inventory Year

Age class	Michigan			Minnesota			Wisconsin		
	1980	1993	2006	1977	1990	2006	1983	1996	2006
0-10	334	270	132.8	252	248	167.6	282	210	100.9
11-20	394	397	184	385	344	238	386	281	286.1
21-30	690	781	533.9	630	710	543.9	672	570	521.2
31-40	1181	1273	955.3	1099	1169	874.4	1154	1040	995.2
41-50	1361	1857	1343	1346	1538	1320	1392	1491	1324
51-60	1537	2047	1622	1463	1740	1421	1574	1654	1692
61-70	1733	2125	2030	1523	1855	1639	1502	1783	1912
71-80	1864	2369	1834	1803	1777	1778	1431	1708	2243
81-90	1658	2305	2513	1945	1798	1803	1595	2112	2106
91-100	1555	2124	2493	2217	1975	1888	1822	2387	2241
100+	2060	2229	2731	682	2046	1530	0	2115	1602

While the interest here is focused on the aspen covertype, it is also important from a utilization standpoint to identify the other covertypes that include substantial aspen volume. Figure 2.3 indicates the percent aspen timberland volume by covertype and suggests both the other species that occur with aspen and the amounts of aspen within other covertypes. Clearly all of the other major forest types are important sources of aspen.

Table 2.4 Area of Aspen Timberland by State, Site Productivity Class (cuft/ac/year), and Inventory Year

Site Productivity Class	Michigan			Minnesota			Wisconsin		
	1980	1993	2006	1977	1990	2006	1983	1996	2006
20-49	435,428	273,300	467,399	766,800	553,700	956,754	347,600	204,552	315,989
50-84	1,250,122	1,177,100	1,193,523	2,707,900	2,609,900	2,585,411	1,548,500	1,273,008	1,123,585
85-119	1,242,718	1,053,600	802,314	1,573,400	1,831,000	1,240,956	1,294,100	1,219,132	1,156,682
120-164	134,330	149,200	88,259	98,900	59,400	69,049	71,300	156,237	148,891
165-224	18,304	22,500	22,144	11,200	4,000	17,144	0	32,279	21,387
225+	0	0	7,229	0	0	0	0	0	1,747
Total	3,080,902	2,675,700	2,580,868	5,158,200	5,058,000	4,869,314	3,261,500	2,885,208	2,768,281

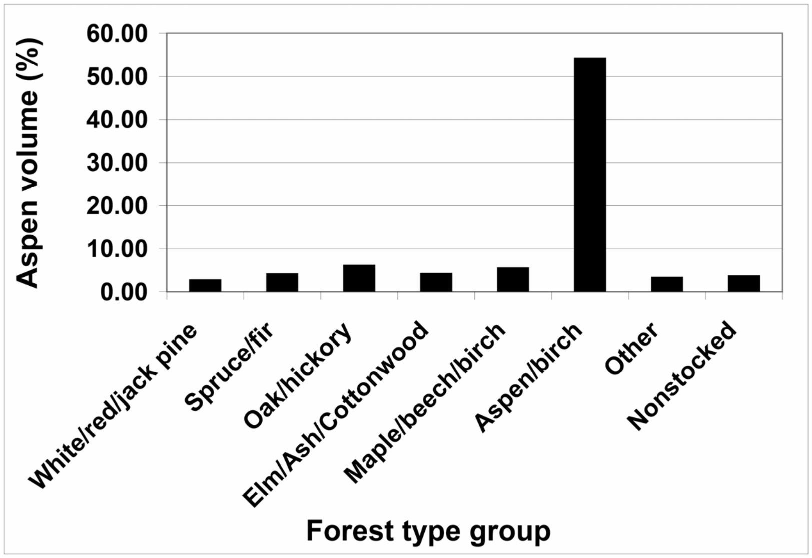

Figure 2.3 Percent of Aspen Timber Volume within Forest Type Groups in the Lake States for the 2006 Inventory Period

2.3 Growth and Yield

Inspection of the empirical yield compilation shown in Figure 2.4 shows conventional yields (net volume of trees > 4.95 inches dbh to a 4 inch top diameter outside bark (dob)) reaching almost 1500 cubic feet per acre at age 50 and slightly higher at age 60. This suggests mean annual increment for most stands peaks at approximately 50 years. However, this is an FIA average yield and stands on better than average sites may perform better at either younger or older rotation ages. Walters and Ek (1993) modeled FIA data from Minnesota. Their results suggest that yields can be much higher on better than average sites (Figure 2.5). Ek and Brodie (1975) showed that stem- and branch-wood volume can be much higher in well stocked stands on good sites (Figure 2.6). Additionally, plantation data suggests potential yields under intensive culture on the order of those achieved for short rotation hybrid poplars (Andrew J. David, pers. comm.). Given that FIA data for aspen include hundreds of plots measured on several occasions, it would be instructive to explore that data for possible trends in aspen stand yields with respect to site conditions, location, disturbance history, and other stand characteristics. New ecological classification systems may help with that; however, few such systems have been rigorously examined with respect to their linkages to health and productivity.

Improvements in naturally regenerated aspen stand yields with early (precommercial) and/or commercial thinning are also of interest. Studies by Graham, Harrison, and Westell (1963), Sorenson (1968), and Perala (1978) suggest that aspen, like many species, will respond well to early thinning at less than 10 to 20 years of age. Those studies also consider the concept of thinning early, light, and often to improve overall rotation yields and product mix. However, those studies have not been fully replicated, if at all. In fact, early and commercial thinning have been demonstrated as physically feasible from an equipment and operational aspect, but growth response data from remeasurements of those studies remain in short supply.

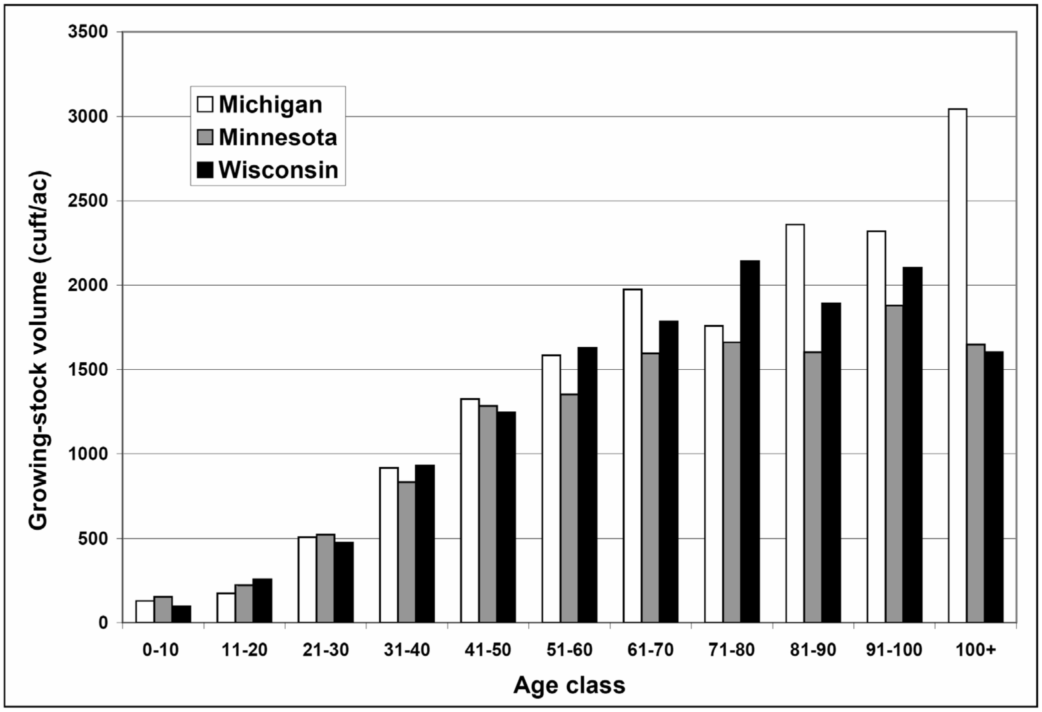

Figure 2.4 Aspen Growing-Stock Volume (cuft/acre) by Age Class and State for the 2006 Inventory Period

