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CURRENT AND LONG-TERM EFFECTS OF UNGULATE BROWSING ON ASPEN STAND CHARACTERISTICS IN NORTHERN LOWER MICHIGAN

By

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ABSTRACT

CURRENT AND LONG-TERM EFFECTS OF UNGULATE BROWSING ON ASPEN STAND CHARACTERISTICS IN NORTHERN LOWER MICHIGAN

By

Delia F. Raymer

The Michigan Department of Natural Resources' (MDNR) objectives for the Pigeon River Country State Forest (PRCSF) and surrounding state lands provide for multiple uses of natural resources. In the 1980's, natural resource managers expressed concern over the potential effects of browsing by white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus nelsoni*) on the regeneration of aspen (*Populus* spp.) stands. Research during the 1980's showed that initial (4-6 year) impacts of ungulate use included decreases in aspen stem densities and vegetation cover, and altered plant species composition. At that time, however, there was no evidence to suggest that ungulate use would have an impact on timber production in the future. To date, the long-term (up to 30-40 years) effects of browsing on stand characteristics and merchantable timber production have not been evaluated. Additionally, current elk densities in some portions of the elk range may be higher than those observed in the mid-eighties, and the effect of this increase on aspen regeneration is uncertain. This study was initiated to determine the current level of browsing compared to historic utilization and to evaluate the potential long-term effects of ungulate use on aspen stand structure and composition.

Browse utilization counts were conducted on fifty-two 1- to 3-year-old aspen clear-cuts during the spring of 1995. Percent twig use, percent stem use, and the densities of twigs and stems were sampled. Habitat suitability index (HSI) values were calculated for landscapes surrounding 8 randomly selected 1- and 2-year-old aspen clear-cuts that were sampled for browse use. Relative abundances of ungulates were determined from transects located in each elk hunting management unit within PRCSF boundaries, and MDNR winter elk surveys. The effects of ungulate browsing on aspen stand characteristics were studied using replicated ungulate-proof exclosures and paired areas open to browsing. Exclosures were constructed on bigtooth (*Populus grandidentata*) and quaking (*P. tremuloides*) aspen clear-cuts during their first growing season. Vegetation sampling was conducted in 18 exclosures constructed between 1983-1985 and 12 new exclosures that were built from 1994-1995. Stem densities, aspen height and DBH (diameter at breast height), vegetation cover, and frequencies of herbaceous species were sampled.

Bigtooth aspen clear-cuts were browsed significantly more ($P < 0.10$) than quaking clear-cuts, and browse use within clear-cuts of both species decreased significantly ($P < 0.10$) with age since harvest. Habitat quality of evaluation areas centered around clear-cuts for elk, as determined by the Michigan elk HSI model, was relatively low, ranging from 0.20 - 0.51. Few differences in vegetation characteristics were found between exclosures and areas open to browsing in 1-year-old clear-cuts, indicating any differences found between treatments in the future may be attributed to long-term browsing effects. In 2-year-old clear-cuts, the greatest number of significant differences between treatments was found for vertical and horizontal cover. Results from

1- and 2-year-old clear-cuts were similar to results documented in the mid 1980's. Data from older (12- to 15-year-old) stands indicate less densely stocked stands with greater understory development may result from exposure to ungulate browsing. Current aspen stem densities and thinning rates in exclosures and areas open to browsing indicate that bigtooth and quaking aspen clear-cuts will likely produce fully stocked stands by age 40. However, continued long-term investigation is necessary to determine the final merchantability of PRCSF stands. The long-term alterations to stand composition and structure by ungulates may impact the habitat quality of stands for other wildlife species. Habitat management has the greatest potential for reducing browse utilization within individual stands. However, both habitat and herd manipulations should be used to provide multiple use benefits within the Pigeon River Country State Forest.

ACKNOWLEDGMENTS

This project was supported by the Federal Aid in Wildlife Restoration Act, Pittman-Robertson Project W-127-R administered through the Michigan Department of Natural Resources, Michigan Agricultural Experiment Station, and the Rocky Mountain Elk Foundation. Special thanks is extended the Brooklyn, Michigan chapter of the Rocky Mountain Elk Foundation for providing not only funding but also for enthusiastic help constructing exclosures.

I would like to express appreciation to my graduate committee for their contributions to this study and for stimulating my professional development. I would like to thank my major advisor, Dr. Henry Campa, for giving me guidance, confidence, and flexibility throughout this study. Thank you for demanding excellence and providing an example of excellence both in research and teaching. To Dr. Scott Winterstein and Dr. Carl Ramm, thank you for advice on data analysis, your long-term involvement with this project, and your unique perspectives on the natural resource profession.

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Finally, and most importantly, I would like to thank my husband Michael Raymer. Mike, I couldn't have done this without you. Thank you for tolerating lonely summers and providing field assistance, editorial comments, computer advice, love, and support. Most of all thank you for believing in me, I wouldn't be where I am now if it wasn't for you.

It's truly a unique opportunity to participate in a long-term study such as this one. Many individuals have contributed their ideas, time, and energy to produce this document. My appreciation is extended to all who have been involved.

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INTRODUCTION

Aspen (*Populus* spp.) provides habitat components for many wildlife species, supplying both food and cover for numerous songbirds, small mammals, and ungulates. The 2 species of aspen that occur in northern lower Michigan, bigtooth aspen (*P. grandidentata*) and quaking aspen (*P. tremuloides*), are particularly important as a food resource for white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus nelsoni*). Aspen forests are also an important resource for the production of various wood products. In Michigan, the 2 aspen species are used indiscriminately for a wide variety of timber products, from paper pulp and particle board to high grade lumber and veneer. Pelletized aspen has even been used as a supplemental cattle feed (Laidly 1990).

The aspen-birch (*Populus* spp.-*Betula* spp.) forest type is the second most abundant forest type in Michigan, covering 7.9 million (mil) hectares (ha) (Leatherberry and Spencer 1996). Of this 7.9 mil ha, 6.6 mil ha are considered dominated by aspen. Twenty-seven percent of the state's aspen forest type is dominated by bigtooth aspen, while 73% is dominated by quaking aspen. The study area, Pigeon River Country State Forest (PRCSF) is located in the northern lower peninsula of Michigan. This region supports 3.5 mil ha of aspen, of which 68% is in seedling/sapling and poletimber stages of succession.

Historically, forest fires were primarily responsible for creating conditions conducive to aspen regeneration. Due to fire suppression policies, however, currently most regeneration occurs following silvicultural manipulations, specifically clear-cutting (Graham et al. 1963, Perala 1990). Regeneration can be very dense following clear-cutting with up to 100,000 suckers/ha (Graham et al. 1963, Maini 1972, Perala 1972). In Michigan, suckers typically reach heights of 1.5-2.0 meters (m) during the first growing season.

The subspecies of elk native to Michigan (*Cervus elaphus canadensis*) was extirpated from the state around 1877, but another subspecies, Rocky Mountain elk (*Cervus elaphus nelsoni*), was successfully reintroduced in the early 1900's. Successful reintroduction of elk began with an initial release of 7 animals just south of Wolverine, Michigan near the western edge of the current elk range. After release, the elk population slowly increased to approximately 200 by 1925 and 300-400 by 1939. By 1961, the population seemed to stabilize at an estimated 1,200-1,500 elk and problems with reduced regeneration of forest types began to occur (Moran 1973). In December, 1964 and 1965, strictly controlled elk hunts were conducted to reduce the herd to around 800 animals and to gain information on herd structure and food habits. Following 1965, habitat successional changes and problems with poaching led to a decline in the elk population, which reached an estimated low of 200 animals by the early 1970's (Moran 1973).

Since the early 1970's the elk population has steadily increased. Currently the herd is estimated at between 1,200-1,300 animals post-harvest (D. Whitcomb, MDNR, pers. commun.) which is higher than the Michigan Department of Natural Resources

(MDNR) post-harvest management goal of 800-900 elk stated in Michigan's Elk Management Plan (Michigan Department of Natural Resources 1984). Approximately 30% of these animals reside within the PRCSF, where elk densities range from 0.2-0.8 elk/km^2 (E. Langenau, MDNR, pers. commun.). Deer densities in the Forest have remained relatively low since the mid-1980's, ranging from approximately 7-10 deer/ km^2 (E. Langenau, MDNR, pers. commun.).