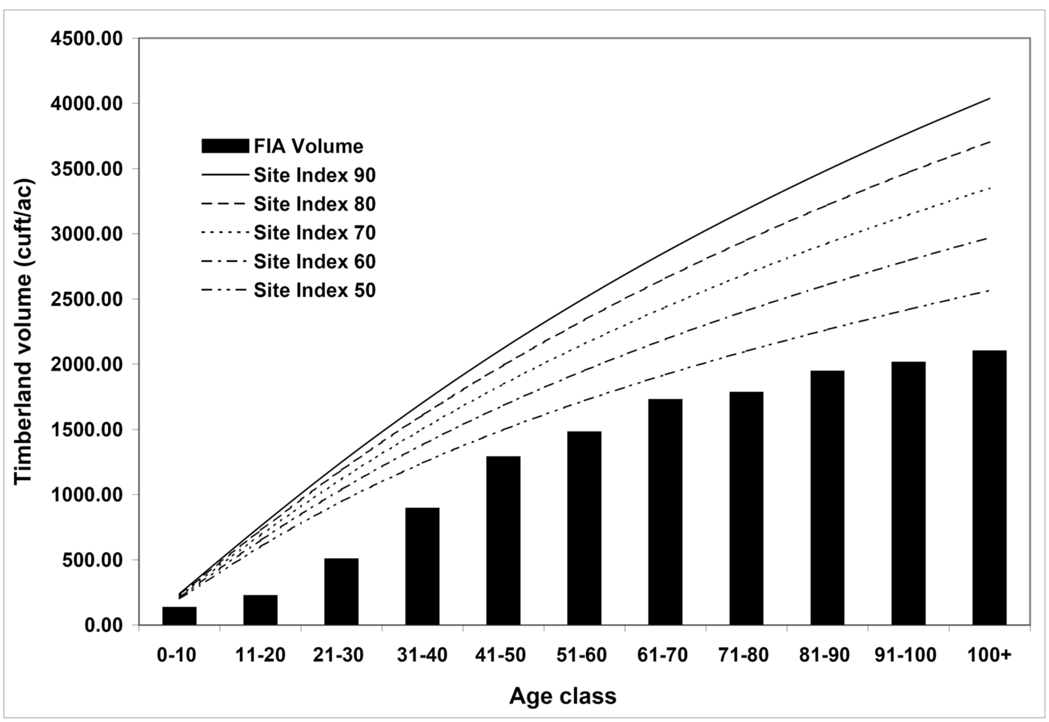

Figure 2.5 Comparison of Aspen Timberland Volume with Volume Equations Developed by Walters and Ek (1993) for Specific Site Indices for the 2006 Inventory Period in the Lake States

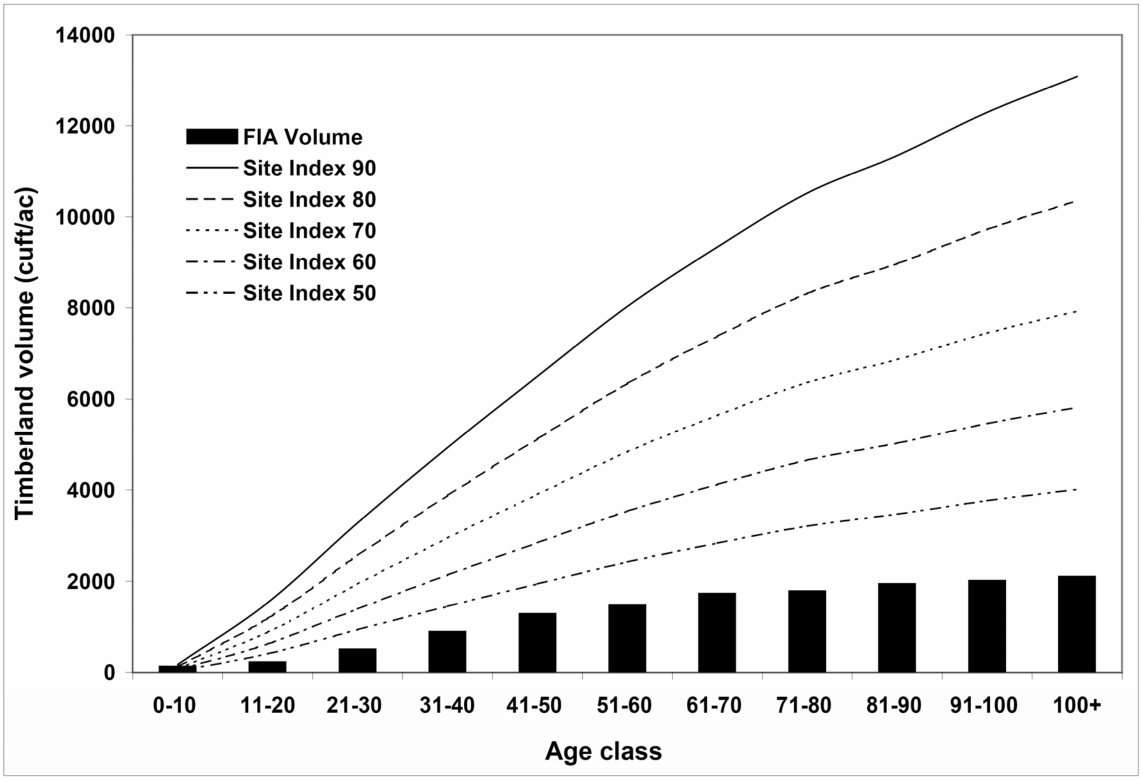

Figure 2.6 Comparison of Aspen Timberland Volume with a Stem- and Branch-Wood Volume Equation Developed by Ek and Brodie (1975) for Specific Site Indices for the 2006 Inventory Period in the Lake States

3.0 BIOLOGY AND ECOLOGY

3.1 Regeneration

Aspen is a prolific seed producer and can begin flowering as early as 10 years of age (Maini 1968; Perala 1990). Once sexually mature, aspen produces good seed crops approximately every 5 years (Perala and Russell 1983; Perala 1990). The light, wind-dispersed seed has a germinative capacity of more than 95% under favorable conditions and typically lasts between 2 to 4 weeks (Maini 1968; Schopmeyer 1974; Perala 1990). Despite high seed viability and regularly abundant seed crops, aspen rarely regenerates sexually (Perala 1990; Peterson and Peterson 1992). This is largely due to a lack of soil moisture during seed dispersal, unfavorable soil temperature and soil chemistry, and the presence of fungal pathogens during the short germination period (Perala 1990; Peterson and Peterson 1992).

Most aspen regeneration comes from adventitious shoots or suckers that arise along its lateral root system (Farmer Jr. 1962; Steneker 1974; Perala 1977, 1990; Heeney, Kemperman, and Brown 1980; Frey et al. 2003) following large-scale stand replacing disturbances. Aspen is also capable of producing sprouts from its root collar and stump; reproduction from these structures, however, is not common (DeByle and Winokur 1985). Where aspen is already present in a stand, suckering is the primary mode of regeneration with success dependent on growth hormones (Farmer Jr. 1962; Steneker 1974), root carbohydrate stores (Schier and Zasada 1973), root size (Kemperman 1977), clonal variation (Maini 1967), soil temperature, root depth, soil moisture (Maini and Horton 1964), soil compaction, previous stand age, herbivory, and plant competition (David et al. 2001). Following natural stand-replacing disturbances and clearcutting, sucker densities of 20,000 to 30,000 stems per acre are not uncommon (DeByle and Winokur 1985; Perala 1990; Peterson and Peterson 1992). The number of aspen suckers quickly declines as clumps self-thin and, by the tenth year after disturbance, most clumps have been reduced to a single ramet (DeByle and Winokur 1985; Peterson and Peterson 1992). The result of this rapid self-thinning is clones of a few to several hundred stems extending from one to five acres (Peterson and Peterson 1992). Inter- and intraclonal competition and mortality continue throughout the life of the stand (Peterson and Peterson 1992).

3.2 Genetics and Improvement

In general, population genetics theory suggests that genetic variation increases with species environmental variation, population size, and range. It is not surprising then that both aspens and balsam poplar are genetically diverse tree species (Barnes 1966; Burns and Honkala 1990; Mitton and Grant 1996; Ostry et al. 1989; David et al. 2001; Madritch, Donaldson, and Lindroth 2006). With separate male and female trees, wind pollination ensures large levels of genetic diversity at the population level (Burns and Honkala 1990; David et al. 2001). Recent work by Madritch and Hunter (2002) and Madritch, Donaldson, and Lindroth (2006) suggests that loss of genetic variation within populations can influence community and ecosystem level processes such as litter decomposition and nutrient cycling. Within seedling-derived aspen populations, the greatest loss of genotypes and genetic variation occurs during the stand initiation phase when density-dependent mortality is at its peak (David et al. 2001). New genes enter populations from other populations via seed migration during seedling establishment and from pollen flow during flowering (David et al. 2001).

In clonally derived sucker stands, aspen genotypes are typically conserved on the site following disturbance so long as sucker production and growth are sustained from one generation to the next and the overall area of sucker production is maintained (David et al. 2001). However, the actual loss in genotypes, if any, associated with a disturbance event is unknown and is probably more closely related to intraspecific competition, an individual genotype's propensity to sucker (Farmer Jr. 1962; Maini 1967; Steneker 1972), and soil conditions (Bates, Sucoff, and Blinn 1998) than the actual disturbance event itself.

Based on the life history traits, natural levels of genetic variation, and geographic range of quaking aspen, the potential for improving any trait is similar to that of most conifers. For volume, that translates into an increase of approximately 15-22 % per generation, but there are no native aspen tree improvement programs for three reasons. First, when most tree improvement programs were initiated (1950s-1980s), aspen had very little economic value. It was considered an undesirable tree and its suckers an impediment to the growth of conifer seedlings which were favored. Second, in areas where aspen was desired, its coppicing ability made regeneration of the stand after harvest silviculturally simple and economically feasible. Therefore, there was no reason to develop an aspen program. Finally, hybrid aspen maintains all the attributes of native aspen with the added bonus of improved growth rates. For this reason, the majority of breeding work has been devoted to aspen hybrids and not native aspen.

There are two active aspen breeding programs in North America and both are based on a cooperative model. The Aspen/Larch Genetics Cooperative (ALGC) is currently located at the University of Minnesota but has its roots in the former Institute of Paper Science and Technology in Appleton, Wisconsin. The other cooperative aspen breeding program is the Western Boreal Aspen Corporation based in Edmonton, Alberta. Of the two, the ALGC is the only breeding program focusing solely on hybrid aspen and, in particular, crosses between quaking aspen and the European aspen (*P. tremula* L.). The *P. tremuloides* x *P. tremula* cross is particularly productive, with a majority of families producing seedlings with hybrid vigor. Whereas our native aspen grow from coppice at roughly 0.25-0.50 cords/ac/year, hybrid aspen families from this breeding program are growing at 1.0-2.5 cords/ac/year, approximately 4 to 10 times the growth rate of the native material (Andrew J. David, unpublished data). At these growth rates, hybrid aspen competes favorably with hybrid poplar and has the added advantage of potential for deployment in an operational forest setting.

These growth and yield observations for hybrid aspen are based on the deployment of seedling-based families. Growth rates could be increased if clonal deployment were possible as in hybrid poplar. In clonal deployment, the very best genotypes are selected, propagated, and then planted in the field. This captures the entire genetic value of the superior genotype with virtually no tree-to-tree variation in the field. Hybrid aspen propagate readily from roots but not from hardwood cuttings like hybrid poplar. Additional gains in growth rate and yield could be attained if there were an economically feasible and reliable vegetative propagation method for hybrid aspen.

Accurate forecasting of hybrid aspen growth and yield would also benefit from volume functions for individual hybrid aspen trees. Currently, the only available volume functions are from a single Swedish study that looked at hybrids of *P. tremula* x *P. tremuloides* in Sweden (Johnsson 1953). Likewise, biomass equations for both native aspen and hybrid aspen in the Lake States would be beneficial for estimating total biomass on a site. Equations such as these are becoming increasingly necessary for accurately estimating both the total accumulated biomass and its economic value.

With the current emphasis on forest certification, there is increasing pressure to exclude the use of non-native or hybrid seedlings in artificial regeneration practices. In the case of hybrid aspen, the most discussed fear is introgression, or gene flow from the hybrid that dilutes the native gene pool. In reality, the issue is much more complex and a thorough investigation of the likelihood of introgression and its impacts is warranted. In order for there to be introgression of *P. tremula* genes into the *P. tremuloides* gene pool, several independent events must occur. First, the aspen hybrids must produce viable pollen. The pollen must then be transported to an individual *P. tremuloides,* where it produces seed. And finally, the resulting seed must land on a site where it can germinate and grow into an adult.

The first two events are not difficult to accomplish in the wild. Hybrid aspen are capable of producing viable pollen or receptive ovules, and crosses between hybrid aspen and *P. tremuloides* have been accomplished with ease in a controlled greenhouse setting (Institute of Paper Chemistry, 1988). The next step in the process of introgression is much more difficult. Once a backcrossed seed is produced, it must find an appropriate place to germinate and grow to sexual maturity. Establishing aspen literally from seed is extremely difficult and less frequent in today's environment than during the presettlement period when aspen existed primarily as a riparian species.

As a riparian species, aspen, like other *Populus* species, was found primarily along rivers and lakes that ebbed and flowed with seasonal adjustments in water levels. This riparian environment, with its constantly shifting sandbars and scoured banks, provided the moist, bare mineral soil with no competing vegetation that is required for establishing aspen from seed. After the harvest of the great pineries and the resulting slash fires from the 1880s to the 1930s, areas distant from rivers became more hospitable for establishing aspen from seed. In this way, the extensive aspen component in the Lake States region that currently exists became established. Today, with the exclusion of stand replacement fires and the control of seasonal river levels, the opportunities for establishing aspen from seed are extremely low. Thus, the opportunity for introgression between hybrid aspen and *P. tremuloides* is also extremely low.

In this discussion of the risk of planting hybrid aspen, it is imperative to include several additional facts related to hybrid aspen's genetic background and its life history traits. Hybrid aspen *per se* is not a genetically modified organism and by definition its genetic component is one-half native aspen. Therefore, there is no risk of an engineered gene escaping into the environment and each successive generation beyond the hybrid would have its *P. tremula* composition decreased by half, i.e., the first introgression event is really a backcross between a hybrid to a native aspen and results in a seedling with 25% of its genetic background derived from *P. tremula*. This first generation backcross introgressant would be composed of 75% *P. tremuloides* and 25 percent *P. tremula* genes.

P. tremuloides and *P. tremula* both belong to subsection Trepidae, section Leuce in the genus *Populus*. They are extremely similar morphologically and ecologically and, like all the members of Trepidae, they can be easily crossed (Einspahr and Winton 1977) and natural hybrids do occur where their ranges overlap (Barnes 1961; Andrejak and Barnes 1969) or where one species has been planted in proximity to another (Peto 1938; Little, Brinkman, and McComb 1957). This information leads some investigators to consider these not as individual species but rather as a single circumpolar species with different varieties or races (Peterson and Peterson 1992).

One relatively unexplored method for controlling pollen and ovule production in hybrid aspen is to create triploid or 3N hybrid aspen for artificial regeneration. As triploids, these individuals have three copies of each chromosome instead of the regular two. Although native aspen with three copies of each chromosome are known in the wild (van Buijtenen, Joranson, and Einspahr 1957; Every and Wiens 1971), during meiosis the chromosome pairing is so mismatched that virtually no viable pollen or ovules are produced (Johnsson 1940). This natural sterility could be used alone or in conjunction with engineered methods of sterility to control the opportunities for introgression in hybrid aspen or genetically modified aspen.

3.3 Soils and Site Productivity

In the Lake States, aspen grows on a variety of soils (primarily Spodosols, Alifsols, and Inceptisols) ranging from shallow and rocky to deep loamy sand and heavy clays (Perala 1990). It grows best on well drained loamy soils with high organic matter and nutrient content and where the water table is between 3 and 8 ft deep (Graham, Harrison, and Westell 1963; Perala 1977, 1990). Some of the most productive aspen stands across its range are in the northern part of the Lake States region and adjacent Canada where soils are cold, well-drained, and rich in lime (Perala 1990). Despite this, most aspen in each of the three Lake States is found on moderately productive sites (Table 2.4).