Following the clear-cutting of aspen, white-tailed deer and elk may browse heavily on new shoots. Browsing pressure by ungulates is especially intense in young (≤3 growing seasons) regenerating aspen stands (Campa 1989). Previous research in Michigan has documented that heavy browsing (browsing on >50% of twigs) can initially impact the ability of suckers to attain maximum tree height, affect the structure and composition of some aspen stands, and induce changes in the browse quality of aspen (Campa 1989, Campa et al. 1993). Furthermore, excessive use of aspen suckers as browse by ungulates has been cited as a major reason for decline of the aspen forest type as well as for reductions in timber production (Westell 1956, Spiegel et al. 1963).

During the late 1970's and early 1980's, natural resource managers in the PRCSF began to observe localized problems with aspen regeneration and were concerned with the implications of browsing impacting the ability of stands to produce merchantable timber. In 1982, a study was initiated to determine the extent and severity of the problem. Browsing effects were quantified using browse utilization counts and replicated exclosures. Campa (1989) found that browse use was significantly greater in bigtooth aspen clear-cuts than quaking aspen clear-cuts, and that browse use decreased with age since harvest. In the simulated browsing portion of the study, aspen stem densities were not affected by any level of browsing, but woody annual productivity, total available twigs, and tree height were reduced under high intensities of simulated browsing (> 50%). During the mid 1980's browsing intensities in some stands within the PRCSF were >50% and therefore could cause changes in stand characteristics and plant composition within these stands.

A number of habitat attributes have been discovered to contribute to the level of browsing within any particular clear-cut including the species of aspen, clear-cut age, and distance from individual clear-cuts to the nearest conifer swamp (Campa 1989). More specifically, browsing was greater on clear-cuts within 445 m of a conifer swamp. Conifer swamps provide optimum winter thermal cover, and less distance between feeding areas and conifer swamps results in lower energy expenditure during traveling and feeding activities. Other aspects of habitat quality may also influence ungulate use of clear-cuts. For example, the quality of thermal cover is directly related to the size of the conifer swamp (Beyer 1987). The presence and distance to other optimum foraging areas, such as young maple stands and wildlife openings, may also influence browse use within a stand. The most important habitat components for quality elk habitat can be combined into a single quantitative value using the Michigan elk Habitat Suitability Index model (HSI) developed by Beyer (1987). HSI values of landscapes surrounding current or proposed clear-cuts quantify relative habitat quality which may be used to predict whether these clear-cuts will have high or low levels of browsing.

Browse utilization also may be correlated to localized elk distribution. During the winter and spring when the majority of browsing occurs elk are typically congregated into groups. These groups tend to concentrate their feeding within local areas for several days to weeks. Local abundance of animals may predict the expected level of browsing within areas. Identifying the association between abundance, HSI values, and browse use may provide valuable information for formulating management goals and could help predict the intensities at which future clear-cuts will be browsed and the resulting habitat quality.

Heavy browsing during the first few years after clear-cutting may create long-term alterations of stand composition and structure. These alterations could effect the ability of stands to produce merchantable timber and provide habitat components for wildlife species such as ruffed grouse (*Bonasa umbellus*) and woodcock (*Philohela minor*). Long-term effects of ungulate browsing on timber production include some variables, such as wood quality, which may not be quantifiable until stands are harvested. Long-term effects may also be confounded with successional changes, so it is imperative that effects are evaluated at repeated intervals during stand development. Currently, the aspen clear-cuts used in Campa's (1989) study are between 12- and 15-years-old. These are ideal ages for determining ungulate effects on sapling-successional-stage aspen stands due to their continued importance as food and cover habitat for elk (Beyer 1987).

It is important to continue to examine the influence of ungulate browsing on aspen regeneration to identify initial impacts as well as long-term ecological effects. Quantifying browsing effects on aspen will ultimately enable biologists to determine whether impacts of browsing are a widespread or localized problem, and whether browsing impacts timber production and the quality of habitat for other wildlife species. Results from this research will provide information which may be invaluable to planning sustained timber production on a landscape level while maintaining adequate numbers of elk within PRCSF for consumptive and non-consumptive recreational opportunities.

OBJECTIVES

Specific objectives of this project were to:

1) Quantify browse use of young (≤ 3 growing seasons) bigtooth and quaking aspen clear-cuts in the PRCSF and compare to levels documented in the mid 1980's.

2) Identify the association between browse use on young (≤ 2 growing seasons) bigtooth and quaking aspen clear-cuts and relative elk abundance, and Habitat Suitability Index (HSI) values of landscapes surrounding clear-cuts.

3) Compare the effects of current browse use on aspen stand characteristics of young (≤ 2 growing seasons) bigtooth and quaking aspen clear-cuts to historically observed effects.

4) Quantify the impacts of ungulate use on the stand characteristics of older (12-15 growing seasons) bigtooth and quaking aspen clear-cuts.

5) Provide management recommendations which will allow sustained production of timber products while maintaining adequate numbers of elk within the PRCSF for consumptive and nonconsumptive recreational opportunities.

STUDY AREA

This study was conducted during 1994 and 1995 in the Pigeon River Country State Forest (PRCSF). The PRCSF is located in the northern region of the lower peninsula of Michigan approximately 21 km east of Vanderbilt. It is located between approximately 45° 05' and 45° 20' longitude and 84° 20' and 84° 35' latitude. The 39,000 ha area contains portions of Cheboygan, Montmorency and Otsego counties (Figure 1). Headwaters of the Sturgeon, Pigeon, and Black river watersheds originate in coniferous forests in the southern portion of the Forest and flow northward toward Lake Huron. Elevations range from 275 m in bottomland areas to 365 m on morainic uplands. The area is typical of the high plateau type of Michigan's lower peninsula's northern highland (Veatch 1953). Podzol soils vary from relatively infertile sandy soils on outwash plains to fertile soils on till plains and moraines (Moran 1973).

The climate is both continental-type and semi-marine with large daily, monthly and seasonal temperature changes. Although winds from Lake Michigan and Lake Superior moderate weather extremes, winter temperatures and snowfall amounts are typically more severe than in surrounding areas (Moran 1973). Mean annual (1961-1990) temperatures range from -10 °C in January to 19 °C in July. The area receives a

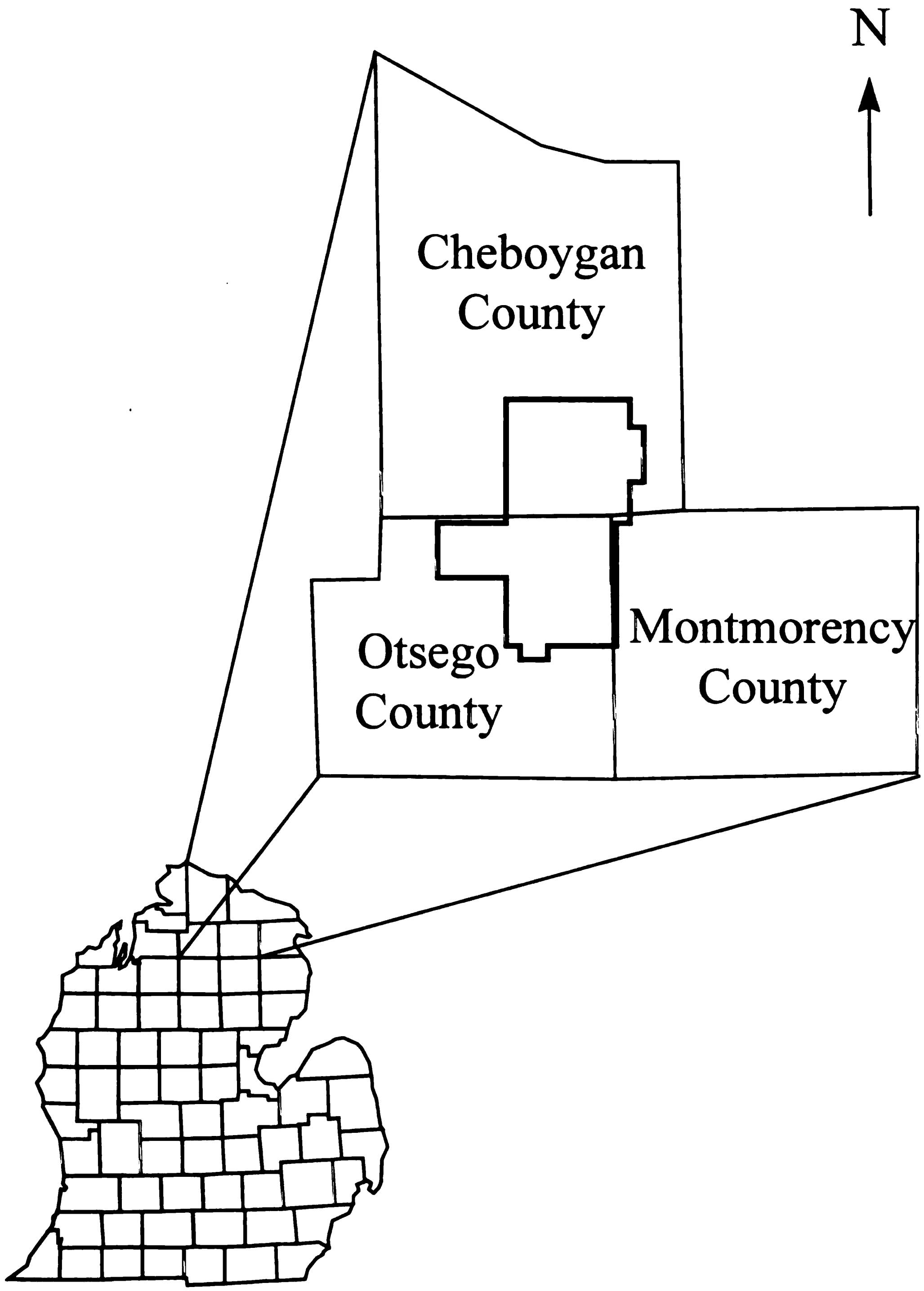
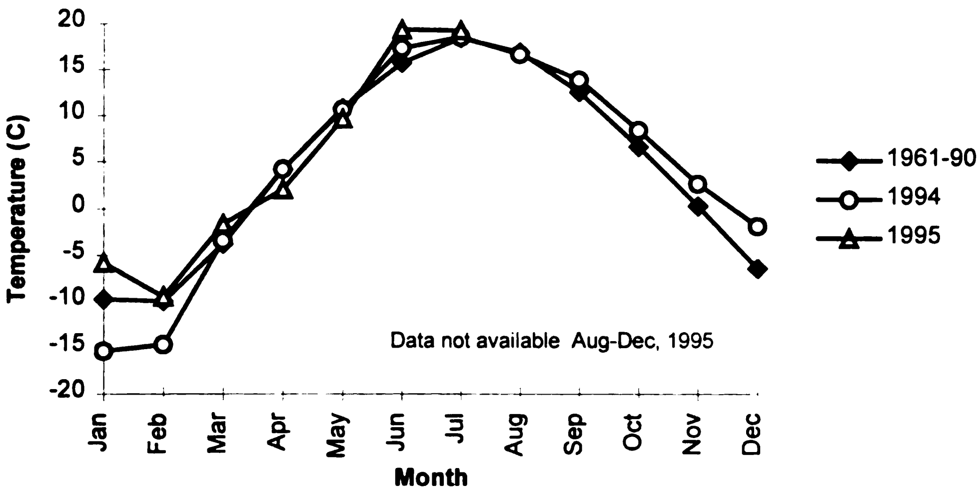


Figure 1. Location of Pigeon River Country State Forest (outlined area) in northern lower Michigan.

mean annual rainfall of approximately 79 cm (National Oceanic and Atmospheric Administration 1994) and average annual snowfall is 290 cm (Tardy 1991). During this study, mean monthly temperatures were similar to the long-term averages (National Oceanic and Atmospheric Administration 1994, 1995a-f) (Figure 2). However, mean monthly precipitation was more varied during 1994-95 (National Oceanic and Atmospheric Administration 1994, 1995a-f) (Figure 2).

The diversity of soil types, topography, and exposures of the region has lead to a variety of vegetation types. Seral stands developed following extensive logging, repeated burning, and limited attempts at agriculture during the late 1800's and early 1900's, further increasing the variety and distribution of habitat types. Spiegel et al. (1963) classified the area into 5 physiographic categories; morainic uplands, steep morainic slopes, outwash plain morainic ecotones, sandy outwash plains, and riverbanks and bottomlands. A sixth category, coniferous swamps, was described by Moran (1973).

Currently, 30 aspen clear-cuts in the PRCSF contain exclosures paired with areas open to browsing to assess the initial and long-term impacts of ungulate browsing on aspen stand characteristics. Eighteen of these exclosures were constructed throughout the PRCSF in the mid 1980's (Campa 1989), 6 were constructed during the summer of 1994, and 6 were constructed during the summer of 1995 (Table 1). Six additional exclosures will be constructed during the summer of 1996.



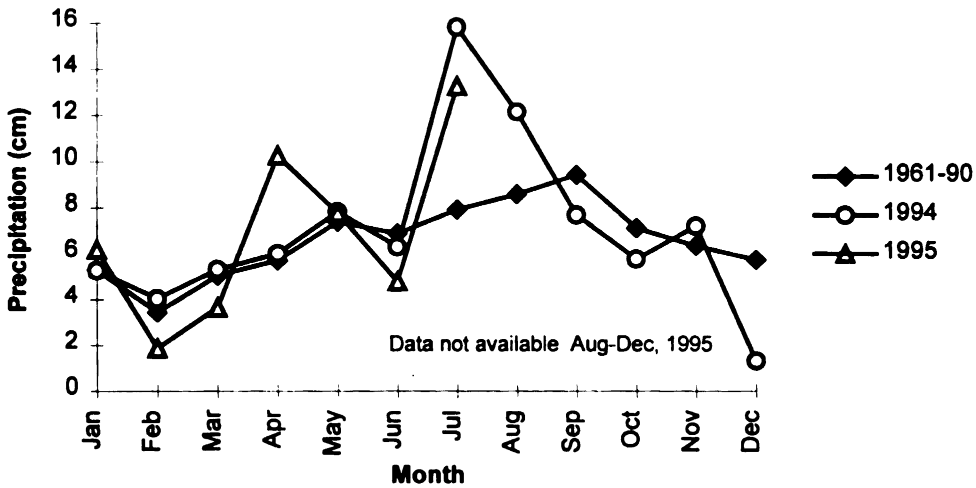


Figure 2. Mean monthly temperatures and precipitation at Vanderbilt, Michigan (21 km west of PRCSF) during years of the study (1994-95) and the long-term average (1961-90).

Table 1. Site number, aspen species, year cut, and legal description of exclosures and areas open to browsing in Pigeon River Country State Forest, Michigan.