There are many studies examining the effects of forest management activities on short- and long-term site productivity and nutrient availability (Bormann et al. 1968; Stone, Swank, and Hornbeck 1979; Alban and Perala 1990; Pennock and van Kessel 1997; Morris 1997; Arikian et al. 1998; Grigal 2000; Stone 2001; Powers et al. 2005). The results of these studies vary widely with location, harvest methods, harvesting intensity and frequency, soil type, disturbance history, forest type, and climate (Bormann et al. 1968; Greacen and Sands 1980; Froehlich 1977; Stone, Swank, and Hornbeck 1979; Grier et al. 1989; Pennock and van Kessel 1997; Morris 1997; Arikian et al. 1998). The most notable effects of harvesting on forest soils and site productivity occur through the alteration of soil physical properties (Greacen and Sands 1980; Grier et al. 1989; Arikian et al. 1998; Grigal 2000). Changes in physical properties can persist for long periods, are not easily repaired, and can produce conditions outside the natural range of variability with negative effects on tree growth and site productivity (Froehlich 1977; Arikian et al. 1998; Grigal 2000). In contrast, nutrient depletion due to forest harvesting has not been well documented and requires long-term studies to see measurable effects (Grigal 2000). That said, it is generally accepted that whenever organic matter is removed from a site, there is also net loss of nutrients from that site (Grier et al. 1989). Those losses tend to be proportional to the volume removed, although total site nutrients stored in woody biomass differs for different forest types and sites (Grier et al. 1989).

In aspen-dominated ecosystems, there is a risk of nutrient loss and reduction in site productivity due to its rapid growth, reproduction strategies, and the fact that it accumulates more nutrients than its common associates (Alban 1982). In a study measuring soil compaction in 18 pure aspen and aspen-hardwood stands in northern Minnesota, Arikian et al. (1998) found that soil compaction following harvests reduced regeneration density. They also found that decreased soil aeration and increased root damage inhibited root growth and productivity, limiting the resources available for residual tree growth (Arikian et al. 1998). In a similar study in northern Minnesota, Bates, Blinn, and Alm (1993) found no significant evidence of soil compaction following clearcut but did document reduced aspen suckering in areas with increased rutting and soil scarification. Stone (2001) found that soil compaction negatively affected aspen sucker growth on clay sites across the Lake States but slightly increased sucker diameter and height growth on sandy sites. Alban and Perala (1990) kept compaction and soil displacement to a minimum to examine the impacts of biomass removal (whole-tree clearcutting and merchantable bole clearcutting) on soil nutrients and site productivity in aspen stands in the Lake States. When compared to control plots, they found that whole-tree and merchantable-bole harvesting had few short-term effects on soil organic matter and nutrient dynamics. In northern Quebec, Belleau, Brais, and Paré (2006) found that whole-tree and stem-only harvesting decreased forest floor net C mineralization to net N mineralization (Cmin/Nmin) ratios and soil potassium (K) and increased extractable phosphorous (P) one year after harvesting. During the second growing season, forest floor organic carbon (C), Kjeldahl N, base cation concentrations of calcium and magnesium (Ca and Mg), base saturation, pH, and effective cation exchange capacity increased. Two years after harvesting, no significant changes in soil minerals were observed.

While it is clear that forest management activities have a variety of impacts on forest soils and site productivity, the long-term effects of these activities are still largely unknown for aspen types. There is a need for more short- and long-term assessments of the effects of different harvesting strategies and equipment on aspen site productivity. These studies must be carried out across the dominant soil types which support aspen in the Lake States to track changes in soil physical properties, nutrient mineralization rates, and organic matter decomposition. These studies will become increasingly important as stand management for energy (which often calls for short rotations and significant biomass removals) becomes more common in the Lake States.

3.4 Forest Health

A variety of biotic and abiotic agencies affect the health and vigor of aspen in the Lake States. Increases in atmospheric CO_2 and tropospheric O_3 can alter ecosystem structure and function (Kubiske et al. 2007). In northern Wisconsin, a free air CO_2 enrichment study by Kubiske et al. (2007) showed that elevated CO_2 encourages aspen growth and gives it a competitive advantage over two common associates, white birch (*Betula papyrifera* Marsh.) and sugar maple (*Acer saccharum* Marsh.) when compared to control stands. However, under elevated O_3, aspen growth was reduced and mortality increased when compared to the two associates and the control plots (Kubiske et al. 2007). In pure aspen stands, there were large clonal differences in growth rate and mortality under elevated CO_2 and O_3 conditions, suggesting that rates of ecological succession may be altered in the future (Kubiske et al. 2007).

Other abiotic factors such as wind, drought, flooding, fire, hail, and extreme temperature fluctuations also impact aspen ecosystem health. These agencies can, in some cases, lead to direct mortality but more often cause tree damage creating opportunities for secondary pests and pathogens (Manion 1991). Wind events such as derechos and tornadoes damaged 68,923 acres of timberland in the Lake States during the most recent FIA inventory period (Figure 3.1). Floods following severe weather events damaged 5,654 acres of timberland across the region and, combined with feeding and flooding damage from beavers, caused 49,392 acres of damage (Figure 3.1).

The aspens have two primary defense systems to guard against damaging biotic agents. The first is chemical defense where aspen accumulates phenolic glycosides and condensed tannins in tissues and coniferyl benzoate in flower buds (Lindroth 2001). The phenolic glycosides are toxic to a variety of pathogens, insects and small mammals, while coniferyl benzoate is toxic to ruffed grouse (Lindroth 2001). The second defense strategy is aspen's capacity to maintain growth and reproduction after repeated defoliation events (Lindroth 2001). This strategy is particularly advantageous for the aspens which are hosts to several outbreak folivores which have the potential to cause extensive and uniform damage during peak periods of defoliation (Lindroth 2001).

Domestic (livestock) animals can cause tree damage through grazing and trampling and can reduce soil quality through compaction (Krzic et al. 2004). During the most recent FIA inventory period, livestock damaged 24,873 acres of aspen timberland (Figure 3.1). Combined with white-tailed deer (*Odocoileus virginianus* Goldman and Kellogg) and other wild ungulates, 43,144 acres of aspen timberland were damaged (Figure 3.1). Beaver (*Castor canadensis* Kuhl) damage from feeding and flooding can also be a significant problem. During the most recent FIA inventory period, 43,738 acres of aspen timberland in the Lake States were stressed and killed by beaver.

Insect pests also play a major role in the aspen ecosystem health. There are many insect pests which prey on the three tree species, but only a few cause widespread damage. Insects damaged 24,387 acres of timberland during the most recent FIA inventory period in the Lake States (Figure 3.1). The forest tent caterpillar (*Malacosoma disstria* Hübner) is a major contributor to this damage, defoliating thousands of acres of aspen each year. Outbreaks occur every 6 to 16 years, each lasting 4 to 5 years (Peterson and Peterson 1992). During the outbreaks, insects can defoliate entire trees (sometimes over multiple years), resulting in reduced vigor and, in some cases, death (Peterson and Peterson 1992). With the exception of the forest tent caterpillar, no insect defoliates more aspen than the large aspen tortrix (*Choristoneura conflictana* Walker). Outbreaks typically precede forest tent caterpillar outbreaks and last 2 to 3 years before the population crashes (Ostry et al. 1989; Peterson and Peterson 1992). During outbreaks, the tortrix consumes buds and leaves causing growth declines and, in extreme cases, death. The last insect pest, the gypsy moth (*Lymantria dispar* L.), is native to Europe and Asia and was introduced near Boston, Massachusetts in the 1860s. It has since spread west to the Lake States where localized outbreaks have occurred. The gypsy moth caterpillar feeds on the foliage of hundreds of different plant species but its most common hosts are oaks and the aspens. With the large aspen resource in the Lakes States, it is likely that the gypsy moth will become a more frequent defoliator as it continues to expand throughout the region.

Hundreds of diseases affect the aspens across the Lake States; however, only a few cause large scale damage and mortality (Lindsey and Gilbertson 1978; Ostry et al. 1989). Most of the fungi associated with the aspens affect standing dead or fallen trees and are of minor importance to live aspen (Lindsey and Gilbertson 1978; Peterson and Peterson 1992). During the most recent FIA inventory period, diseases caused 7,481 acres of timberland damage (Figure 3.1). The fungus *Phellinus tremulae* (Bond.) Bond. & Borisov causes white trunk rot in living aspen and results in more volume loss than any other disease (Lindsey and Gilbertson 1978; Ostry et al. 1989). The spores from the fungus land and germinate in wounds on aspen stems and dark brown, hoof-shaped conks develop and lead to decay (Ostry *et al.* 1989). The fungi are most common in over-mature aspen stands where branch breakage and stem damage are common and in young stands which were damaged during mechanical thinning. Another fungus which affects aspen in the Lake States is the Hypoxylon canker (*Entoleuca* mammata (Wahlenberg: Fr.) J.D. Rogers & Y.-M. Ju (≡ *Hypoxylon* mammatum (Wahlenberg: Fr.) P. Karst.) (Rogers and Ju 1996). This fungus is the most common and damaging disease of quaking aspen and, like *Phellinus*, infects trees through wounds on stems and branches

(Lindsey and Gilbertson 1978; Ostry et al. 1989). Once the spores have germinated, the fungus grows rapidly into the main stem where it girdles and kills the tree (Ostry et al. 1989). It is most common in understocked stands and where bark-feeding mammals or insects wound stems and branches and in stands damaged during thinning operations. Armillaria root disease and butt rot are caused by several species of fungi in the *Armillaria* genus. It is most common in stressed or over-mature trees but is also found in highly productive aspen stands managed on short rotations (Stanosz and Patton 1987a; Ostry et al. 1989; Peterson and Peterson 1992). It spreads from tree to tree by rhizomorphs which grow through the soil until they contact and infect the root system of uninfected trees (Peterson and Peterson 1992). Armillaria root rot may limit rotation length and the number of times that aspen stands can successfully regenerate vegetatively (Stanosz and Patton 1987b; Peterson and Peterson 1992).