Site	Aspen species	Year cut	Township	Range	Section
3	Bigtooth	82	T33N	R1E	NE1/4, SE1/4, Sec. 21
4	Bigtooth	82	T33N	R1E	NW1/4, SW1/4, Sec. 27
5	Quaking	82	T33N	R1W	NE1/4, SW1/4, Sec. 24
10	Bigtooth	82	T33N	R1W	SE1/4, NE1/4, Sec. 33
12	Bigtooth	81	T32N	R2W	SW1/4, NE1/4, Sec. 3
13	Bigtooth	81	T32N	R2W	NW1/4, NW1/4, Sec. 11
14	Quaking	81	T32N	R1W	SE1/4, SW1/4, Sec. 22
15	Quaking	81	T32N	R1W	SW1/4, SE1/4, Sec. 22
16	Bigtooth	81	T32N	R2W	NW1/4, NE1/4, Sec. 11
20	Quaking	81	T32N	R1W	NW1/4, SW1/4, Sec. 23
40	Quaking	82	T32N	R1W	SW1/4, NE1/4, Sec. 28
70	Quaking	82	T32N	R1W	NE1/4, NE1/4, Sec 29
71	Quaking	83	T32N	R1W	NW1/4, SW1/4, Sec 5
72	Bigtooth	83	T32N	R1W	NW1/4, SE1/4, Sec. 3
73	Bigtooth	83	T32N	R1W	NE1/4, SE1/4, Sec. 3
74	Bigtooth	83	T33N	R1E	NE1/4, SW1/4, Sec. 22
75	Quaking	83	T32N	R1W	NW1/4, NE1/4, Sec. 3
76	Quaking	83	T33N	R1W	NE1/4, NW1/4, Sec. 35
101	Quaking	94	T33N	R1W	NW1/4, NW1/4, Sec. 16
102	Quaking	94	T33N	R1W	NW1/4, SE1/4, Sec. 16
103	Quaking	94	T33N	R1W	NE1/4, SW1/4, Sec. 28
104	Bigtooth	94	T33N	R1W	SE1/4, SW1/4, Sec. 28

Table 1 (cont.)

Site	Species	Year cut	Township	Range	Section
105	Bigtooth	94	T33N	R1W	NE1/4, SW1/4, Sec. 33
106	Bigtooth	94	T21N	R1W	NW1/4, NE1/4, Sec. 13
107	Quaking	95	T33N	R1E	NW1/4, NE1/4, Sec. 3
108	Quaking	95	T33N	R1W	NE1/4, NE1/4, Sec. 13
109	Quaking	95	T32N	R2W	SE1/4, NE1/4, Sec. 19
110	Bigtooth	95	T34N	R1E	NE1/4, NE1/4, Sec. 29
111	Bigtooth	95	T33N	R1W	SE1/4, SW1/4, Sec. 7
112	Bigtooth	95	T32N	R1W	NE1/4, NW1/4, Sec. 5

BROWSE USE OF YOUNG ASPEN CLEAR-CUTS BY UNGULATES

Introduction

During the 1960's and 70's, natural resources managers expressed concern over the decline of the aspen forest type in the Great Lakes region. The primary cause of this decline was the succession of mature aspen stands into other forest types (Byelich et al. 1972, McGuire 1972). Heavy browsing by ungulates and the absence of fire also contributed to the decline of aspen forests in some areas (Westell 1954, Spiegel et al. 1963). Browsing can cause reductions in aspen forests by reducing regeneration, affecting growth rates, and altering the species composition of stands. In extreme cases, heavy browsing can reduce regeneration to such an extent that the stand may be converted into a grassland vegetation type (Spiegel et al. 1963). Excessive use of aspen suckers as browse by ungulates has also been cited as a major reason for reductions in timber production by reducing maximum tree height and altering growth forms (Westell 1954, Spiegel et al. 1963).

Historically, conditions suitable for the regeneration of aspen stands typically occurred following forests fires. Due to present management policies, however, the role of fires and other natural disturbances in setting back succession has been greatly reduced. Currently, most aspen regeneration occurs after silvicultural manipulations. Clear-cutting is the predominant silvicultural technique used to regenerate aspen because clear-cutting results in the greatest number of suckers (Graham et al. 1963, Schier and Smith 1979, Perala 1990). Furthermore, dormant season clear-cutting typically results in greater regeneration than growing season clear-cutting because nutrients have been transferred from the leaves to the root systems prior to leaf senescence. Thus, more stored energy is retained on site for sucker growth (Zehngraff 1949, Perala 1990).

Aspen regeneration in the Lake States can be very dense following clear-cutting, with typically 8,000 - 75,000 suckers/ha and occasionally up to 100,000 suckers/ha (Graham et al. 1963, Perala 1972, Laidly 1990, Perala 1990). Generally, quaking aspen clear-cuts produce more dense regeneration than bigtooth aspen clear-cuts (Campa 1989, Laidly 1990, Perala 1990). Sucker growth for both species is very rapid in the Great Lake states, and suckers can reach heights of 0.9-2.5 m during the first growing season.

The dense stands that arise after clear-cutting typically ensure the development of merchantable aspen stands because numerous stems can be lost before minimum stocking levels are reached (Westell 1954, Stoeckeler and Macon 1956, Graham et al. 1963). Many suckers die due to competition and natural thinning during the first several years of growth. Additional stem losses can occur due to browsing, trampling, and breaking of suckers by ungulates (Graham et al. 1963, DeByle 1985). However, losses in densely stocked stands are usually inconsequential to timber production unless ungulate numbers are exceptionally high regionally or locally (Packard 1942, Westell 1956, Alverson et al. 1988, Tilghman 1989, Perala 1990).

Young aspen suckers are a preferred browse by white-tailed deer and elk. White-tailed deer typically browse aspen during the summer, fall and winter (Aldous and Smith 1938, McCaffery et al. 1974, Rogers et al. 1981), while elk typically browse aspen in fall, winter, and spring (Moran 1973, Hobbs et al. 1979, Nelson and Leege 1982). Use of aspen by both ungulates occurs predominately during the fall and winter seasons. Young aspen stands typically experience the highest browse use (Spiegel et al. 1963, Beyer 1987), particularly stands < 4 growing seasons old (Campa 1989).

Heavy browsing, especially repeated browsing, can exhaust carbohydrate reserves in suckers, causing reduced growth and increased mortality (Perala 1990). Weakened suckers become more susceptible to browsing injuries that allow access for secondary attacks by insects or pathogens. Extensive browsing can result in a stand dominated by weakened and diseased trees with little value as timber (Graham et al. 1963, Perala 1990). Thus, herbivory has often been cited as one of the greatest hindrances to regenerating productive stands of aspen (Graham et al. 1963, Mueggler and Bartos 1977, DeByle 1979, Marquis and Brenneman 1981).

Heavy browse use within any particular stand can be the product of a combination of behavioral, environmental, and habitat-related factors. Campa (1989) found that browse use in clear-cuts in PRCSF can be predicted by the species of aspen, clear-cut age, and distance to the edge of the nearest coniferous swamp. Lyon and Ward (1982) have associated browse use with cover within or at the edge of the clear-cut and human access. Cover within and along the edge of the clear-cut provides security cover for animals while foraging, and is especially important if the clear-cut is accessible by humans. Ungulate use of clear-cuts and openings has been negatively correlated with road access into or near the opening (Knight 1975, Lyon and Jenson 1980, Lyon and Ward 1982, Grover and Thompson 1986).

Because many of the factors associated with browse utilization are related to habitat attributes, browse use within a clear-cut may be predicted by the overall quality of the habitat surrounding that clear-cut. According the HSI model developed by Beyer (1987), quality elk habitat can be quantified by the habitat components that potentially limit elk abundance. The 3 potentially limiting factors for elk relate to winter cover, winter food, and spring food. These components of quality elk habitat can be summarized into 1 value using the Michigan elk HSI model. Thus, the HSI value of landscapes surrounding current or proposed clear-cuts may be able to predict the levels of browsing that will occur within those clear-cuts.

Browse utilization may also be associated with localized elk distribution. During the seasons when the majority of browsing occurs, elk are typically congregated into groups (Beyer 1987). These groups tend to concentrate foraging efforts within local areas for several days to weeks. Local abundance of animals may predict the expected level of browse use within an area. Identifying the association between abundance, HSI values, and browse use may provide valuable information for formulating management goals by predicting the intensities at which future clear-cuts will be browsed and the quality of the resulting habitat.

In the 1980's, Campa (1989) found browse utilization in the PRCSF was significantly greater in bigtooth aspen clear-cuts than in quaking aspen clear-cuts and that browsing declined with age since harvest. Browse use in bigtooth clear-cuts ranged from 32 - 97% in 1-year-old cuts to 19% in 5-year-old cuts. Quaking aspen had 11 - 75% browse use in 1-year-old clear-cuts and 6 - 12% browse use in 5-year-old cuts. This variability in browse use maybe due to yearly changes in use as well as inherent site and landscape characteristics of individual clear-cuts. The forest-wide densities of white-tailed deer and elk in the 1980's is similar to the current forest-wide densities, however, since the 1980's elk densities have increased in some areas of the Forest and decreased in others (D. Whitcomb, MDNR, pers. commun.). Furthermore, a greater proportion of elk may be wintering outside of Forest boundaries, potentially reducing over-winter browsing pressures within the Forest (J. Jareki PRCSF area manager, pers. commun.).