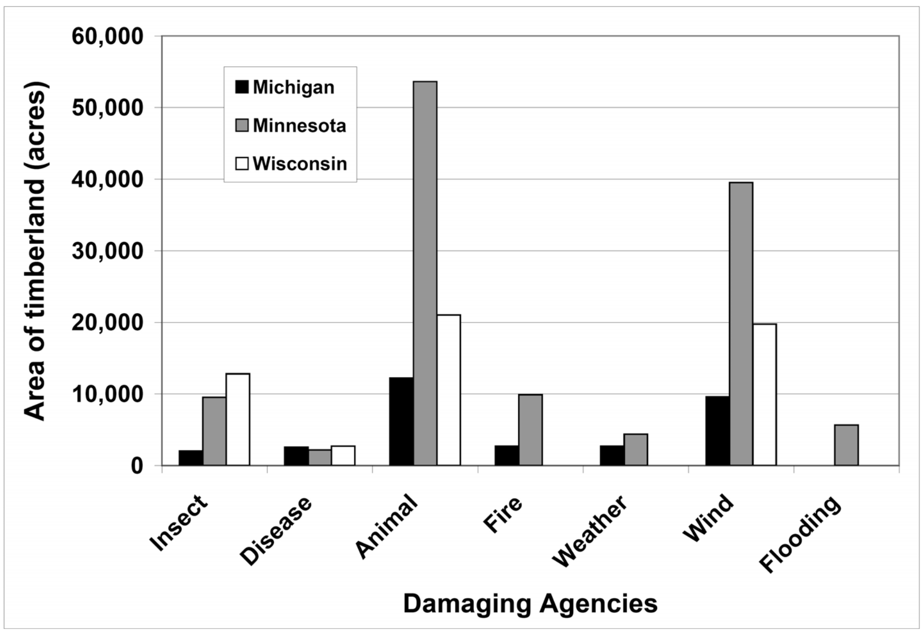

Figure 3.1 Area of Aspen Timberland Damaged by Biotic and Abiotic Agencies during the 2006 Inventory Period in the Lake States

There has been a limited amount of research on management strategies to mitigate the effects of insect pests and pathogens on aspen in the Lake States. Some work on chemical, mechanical, and biological control agents has been conducted, but the results are often site- or clone-specific. More work is needed, particularly as it relates to early thinning, clonal selection, and disease resistance. Studies examining the effects of global climate change on insect outbreak patterns and the associated interactions with aspen are also appropriate. There is also a shortage of studies documenting the mechanisms driving various biotic and abiotic interactions which affect aspen forest health. Further study on the biology and ecology of *Armillaria* root disease in managed stands is also needed, particularly on productive sites. Finally, as the gypsy moth continues to expand its range, monitoring should continue and control measures should be taken wherever possible.

3.5 Wildlife Habitat

Aspen-dominated ecosystems provide food, cover, and breeding habitat for a variety of wildlife species (Gullion 1977, 1984; DeByle and Winokur 1985; Hoover and Wills 1987). In the Lake States, the two species most commonly associated with aspen forests are the white-tailed deer and ruffed grouse (*Bonasa umbellus* L.) (Graham, Harrison, and Westell 1963; Byelich, Cook, and Blouch 1972; Gullion 1977, 1984, 1987, 1990). White-tailed deer rely on young aspen stands primarily for food (Byelich, Cook, and Blouch 1972). The prolific root suckering ability of aspen provides abundant, highly palatable foliage during the spring and summer months (Byelich, Cook, and Blouch 1972). As aspen stands begin to self-thin into evenly-spaced poles, they provide ideal vertical cover for ruffed grouse (Gullion 1990; Peterson and Peterson 1992). Ruffed grouse prefer to feed on male aspen clones which are 30-50 years old (Peterson and Peterson 1992). They feed on the foliage during the summer, staminate flower buds during the winter, and catkins in early spring (Gullion 1990). The highest concentrations of ruffed grouse are found in areas where there are a variety of aspen age classes available for food, drumming structures, and cover (Gullion 1990).

Other wildlife species also use aspen-dominated ecosystems. Black bear (*Ursus americanus* Pallas) feed on aspen catkins and leaves in late spring after emerging from their dens (DeByle and Winokur 1985; Rogers et al. 1988). Beaver feed on stems and branches and use aspen as construction material for dams and lodges (Skinner 1984). Cottontail rabbits (*Sylvilagus nuttalli* Bachman), snowshoe hare (*Lepus americanus* Erxleben), and porcupines (*Erethizon dorsatum* L.) feed on the bark of young aspen stems (Graham, Harrison, and Westell 1963; Banfield 1974). Many small mammals—including shrews, mice, chipmunks, and voles—inhabit aspen understory environments (Westworth, Brusnyk, and Burns 1984; Moses and Boutin 2001). These species play an integral part in the trophic dynamics of forests as both prey for large carnivores and as consumers of insects and other invertebrates, plant material (particularly fruits and seed), and fungi (Hamilton Jr. 1941; Westworth, Brusnyk, and Burns 1984; Peterson and Peterson 1992; Carey and Johnson 1995; Elkinton et al. 1996; Moses and Boutin 2001).

Aspen stands also provide habitat for a variety of bird species (Thomas 1979; DeByle and Winokur 1985; Yahner 1991; Peterson and Peterson 1992; Schulte and Niemi 1998). Many of these species specifically rely on standing (snags) and downed material for drumming, excavation, nesting, and shelter (Thomas 1979; Petit et al. 1985; Gullion 1990; Telfer 1993; Schulte and Niemi 1998). Schulte and Niemi (1998) documented 53 bird species in burned and logged aspen stands in northern Minnesota. The most common species were the Nashville warbler (*Vermivora ruficapilla*), chestnut-sided warbler (*Dendroica pensylvanica*), mourning warbler (*Oporornis agilis*), common yellowthroat (*Geothlypis trichas*), white-throated sparrow (*Zonotrichia albicollis*), and song sparrow (*Melospiza georgiana*) (Schulte and Niemi 1998). In a study comparing bird diversity in recent clearcuts and clearcut with residual (uncut) patches, Merrill, Cuthbert, and Oehlert (1998) documented many of the same species as Schulte and Niemi (1998) in residual patches. In the clearcuts without residual patches, the most common species were the veery (*Catharus fuscescens*), least flycatcher (*Empidonax minimus*), ovenbird (*Seirus aurocapillus*), winter wren (*Troglodytes troglodytes*), rose-breasted grosbeak (*Pheucticus ludovicianus*), Canada warbler (*Wilsonia canadensis*), and black-throated green warbler (*Denroica virens*) (Merrill, Cuthbert, and Oehlert 1998).

Most of the research examining wildlife habitat values of aspen-dominated ecosystems in the Lake States has focused on game species, particularly white-tailed deer and ruffed grouse. There is a shortage of information on aspen ecosystems as non-game habitat. Assessments of game and non-game species abundance, inter- and intraspecific interactions, and habitat usage are needed in order to develop new wildlife management recommendations and amend current practices. Strategies to incorporate wildlife management into current silvicultural practices for aspen and mixedwood stands are also of interest.

4.0 SILVICULTURE

Aspen stands in the Lake States have historically been managed with the clearcut-coppice silvicultural system, where the nominal rotation age is often determined by the culmination of mean annual increment or a diminishing economic rate of return (Perala 1977; Puettmann and Ek 1999). In practice, however, rotation age has much to do with achieving merchantable tree size for economic harvesting. A typical silvicultural prescription called for mature aspen stands to be clearcut at age 40-60 years (depending on site and clone) thereby creating near optimal conditions for root suckers to become established. The ramets self-thin as the stand matures and, at maturity, the process is repeated (Cleland, Leefers, and Dickman 2003). This rather simplistic approach has been used for decades in situations where net volume yield, wood uniformity, and sustainability (regeneration in this case) have been the primary management objectives. With the cost of regeneration being very low (typically just the harvest cost), this approach has also proved economically attractive.