The management objectives of PRCSF attempt to provide for multiple uses of natural resources. Some of the major objectives are to provide favorable habitat for elk for consumptive and nonconsumptive purposes, to allow harvest of timber resources, and provide quality habitat for other wildlife species. To facilitate the fulfillment of the Forest's goals, the objectives of this portion of the study were: 1) to quantify browse utilization of young (≤ 3 growing seasons) bigtooth and quaking aspen clear-cuts in the PRCSF and compare to levels documented in the mid 1980's and 2) to identify the association between browsing intensity on young (≤ 2 growing seasons) bigtooth and quaking aspen clear-cuts and relative elk abundance, as well as the association between browsing intensity and to the HSI value of landscapes surrounding clear-cuts.

Methods

Experimental design

To evaluate the current levels of browsing on young bigtooth and quaking aspen clear-cuts, browse estimates were conducted in 52 clear-cuts in the PRCSF. Browse utilization counts were conducted prior to the development of current annual growth and leaf-out to quantify fall and winter utilization of twigs. All aspen clear-cuts (n = 52) were between 1- and 3-years-old and were classified by species (bigtooth, quaking, or mixed). Sampling was stratified by species within clear-cuts having mixed species composition of both bigtooth and quaking aspen. All clear-cuts were sampled during early spring, April and May, 1995.

To quantify the relationship between the browsing intensity on young aspen clear-cuts and relative abundance of elk to HSI values of landscapes surrounding clear-cuts, 8 1- and 2-year-old bigtooth and quaking aspen clear-cuts were randomly selected from the clear-cuts sampled for browse use. Beyer's (1987) elk HSI model was used to calculate HSI values for the landscapes surrounding aspen clear-cuts. All stands within 10 km^2 of the selected clear-cuts, the minimum area required to provide food and cover as defined in the model, were classified according to cover type and stocking density. Stocking classes (sapling, poletimber, and sawtimber) were defined using Michigan State Forest Operations Inventory (1982) (Table 2). Ten vegetation and stand characteristics were measured within 7 distinct cover types (Table 3). Variables were measured in 3 randomly selected stands representing each cover type and stocking class within the 10 km^2 evaluation areas.

To assess local abundances and concentrations of ungulates, 3 permanent 24-32 km (15-20 mile) driving survey routes were conducted in the PRCSF during April and May, 1995, and November 1994 and 1995. A survey route was located in each of the major elk hunting management units within the PRCSF boundaries (Figure 3).

Table 2. Stocking class code, growth stage, mean DBH, and stocking density for forest stands as defined by the Michigan State Forest Operations Inventory system (1982).

Stocking class code	Growth stage	Mean DBH (cm)	Stocking density
0	Nonstocked		< 17%
1	Seedling-sapling	0.0-12.6	Poor (17-39%)
2	Seedling-sapling	0.0-12.6	Medium (40-69%)
3	Seedling-sapling	0.0-12.6	Well (> 69%)
4	Poletimber	12.7-25.3	Poor (2.3-9.1 m^2/ha)
5	Poletimber	12.7-25.3	Medium (9.2-16.0 m^2/ha)
6	Poletimber	12.7-25.3	Well (> 16.0 m^2/ha)
7	Sawtimber	> 25.3	Poor (2.3-9.1 m^2/ha)
8	Sawtimber	> 25.3	Medium (9.2-16.0 m^2/ha)
9	Sawtimber	> 25.3	Well (> 16.0 m^2/ha)

Table 3. Elk habitat suitability index (HSI) model (Beyer 1987) and Michigan State Forest Operations Inventory (1982) (MSFOI) cover type classifications for wooded areas.

HSI model cover type	MSFOI cover type code	MSFOI cover type
Aspen	A	Aspen
Cedar	C	Cedar
Maple	M	Maple
Oak	O	Oak
Other hardwoods	B	Paper birch
	E	Swamp hardwoods
	P	Balsam poplar
Swamp conifers	H	Hemlock
	Q	Mixed swamp conifers
	S	Black spruce
	T	Tamarack
Upland conifers	F	Upland spruce-fir
	J	Jack pine
	R	Red pine
	W	White pine

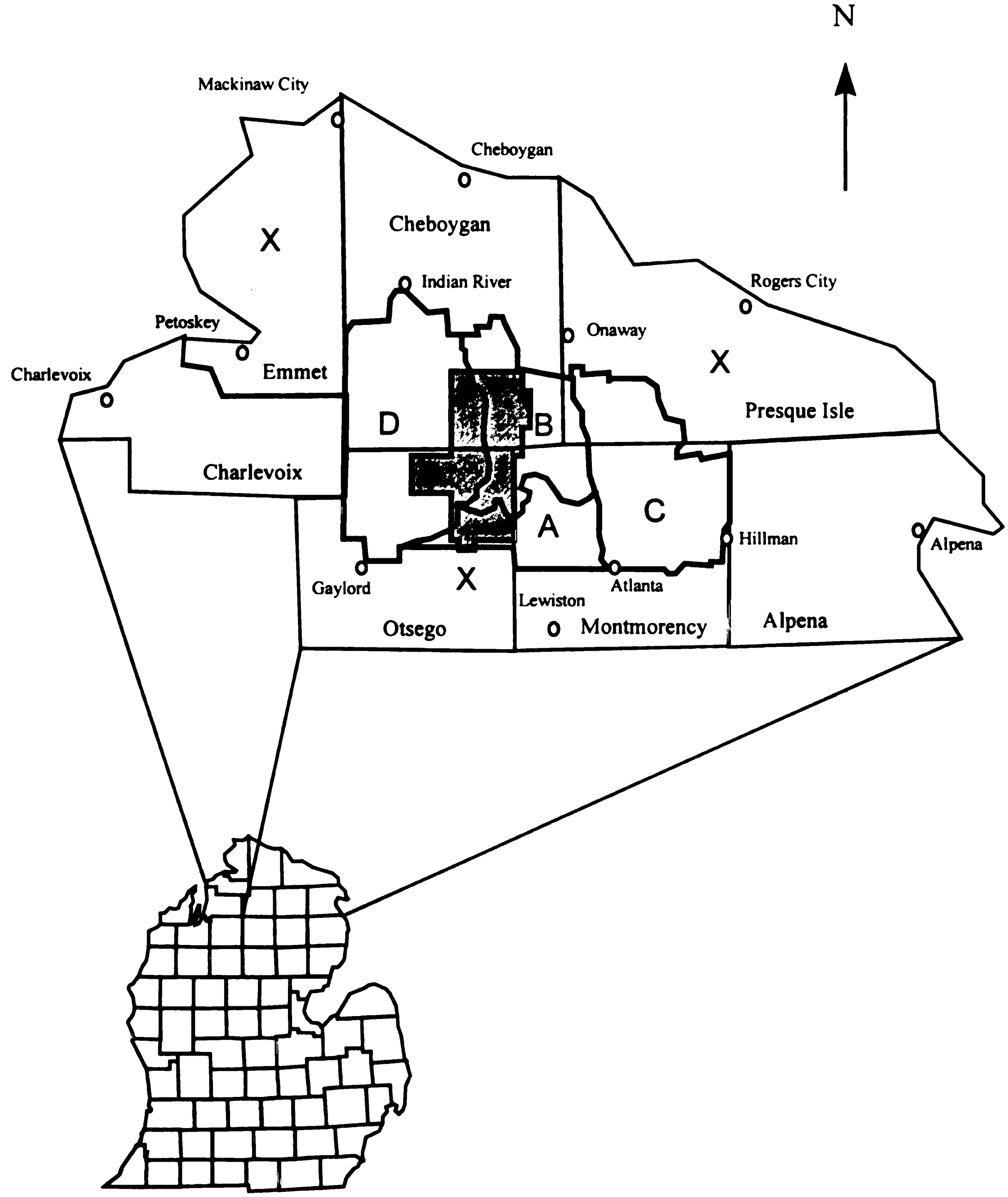


Figure 3. Location of MDNR elk management units within northern lower Michigan. The PRCSF (shaded area) is located within portions of management units A, B, and D.