In recent years, forest management practices in the region have begun to focus less on timber production and more on practices which meet environmental standards (e.g., for forest certification) and maintain the structure and function of ecosystems for various objectives. Table 4.1 summarizes historic and contemporary aspen management objectives and corresponding silvicultural treatments documented in the Lake States. Some treatments listed have been conducted on an experimental basis while others are commonly used in practice. In order to address changing forest management interests, forest managers must mix traditional silvicultural techniques (e.g., clearcutting) with contemporary approaches (e.g., early and commercial thinning, variable density thinning, retention patches in clearcuts, and clearcutting with residuals) to manage for non-timber objectives or multiple objectives, while capitalizing on specific aspen characteristics, e.g., its regeneration ability, clonal nature, and high level of genetic diversity (Perala 1977; Weingartner and Doucet 1990; David et al. 2001). Such management complexity is especially evident on public lands. However, short- and long-term losses in yield with the adoption of complex management practices have not been carefully examined. For example, in leaving competing tree species, yields may be reduced and aspen acreage lost. Additionally, the environmental gains from such management practices have not been well documented. For example, the various practices may favor biological diversity and/or certain wildlife species over others, yet terms such as diversity are difficult to define. Further, the stated desired conditions can be short-lived and expensive to maintain. Old growth or aesthetics can be especially fleeting objectives with expensive consequences for subsequent restoration or conversion. Finally, most of the contemporary non-timber management objectives have been developed at the stand level, based on ecological, habitat, or aesthetic concepts and interests, with little quantitative attention to the overall forest implications for yield, costs, operational or long-term management considerations. This situation indicates the scheduling of the various non-timber focused treatments and stand conditions across large ownerships is a neglected activity in practice and a potentially very instructive area for research.

A renewed interest in early or precommercial thinning has occurred in recent years because of the predicted aspen timber shortages in the Lake States due to an imbalance in the aspen age class structure. This imbalance is a result of the rapid 1850-1930 harvest of the original mature pine and other mixed forest and its replacement by aspen as the dominant covertype. The result has been characterized as a “wall of wood” moving forward across the region as the aspen has matured. Harvesting overall has tended to replace older stands by younger ones; in part as an attempt to create an equal distribution of acres in each age class. However, as harvesting has varied by decade and location, the age class structure remains uneven and younger stands have not yet reached merchantable size, thus the apparent shortage of aspen until they do so. Importantly, even then, reduced acreages of aspen may still limit supplies (Figure 2.4). As a result of the aspen supply problem, there has been an increased emphasis on obtaining high quality fiber from younger stands (David et al. 2001). In young aspen stands where sucker and sprout densities are very high (up to

20,000 to 30,000 stems/ac), precommercial thinning has been used to shorten the length of pulpwood rotations, promote the diameter growth of residual stems, and favor superior clones (Graham, Harrison, and Westell 1963; Perala 1977; Jones, Berguson, and Vogel 1990). Another technique used to favor superior clones and thus shorten rotation lengths in heavily stocked juvenile stands is “stem flattening.” This technique typically results in alternating strips (6-8 ft wide) of flattened, but not severed, juvenile aspen stems (8-10 years old) and untreated strips (6-10 ft wide) (Zasada et al. 2000; David et al. 2001; Cleland, Leefers, and Dickman 2003). The flattened stems are killed and the new suckers are suppressed under the shade of the residual strips. In severely understocked juvenile aspen stands, shearing has been an effective technique used to restore full stocking (Perala 1983). However, data on the effectiveness of these approaches in terms of yield is very limited.

The interest in thinning has also been stimulated by the introduction of new harvesting technologies, specifically cut-to-length (CTL) whole tree processors. These processors can reduce damage to the residual stand because of their improved maneuverability relative to older harvesting equipment (David et al. 2001) and a reduction in skidding damage. Some CTL equipment operating on clearcut travel strips can reach as far as 23 ft into a stand that is being thinned. Feller buncher harvesting equipment may also be used in this manner. Commercial thinning has been recommended for aspen growing on good sites (site index 80 or better) that are at least 20-30 years old and have basal areas of 120-140 ft^2/ac (Perala 1977; David et al. 2001).

Depending on management objectives, thinning from above (which calls for the removal of co-dominant and dominant trees to release other co-dominant and intermediate individuals) or below (which calls for the removal of suppressed and intermediate trees to favor co-dominant and dominant individuals) could easily be implemented with CTL harvesting equipment. Furthermore, variable density thinning (a technique which calls for unthinned areas and heavily thinned patches, along with variable levels of thinning and residual density) could be carried out with CTL equipment. Again, the yield response in terms of mortality salvaged and increased growth of the residual stands from such practices is not well documented for the range of clones, sites, and locations germane to aspen management across the region.

Clearcutting with reserves or retention harvesting can be thought of as a continuum from uniformly distributed to highly aggregated (David et al. 2001). This silvicultural approach may be a viable option in even-aged aspen stands where the primary objective is to convert the stand to a multi-cohort, mixed species assemblage. Again, the yield response and non-timber (e.g., biodiversity) gains, if any, are not well documented.

Given an interest in both pulpwood and biomass for energy, improved native aspen or hybrid aspen managed in plantations may also become more common across the region. Currently, superior clone selection is practiced in native stands where the desire is to improve stem form or growth potential of the stand (Perala 1977). The possibility for long-term genetic improvement of an aspen stand exists; however, there are some drawbacks. First, it is difficult to identify individual clones during winter (leaf off) harvest conditions, so inferior clones are often left unintentionally. Second, elimination of unwanted clones, even with the use of herbicides, is not always effective. Assuming plus clone selection were to be practiced during consecutive harvests in the same stand, the potential for changing stand genetics is great but does require multiple selection events.

Several decades of research in the Aspen/Larch Genetics Cooperative at the University of Minnesota have demonstrated improved growth with three distinct plantation approaches: intensively managed, conventional, and dense packs. Although it is possible to use either native aspen or hybrid aspen in a plantation setting, hybrid aspen is typically deployed due to its superior growth rate.

The intensively managed plantation method is identical to hybrid poplar culture, with extensive alteration of the ground (competing) vegetation and soil surface through mechanical and/or chemical site preparation and vegetation management for the first two to three years until crown closure is attained. This method exploits the genetic potential of aspen seedlings by reducing competing vegetation and supplying seedlings with necessary resources during early stand development. For the production of pulpwood and biomass for energy, realistic rotation ages for both hybrid aspen and hybrid poplar range from 12 to 20 years depending on site, growing conditions, genotypes used, and success in controlling competing vegetation. Under these conditions, hybrid aspen competes well with hybrid poplar while providing wood fiber with superior whiteness and the ability to regenerate the site after harvest at minimal cost (David 2003).

Table 4.1 Silvicultural Practices for Aspen Management in the Lake States (adapted from Cleland, Leefers, and Dickman 2003).[a]

Silviculture	**Management Objective**				
	Timber/Fiber Production			**Wildlife habitat or diversity**	**Old growth or aesthetics**
	Natural	**Managed**	**Plantation**		
Harvest	Clearcut commercially mature stands	Clearcut commercially mature stands	Clearcut commercially mature stands	Clearcut or variable retention of other desirable species	None[b], variable aspen retention, clearcut, or burn as stand breaks up
Size of harvest units	Generally large (25+ acres) or entire stand	Generally large (25+ acres) or entire stand	Generally large (25+ acres or entire stand	Extremely variable depending on habitat objectives	<5 acres to entire stand
Rotation or cutting cycle	35 to 70 years[c], depending on site and clones	30 to 70 years[c], depending on site and clones	15 to 30 years[c], depending on site and clones	20 to 80+ years depending on the area age class distribution	60-120+ years
Site preparation	None[d], except where a dense understory of tolerant trees requires cutting, disking, burning or herbicide treatment	None[d]	Variable; extensive chemical and mechanical in agroforestry setting, some chemical and/or mechanical in operational forestry setting	None[d]	None[d]
Tending	None	Precommercial thinning for dense stands or commercial thinning to expand desirable clones or capture early economic return	Agroforestry - 2 to 3 years mechanical and chemical vegetation control; shearing option at 6 to 12 years for seedling derived plantations	Generally none	Optional; thinning will produce large-diameter trees more quickly
Overstory composition	Pure stands preferred (less than 15 percent other tree species)	Pure stands preferred (less than 15 percent other tree species)	Pure stands preferred	Pure or mixed species, multistoried stands depending on habitat objectives	Pure or mixed species, multistoried stands

[a] This table highlights silvicultural practices prescribed to accomplish different management objectives in the region. Many of the practices used to achieve a particular objective have proven useful in meeting other management objectives (e.g., clearcutting for timber production also benefits certain wildlife species). In all cases retention of aspen is the goal.