Sampling methods

Browse use intensity was estimated by the number of browsed twigs (≤ 2.0 m in height) of the first 100 twigs encountered in 1 m-wide belt transects randomly placed within young (≤3 growing season) clear-cuts (Gysel and Lyon 1980). A 2.0 m height was used because vegetation above this height is generally unavailable for use by white-tailed deer and elk (Gaffney 1941, Aldous 1952, Alverson et al. 1988). Twigs were defined as individual branches whereas stems were defined as individual suckers. Twigs per ha, percentage of browsed stems, and stems per ha were recorded to compare browse use with browse availability.

Adequate sample sizes for all variables were determined using Freese's (1978) formula with a 90% confidence interval and an allowable error of 10% of the mean.

$$\text{Sample Size } (n) = \frac{s^2 * t^2}{(\bar{x} * \alpha)^2}$$

Where:
s^2 = variance
t^2 = critical t for n degrees of freedom and α
$\bar{x}$ = sample mean
α = allowable error

Freese's (1978) formula was initially calculated from a preliminary sample (simple random sample with replacement). Additional samples were taken and Freese's formula was recalculated using all samples until the recommended n was reached or 20 samples were collected. Twenty samples were determined as the maximum desired sampling effort per clear-cut to enable a greater number of clear-cuts to be sampled during the time available.

The Michigan elk HSI model consists of 3 sub-models (winter thermal cover, winter food, and spring food) and includes 10 modifying variables. All cover types within 10 km^2 of the selected clear-cuts were sampled to assign sub-model SI values based on the variable modifiers. Table 4 describes a list of the habitat variables measured, the appropriate cover types sampled for each variable, and the sampling technique used. Four variables (stand size, canopy closure, management system, and tree height) were measured within cedar, swamp conifer, and upland conifer stands (Table 4). Additionally, density of cedar < 7.5 m in height was recorded within cedar stands and hardwood stem density was recorded within upland conifer stands. Hardwood stem density, tree DBH (diameter at breast height - 1.4 m above the ground), and frequency of conifers in the understory were measured in maple, oak, and other hardwood stands. Aspen stands were sampled for 3 variables: tree DBH, frequency of conifers in the understory, and tree height. Basal area (BA) (the stem area occupied by trees) of the stand (m^2/ha) was calculated from tree DBH and tree density. BA was calculated for maple, oak, aspen, and other hardwood stands. Vegetation characteristics were sampled in 3 randomly (simple random selection without replacement) selected stands representing each cover type and stocking class within the 10 km^2 evaluation areas. A simple random sampling design with replacement was used to locate 3 vegetation sampling locations within each stand.

The SI value of each sub-model was calculated for each evaluation area. Final HSI values for an evaluation area, as described by Beyer (1987), equals the lowest sub-model SI value. Winter cover suitability values (WCSV) were calculated from the optimum SI value (assigned by cover type) multiplied by the SI of all applicable

Table 4. Elk habitat suitability index (HSI) model (Beyer 1987) habitat variables and modifiers, their associated cover types and sampling technique.

Variable or modifier	Cover type(s)	Sampling technique
MOD 1 = stand size	Cedar Swamp conifers Upland conifers	Michigan State Forest Operations Inventory
MOD 2 = canopy closure	Cedar Swamp conifers Upland conifers	Line intercept (20 m) vegetation ≥ 2.0 m
MOD 3 = management system: even-aged or uneven-aged	Cedar Swamp conifers Upland conifers	Field inspection
MOD 4 = tree height	Cedar Swamp conifers Upland conifers	Haga altimeter (Forestry Suppliers, Inc., Jackson, Miss.) n=10 systematically selected trees/20 x 4 m plot when available
MOD 5 = basal area	Aspen Maple Oak Other hardwoods	Calculated from DBH
MOD 6 = tree DBH	Aspen Maple Oak Other hardwoods	DBH tape n=10 systematically selected trees/20 x 4 m plot when available
MOD 7 = frequency of conifers in understory ≥ 1 m	Aspen Maple Oak Other hardwoods	3 - 5 x 5 m sub-plots associated with each 20 x 4 m plot
MOD 8 = tree height	Aspen	same as MOD 4
MOD 9 = density of cedar (<7.5 m)	Cedar	Plot sampling (20 x 4 m)
MOD 10 = hardwood stem density	Upland conifers Maple Oak Other hardwoods	Plot sampling (20 x 2 m)

modifying variables. Tree height (Mod 4) is used only for uneven-aged stands. Winter cover suitability index (SI) values are calculated for the stands that represent 10% of the total area with the highest potential SI values. For all evaluation areas, these stands were within cedar, swamp conifer, and upland conifer cover types. Furthermore, only older, more developed stands (age class 2 - poletimber and 3 - sawtimber) were used to calculate the WCSV because these stands potentially provide better winter thermal cover than young sapling (age class 1) dominated stands. The WCSV equals the sum of winter cover SI values divided by the total area of the stands (10%) (Beyer 1987). Winter food and spring food are calculated in a similar manner. Again, only a percentage of the area is used to calculate the sub-model SI values - 15% for winter food suitability values (WFSV) and 10% for spring food suitability values (SFSV). WFSVs were calculated from SIs of seedling-sapling age aspen stands. SFSVs were calculated from SIs of managed openings, natural openings, and seedling-sapling age aspen stands. Managed openings are defined as openings that the MDNR maintains by mowing, discing, or planting with alfalfa, rye, buckwheat, or clover.

To assess local abundances and concentrations of ungulates, driving surveys were conducted from 1 to 1½ hours after dawn and before dusk. Survey routes were driven as many times as possible during the time available subject to weather. Surveys were not conducted during adverse weather conditions (rain, heavy wind, snow, and fog). The number and sex of elk, number of elk groups, and general location were recorded for each observation. The same information regarding white-tailed deer was also collected.

Data analysis

Browse use and twig density between aspen species and among clear-cut age classes were compared using 1-way analysis of variance in conjunction with Tukey's multiple comparisons (Gill 1978). Current (1995) and historical (pooled years 1983-86) browse utilization levels were compared with 2-tailed t-tests (Gill 1978). For parametric tests, percentage data were transformed with the arcsine function prior to statistical analysis (Steel and Torrie 1980). Correlation coefficients were calculated for browse use and relative clear-cut isolation by clear-cut species using Spearman's rank-order correlation coefficient (Siegel 1988). Regression analysis was used to test for linear association between relative isolation of clear-cuts and percent browse use for bigtooth and quaking aspen clear-cuts (Gill 1978). Correlation coefficients were not calculated for browse use and HSI values and for browse intensity and relative abundance of elk due to the small sample sizes for these variables. The minimum acceptable level of significance for all tests was set at $\propto = 0.10$.

Results and Discussion

Browse use of 1- to 3-year-old clear-cuts

Percent browse use varied with species and age of clear-cut. For each species, browse use was highest in 1-year-old cuts with bigtooth use at 83% ± 1% (standard error) and quaking use at 38% ± 1%. Percent browse use was lowest for both species in 3-year-old clear-cuts with bigtooth use at 43% ± 2% and quaking use at 4% ± <1% (Table 5). Browsing intensity decreased significantly ($P < 0.01$) with age since harvest on bigtooth and quaking clear-cuts with one exception. There was no significant difference in browse use between 2- and 3-year-old quaking aspen clear-cuts. Bigtooth aspen clear-cuts were browsed significantly ($P < 0.01$) more than quaking aspen clear-cuts for all age classes.