[b] No management or disturbance may lead to succession from aspen to other species.

[c] Very short rotations (less than 20 years) may lead to deterioration of aspen root systems.

[d] Provided adequate potential for sucker reproduction exists.

The conventional approach is based on a conifer plantation model where site conditions, location, and costs prohibit intensive management. In this approach, chemical and/or mechanical site preparation is used to prepare the site for planting aspen or hybrid aspen seedlings at a density of 540-890 per acre. After planting, control of competing vegetation is minimal with the use of herbicide as a release option and is encouraged if growth rates stagnate due to competition. At age 6-10, the plantation should be evaluated for stocking, growth rate, annual mortality rate, and incidence of insects and disease. This evaluation will assess the risk of carrying the existing plantation to harvest or, alternatively, sheering the entire hybrid aspen stand and regenerating the plantation from coppice. Although sheering appears to delay the time to harvest by the age of the plantation at sheering, the established root systems from the planted hybrids allow for rapid growth of the new suckers. This rapid growth decreases the discrepancy between the predicted harvest dates of the sheered and unsheered stands. As an added advantage, sheering will increase stocking and improve the average stem form.

The third plantation approach has been called the dense pack design. In this case, small groups of 25-81 seedlings are planted at 1-2 foot spacing. The distance between these dense packs varies from 30 to 60 feet so that there are approximately 16-49 dense packs per acre. There are a few major differences between dense pack plantation establishment and the conventional method. First, in the dense pack design, the seedlings are planted in groups as opposed to a systematic grid pattern of single seedlings spread evenly across the whole site. Second, because the planted seedlings are in groups with unforested areas between them, the dense packs must be sheered once the root systems have establish in order for new suckers to capture the unforested areas and achieve full site stocking.

Mandatory sheering with the dense pack design does increase the length of the first rotation. Because the seedlings are grown together in groups, they are typically smaller than seedlings planted in the conventional method at the same age so sheering is recommended at the slightly older age of 8-12 years. Additionally, with this method there is the risk that if a dense pack is growing poorly or fails altogether, stocking levels in the vicinity of that dense pack will be low or non-existent. Understocked sites may require a second or third sheering to achieve adequate stocking. The primary advantages to the dense pack design are lower site preparation and tending costs because initial site preparation is required only in the vicinity of each dense pack and, when grown in groups, release efforts are typically not required. Also, seedlings are less susceptible to browse, vegetative competition, and extreme climate conditions because the tightly spaced seedlings mimic the spacing found in a stand regenerating from coppice. Since each dense pack is a group of seedlings, it is possible to lose individual stems but still maintain an aspen presence and therefore the ability to regenerate a specific area. This concept is similar to a coppice-derived stand where suppressed stems are outcompeted and die leaving dominant stems to control the site.

5.0 ECONOMICS

The economics of aspen management at the stand level can be attractive due to the relative ease of establishing aspen stands, simplicity of management, and potentially short rotations. Technological adaptations by industry to use aspen as a raw material for a wide range of manufacturing processes and products have resulted in a high demand for aspen roundwood, particularly for engineered wood products like oriented strand board (OSB) and waferboard (Balatinecz and Kretschmann 2001). This was not the case as recently as 25 years ago, when lack of markets in Minnesota necessitated programs that actually paid loggers to “recycle” old aspen stands. Aspen has also come to be appreciated as key habitat for certain wildlife, particularly game species. In particular, early- to middle-age aspen stands provide important habitat for a variety of wildlife species. Before markets were established for aspen, much of the forest management in this type was conducted solely for improving wildlife habitat.

Figure 5.1 indicates historical stumpage prices for Lake States aspen. Published prices of aspen roundwood sold by public land management agencies in Minnesota from 1989 to 2006 indicate an average annual increase (nominal) of over 17& through 2005 (MNDNR 2006). While not as dramatic, aspen stumpage prices in Michigan and Wisconsin also increased considerably over this same time period. In 2006, a downturn in the housing market, combined with aging facilities and the growing cost of production, led to sharp declines in stumpage prices across the region, particularly in Minnesota (Figure 5.1).

Kilgore and MacKay (2007) compared aspen stumpage and forest land value changes occurring from 1989 to 2003. Given the rapid increase (averaging 13% per year) in the median price of Minnesota forest land, the relationship between stumpage and forest land prices change was assessed during this period. Forest land capitalization rates, which are a measure of investment over time, were calculated from 1989 to 2003 using aspen stumpage prices and growth rates as a proxy for annual timber rents. During the first seven years of this time period, Minnesota's forest land capitalization rate increased to its peak of 3.2%, reflecting the substantial rise in stumpage prices relative to forest land values. After 1995, the capitalization rate steadily decreased to 1.2% in 2003 – just 0.1% below the capitalization rate that existed in 1990 and 0.3% above the 1989 rate. Thus, in spite of the rapid increase in forest land values and stumpage prices during this period, the competitiveness of forestry as an income-producing use of the land was greater in 2003 (when the median price of forest land was $981 per acre) than it was in 1989, when the median price of forestland was less than $200 per acre (Kilgore and MacKay 2007). Updated forest land sales and aspen stumpage price data through 2005 indicate the value growth of aspen relative to forest land has increased since 2003 but is still lower than when the trend reversed in 1995 (Figure 5.2).

Current research on the economics of aspen management in the Lake States is almost non-existent and severely outdated. Ek and Brodie (1975) conducted one of the more thorough assessments of alternative strategies to maximize financial returns to the landowner according to the intensity of management, site quality, and product utilization. Other studies addressing the economics of aspen management include Husain (1996); Bella and Yang (1991); Hove (1990); Graham and Betters (1985); Nordeen (1968); Perala (1983); and Zasada (1952). Several of these studies are not specific to Lakes States aspen. Moreover, nearly all were conducted under vastly different market, price, cost, and utilization conditions than exist today.

It can be argued that economics has become a secondary consideration in aspen management at the stand level on some public forests. In contrast, many timber companies, counties, and other forest owners are more sensitive than ever to the need for forest management investments to be successful in terms of stand outcomes, yields, and allowable harvest calculations. Harvest scheduling models (Hoganson and Rose 1984; Borges and Hoganson 1999; Wei and Hoganson 2005) have become an essential tool to providing forest management plans that are operationally feasible, financially efficient, and sensitive to the diverse environmental constraints faced in managing large forested landscapes. Such model-based planning can add great clarity about tradeoffs in choices involving rotation ages and stand treatments that affect outputs and services at the stand and forest level. The approach can also identify meaningful allowable harvests that less quantitative approaches have missed.

As an example of scheduling issues, consider that aspen in the 1-10-year age class is thought to be prime habitat for ruffed grouse. Managing aspen on 50 year rotations provides such habitat 20% of the time. However, managing some aspen stands on 40 year rotations provides such habitat 25% of the time. Clearly, rotation age choices and their distribution across the landscape are important considerations in wildlife management.

Finally, there is the increasing interest within state governments to address the highly competitive and global nature of today's forest products industry. This interest is largely driven by the desire to retain jobs in the forest-based sector or encourage industrial expansion and the associated economic multiplier effect. While global forest products firms may view investments on a location and profitability basis, states may view investments in forest management as "jobs per 1,000 cords." Thus, stand-level economic considerations may pale in comparison to regional employment and ecosystem service needs. The Lake States forests, which have evolved into a complex set of public and private forest ownership conditions and associated policies and management strategies, have the potential to play a major role in fostering economic development. While this report necessarily considers the economics of stand-level aspen management, the possibilities and implications for larger scale investments need to be considered.