The overall mean percent browse use combined for both species and all age classes was 45% ± 4%. This value is more comparable to previously reported browse use values that do not separate clear-cuts by age or species. For example, Westell (1954) reported a mean browse use of 21% in clear-cuts located in the northwestern portion of the lower peninsula of Michigan, and 42% in the northeast. His northeastern sampling area includes portions of the elk range, so these estimates likely include both white-tailed deer and elk browsing. Furthermore, his reported value of 42% is very similar to the overall mean of 45% found currently in the PRCSF. Spiegel et al. (1963) conducted a study in the early 1960's in the PRCSF on the effects of elk browsing on woody plant succession. They reported browse use of aspen in young aspen stands of up to 100% in some areas, particularly for bigtooth aspen. Similar to current trends, Spiegel et al. (1963) also found that quaking aspen use was much lower than bigtooth use.

When comparing browse use among years, the current levels of browsing were similar to values measured previously in the 1980's (Table 6). No significant differences ($P > 0.10$) were found between current and historic levels of browsing on any age of bigtooth aspen clear-cut. Two and 3-year-old quaking cuts showed significantly ($P < 0.10$) less browsing in 1995 than in the pooled years 1983 through 1986. These lower values may be attributed to changes in management practices within the PRCSF, relative abundance of ungulates, or relative abundance of food resources.

Table 5. Mean percent browse use of twigs (standard error) on 1-, 2- and 3-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

	Age		
Aspen species	1	2	3
Bigtooth	83 (1) A*	64 (1) B	43 (2) C
Quaking	38 (1) D	10 (1) E	4 (<1) E

* Means within a row or column with different letters are significantly different (P < 0.01) (ANOVA, Tukey's multiple comparisons, Gill 1978).

Table 6. Significant differences (P < 0.10) in mean percent browse use of twigs (standard error) on 1-, 2- and 3-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan between years (1983-6 and 1995).

	Age					
	1		2		3	
Aspen species	1995	1983-86	1995	1983-86	1995	1983-86
Bigtooth	83 (1)	71 (14)	64 (1)	75 (11)	43 (2)	68 (13)
Quaking	38 (1)	45 (13)	10 (1)*	36 (9)	4 (<1)*	21(4)

Data from 1983-1986 1- to 3-year-old clear-cuts is from Campa 1989.
* = Significantly different (P < 0.10) than pooled years 1983-86 (t-test, Gill 1978).

Since the early 1980's managers in PRCSF have endeavored to reduce browse use in aspen clear-cuts by attempting to decrease the isolation of individual clear-cuts, distribute clear-cuts more homogeneously throughout the forest, and increase available acreage of cultivated openings to (J. Jarecki, PRCSF, pers. commun.). However, if lower browse use is desired, the lack of browse use reduction since the 1980s suggests these techniques may not be adequately addressing the problem.

There is little evidence to suggest that decreasing the isolation of clear-cuts reduces the level of browsing they sustain. Browse use on quaking aspen clear-cuts was not significantly correlated ($P > 0.50$) to the number of other clear-cuts within 1.6 km (Figure 4). Furthermore, browse use on bigtooth aspen clear-cuts was positively correlated ($P < 0.001$) with the number of other clear-cuts within 1.6 km (Figure 4). However, no significant linear relationships were identified for either bigtooth ($R^2 = 0.35$) or quaking ($R^2 = 0.001$) aspen clear-cuts. More investigation is necessary to evaluate the effects of clear-cut distribution on browse use.

As a whole in 1994, 1- to 3-year-old clear-cuts were distributed relatively homogeneously throughout the PFCSF, however distribution was not homogeneous when clear-cuts were separated by age and species. For example, all 2- and 3-year-old quaking aspen clear-cuts, the age classes in which browse use has significantly decreased since the early to mid-eighties, were located within MDNR elk management units B and D where elk numbers have increased since 1985 (D. Whitcomb, MDNR, pers. commun.). Homogeneous distribution of clear-cuts within 1 cutting season may be more important than homogeneous distribution across several cutting seasons due to the greater browse use observed on 1-year-old clear- cuts (Table 5). In 1994, the mean number of hectares

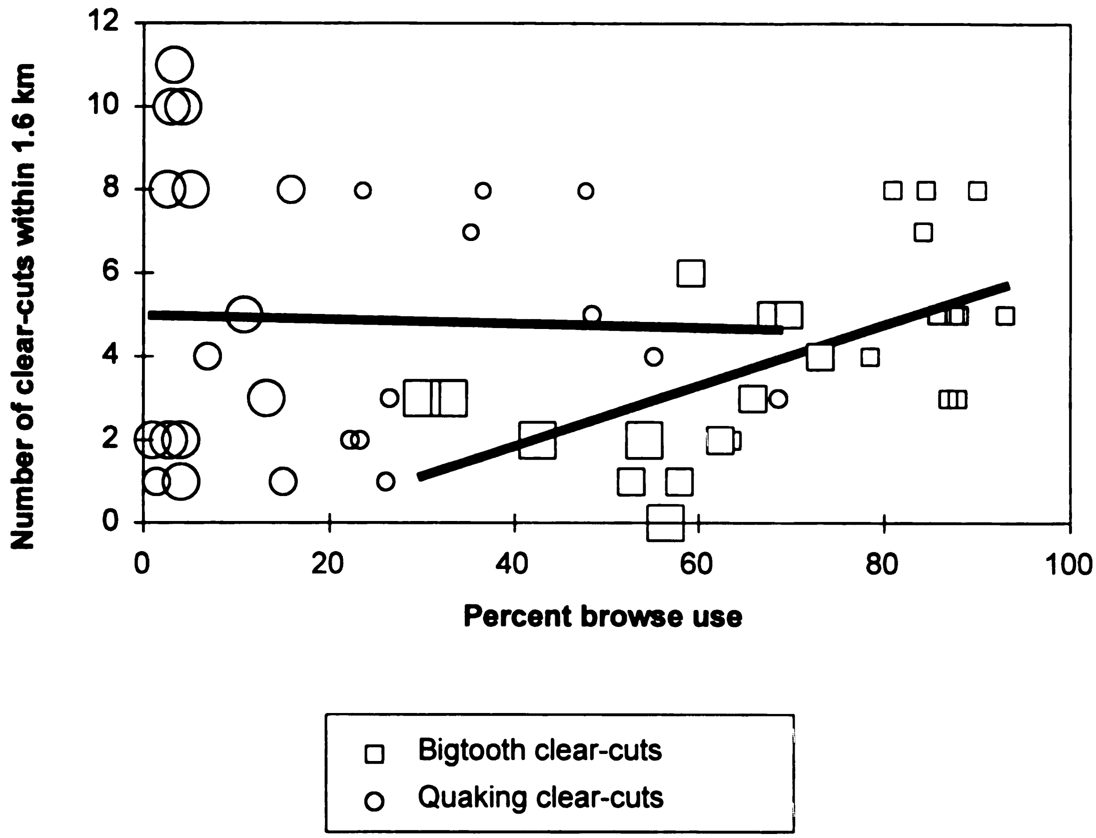


Figure 4. Least squares estimates of the relationship between the relative isolation (number of other aspen clear-cuts within 1.6 km) and percent browse use 1- (larger symbols) to 3-year-old (smaller symbols) on bigtooth ($R^2 = 0.35$, slope = 0.1, intercept = -2.5) and quaking ($R^2 = 0.0.001$, slope = -0.007, intercept = 5.1) aspen clear-cuts in the Pigeon River Country State Forest, Michigan, with linear regression trends indicated for each species.

of culturally treated openings in PRCSF was less than ½ the number of hectares treated per year from 1982-1985 (J. Jarecki, PRCSF, pers. commun.). Thus the reduction of browse use on 2- and 3-year-old quaking aspen clear-cuts may be related to the availability of foraging areas other than managed openings such as bigtooth clear-cuts, regenerating maple and other hardwoods, and private lands. The lack of reduction in browsing intensities on bigtooth aspen clear-cuts may be a result of the limited and localized distribution of this species in the PRCSF and its greater nutritional qualities than quaking aspen (Campa et al. 1992).