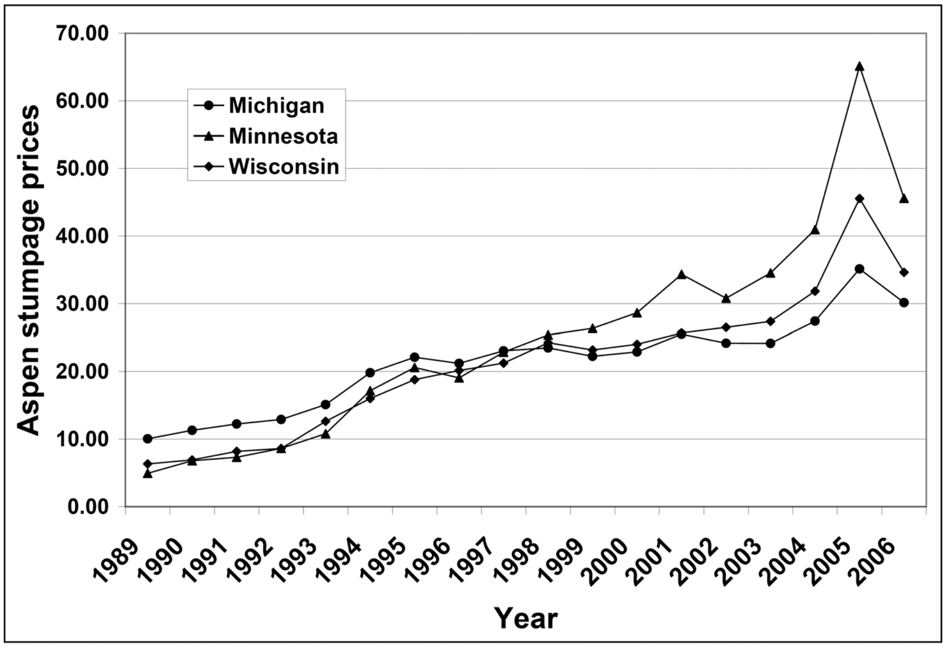

Figure 5.1 Historical Stumpage Prices for Aspen in the Lake States

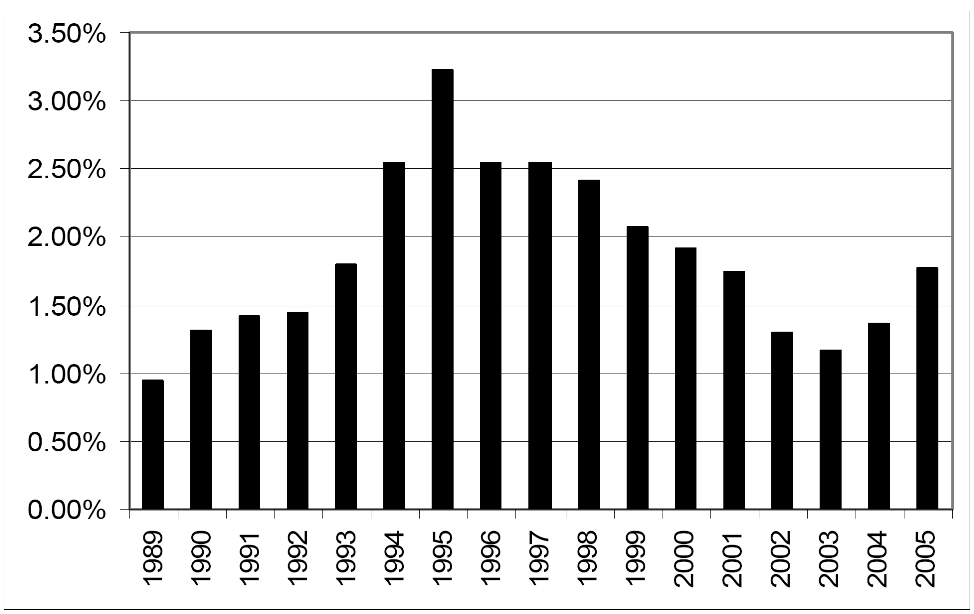

Figure 5.2 Relationship between the Value of Annual Growth of Aspen Roundwood Stumpage and Forest Land Sale Prices in Minnesota: 1989-2005

6.0 RESEARCH NEEDS AND STRATEGIES

This review has covered much of what we know about aspens and their management. Clearly, the retention of aspen and its management is important to the forest products industry and the diverse forest landowners in the Lake States for a variety of purposes. With this interest and the findings from review, it is apparent that research on aspen and its management has been very modest at best. This research needs further focus, organization and resources.

6.1 Resources Status and Trends

- Examine aspen covertype acreage losses with respect to contributing ecological, management and harvesting factors, including ownership. Additionally, a full set of economic and ecological implications and restoration strategies needs to be developed.
- Develop improved growth and yield models for aspen management with capability for estimating the gains from the application of early and commercial thinning for pulpwood and energy potentials and including both stem and full tree utilization levels.
- Assess trends in aspen stand yields with respect to site conditions, location, disturbance history, and other stand characteristics.
- Develop volume functions for individual hybrid aspen trees to accurately forecast hybrid aspen growth and yield.
- Examine growth responses to early (precommercial) thinning treatments.
- Develop biomass functions for both native aspen and hybrid aspen in the Lake States for estimating total biomass on a site.

6.2 Biology and Ecology

- Identify clone, site, insect, and disease interactions and appropriate aspen management options and potential problems.
- Examine aspen insect and disease problems in early thinning operations.
- Examine aspen clonal resistance to decay fungi.
- Examine the biology and ecology of *Armillaria* root disease in managed aspen stands.
- Articulate tree and clone improvement strategies for traditional and intensive plantation management and for addressing the potential of climate change.
- Develop clonal propagation methods that are physiologically reliable and economically feasible.
- Develop clonal propagation methods that could be used in response to potential climate change.
- Assess mechanisms driving various biotic and abiotic interactions which affect aspen forest health.
- Assess harvesting impacts on site productivity, especially with respect to nutrient removal and future species composition.
- Thoroughly investigate the likelihood of gene flow from hybrid aspen to the native aspen gene pool and its impacts.
- Improve documentation of the ecological (e.g., biodiversity) contributions of managed aspen forests at the stand and landscape scales.
- Assess game and non-game species abundance, inter- and intraspecific interactions, and habitat usage in aspen and mixedwood stands to develop new wildlife management recommendations and amend current practices.
- Develop strategies to incorporate wildlife management into current silvicultural practices for aspen and mixedwood stands.

6.3 Silviculture

- Assess management activities such as plus clone selection, clearcutting, and variable retention harvesting on genetic diversity at the stand level.
- Identify rotation ages and thinning strategies appropriate to timber and non-timber objectives.
- Examine and articulate harvest scheduling strategies for entire forests that are conducive to timber, non-timber and multiple objectives over long time periods.
- Examine short- and long-term losses in yield with the adoption of complex management practices (e.g., early and commercial thinning, variable density thinning, retention patches in clearcuts, and clearcutting with residuals).
- Examine management strategies to mitigate the effects of insect pests and pathogens on aspen in the Lake States.
- Examine changes in yield from mortality salvaged and increased growth of the residual stands resulting from thinning treatments for the range of clones, sites, and locations germane to aspen management across the Lake States.

6.4 Economics

- Conduct financial evaluations of aspen management regimes that incorporate alternative thinning, site preparation, and final rotation strategies.
- Identify economic trade-offs associated with managing the aspen covertype on an extended rotation policy.
- Identify and evaluate important factors impacting capital investment decisions that utilize the aspen resource in the Lake States.
- Identify financial and economic implications of alternative land tenure arrangements and associated management strategies for the aspen resource.
- Identify strategies to increase the global competitiveness of the aspen resource as a wood fiber source in the Lake States.
- Estimate willingness to pay for aspen stumpage for roundwood and energy uses in the Lake States.
- Identify and evaluate economic trade-offs associated with managing aspen stands for fiber versus non-timber benefits (primarily older age stands for wildlife habitat) in the Lake States.

Research developed to address these needs will, in all likelihood, be conducted by existing university and agency research programs within the region. We recommend an increased focus on aspen research needs identified in this report with targeted requests for proposals (RFPs) or other dedicated resources. Existing data from FIA and other sources should contribute to this effort. However, it will also be important to establish experiments and field trials on a level comparable to that already conducted for the most studied species in the region (i.e., red pine and white spruce). It may also be appropriate to establish an aspen cooperative of some type to develop and synthesize research on these topics. The Minnesota Tree Improvement Cooperative, where industry and agencies provide "in kind" support is one model for this effort. New information tools such as the web-based Forest Management Guides for the North Central Region (http://www.ncrs.fs.fed.us/fmg/nfmg/) (Domke et al. 2006) may be a particularly effective vehicle for transferring information and technologies to landowners.

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