There are 3 ways ungulates can use food in relation to its availability: 1) relatively, 2) absolutely, and 3) preferentially. Relative use implies that ungulates remove an equal proportion of food available. In this case the percent browse use measured would be equal regardless of clear-cut age or species. For example, given 18 clear-cuts of a variety of ages and species composition, mean percent browse use would be 50% for each clear-cut. As discussed, however, percent browse use in the PRCSF is not equal across species and age class (Table 5). The next possible theory is that ungulates use a consistent absolute amount of food, meaning there is a threshold limit to consumption at which ungulates become satiated. In this case, the actual number of twigs removed by ungulates should be equal across clear-cuts rather than the proportion of twigs. For example, given 18 clear-cuts of various ages and species composition, 1,000 twigs of each individual clear-cut would be browsed by ungulates. This may be a mean percent browse use of 50% for clear-cut "A" but 30% for clear-cut "B". In the PRCSF, the absolute number of twigs removed from clear-cuts varied by clear-cut age and species (Table 7), indicating ungulate use of aspen is not absolute. However, mean total percent

Table 7. Mean number of twigs browsed per hectare (standard error) on 1-, 2-, and 3-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

	Age		
Aspen species	1	2	3
Bigtooth	37,748 (319)	53,754 (867)	50,162 (2783)
Quaking	25,916 (967)	16,634 (3277)	15,554 (1207)

of twigs browsed does not account for the days of use or the number of ungulates feeding within a clear-cut. Animals may remain in an area for several days, and by becoming satiated each day, increase the total percent browse use for that clear-cut. If animals remain in an area to feed for several days they are showing a preference for that area. Preferential use of forage means animals are using a particular food more often than another food in relation to each food's availability.

The preference of bigtooth aspen over quaking became evident when comparing the percent browse use of each species to its availability. Quaking aspen clear-cuts had significantly greater ($P < 0.05$) numbers of twigs per ha than bigtooth stands of the same age (Table 8), but ungulates removed a smaller portion of available twigs from quaking cuts than from bigtooth cuts (Table 5). Not only were a greater proportion of bigtooth twigs browsed, but also a higher total number of bigtooth twigs were browsed regardless of their lower availability. These data support previous research by Campa (1989) showing a preference for bigtooth aspen over quaking aspen. Furthermore, for both species the total number of twigs increased significantly ($P < 0.05$) with age, but browse use decreased with age.

Preference for bigtooth aspen may be related to the species' chemical composition and/or vegetation structure. First, there is some evidence that greater browsing pressures inflicted on bigtooth aspen may be due to its higher nutritional value and palatability to ungulates (Campa et al. 1992). Likewise, younger aspen suckers are preferred over older suckers because young suckers have greater protein levels and digestibility, and possibly lower secondary plant compounds (Campa 1989). Secondly, preference of bigtooth aspen over quaking aspen may be related to tree structure. Clear-cuts with greater levels

Table 8. Mean number of twigs per hectare (and standard error) on 1-, 2-, and 3-year-old bigtooth and quaking aspen clear-cuts Pigeon River Country State Forest, Michigan (1995).

	Age		
Aspen species	1	2	3
Bigtooth	45,640 (1,635) A	83,747 (6,682) B	116,170 (6,331) B
Quaking	68,890 (1,380) C	166,837 (11,297) D	362,988 (16,020) E

* Means within a row or column with different letters are significantly different ($P < 0.10$) (ANOVA, Tukey's multiple comparisons, Gill 1978).

of browsing had significantly fewer ($P < 0.001$) mean twigs per stem than areas with less browsing. Twigs in the middle of dense clumps may be less available to ungulates, thus effectively reducing browse availability within these stands. Likewise, more densely branched suckers could hinder ungulate movement throughout the clear-cuts, again reducing total available forage. The lower numbers of twigs per stem on more highly utilized clear-cuts could be a direct of indirect artifact of that use. Intensive browse use may remove such a large proportion of the twigs that direct removal is resulting in significantly fewer twigs per stem. Alternatively, the removal of twigs may result in a physiological response by the tree resulting in fewer branches. Further investigation is warranted to discern the causal relationship between tree structure and browse use.

Elk abundance indices

Driving surveys were conducted in November 1994, and April, May, and November 1995. Survey information from April and May was pooled into 1 spring index. Because the 3 routes were not the same length (A = 28 km, B = 24 km, D = 27 km), the number of elk observed per km was calculated to standardize the data. Mean elk observations, number of elk groups, and mean elk/km were higher in spring (April and May) than fall (November) (Table 9).

The number of elk observed during driving routes is likely related to the seasonal behavior of elk. More elk were observed in spring because animals are concentrated in open areas where they are highly visible (Beyer 1987). During November elk tend to be in less open vegetation types, thus making them more difficult to observe. The number of elk groups observed was highest in spring, when cows begin to separate from larger groups for calving (Moran 1973). Additionally, visibility may be influenced by human

Table 9. Mean number of elk observed (standard error), mean number of groups (standard error), and mean elk/km (standard error) within elk management units in Pigeon River Country State Forest, Michigan (1994-5).

Date	Management unit	Number of transects	Number of elk observed	Number of groups	Elk/km
Fall 1994	A	2	0.5 (0.4)	0.5 (0.4)	0.0 (0.0)
	B	2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	D	2	2.0 (1.4)	0.5 (0.4)	0.1 (0.1)
Spring 1995	A	8	8.9 (4.3)	1.1 (0.2)	0.3 (0.2)
	B	8	7.9 (3.6)	1.5 (0.4)	0.3 (0.1)
	D	8	5.4 (1.4)	2.0 (0.5)	0.2 (0.1)
Fall 1995	A	4	0.3 (0.3)	0.3 (0.3)	0.0 (0.0)
	B	4	4.8 (1.7)	1.0 (0.4)	0.2 (0.1)
	D	4	0.5 (0.3)	0.5 (0.3)	0.0 (0.0)

activities such as hunting, hiking, and mushroom, berry, and timber harvesting. For example, Bender (1992) found that the flight distance of elk, or the distance to which a person can approach an elk without causing it to flee, had increased since the initiation of annual hunting in 1984. Thus human activities, as well as season may, effect elk visibility.

Elk habitat suitability index (HSI) values

The HSI values for all 8 evaluation areas were relatively low (0.20 - 0.51) (Table 10). For 6 of the 8 evaluation areas the HSI values were determined by the winter cover suitability value (WCSV), while the winter food suitability value (WFSV) was the limiting factor which determined the overall HSI for the other 2 areas. Spring food suitability values (SFSV) were also low, ranging from 0.29 - 0.63.

In most cases, the dominating factor that led to low HSI values was the lack of minimum area in optimum cover types. Ten percent of the evaluation area must contain stands with optimum winter cover suitability values and spring food suitability values and 15% of the evaluation area must contain optimum winter food suitability values. For example, only cedar and swamp conifer cover types can provide optimum winter thermal cover, and each evaluation area contained less than 10% of these cover types. Likewise managed openings represented the highest potential for spring food but were underrepresented within evaluation areas. Optimum elk habitat contains a minimum of 10% area within the managed opening cover type (Beyer 1987). The specific habitat attributes within cover types which caused the HSI values to be low can be identified by examining the SI values contributing to each individual sub-model. For the WCSV sub-

Table 10. Mean winter cover suitability values (WCSV), winter food suitability values (WFSV), spring food suitability values (SFSV), and habitat suitability index (HSI) values of landscapes surrounding 1- and 2-year old bigtooth and quaking aspen clear-cuts in Pigeon River County State Forest, Michigan for each evaluation area.

Species	Age	WCSV	WFSV	SFSV	HSI
Bigtooth	1	0.36	**0.33**	0.48	**0.33**[a]
	1	**0.27**	0.45	0.58	**0.27**
	2	**0.24**	0.33	0.35	**0.24**
	2	**0.20**	0.35	0.39	**0.20**
Quaking	1	**0.40**	0.67	0.63	**0.40**
	1	**0.28**	0.34	0.39	**0.28**
	2	0.61	**0.18**	0.29	**0.18**
	2	**0.51**	0.67	0.57	**0.51**

[a] HSI value equals the lowest of the 3 sub-model suitability values (SV) (Beyer 1987). The SV which determines the final HSI value is in boldface.

model, the variables contributing the lowest SI values (≤ 0.70) were primarily the width of the stand (Mod 1) and stand management system (Mod 4: even- or uneven-aged) (Table 11 - Table 14). Optimally, conifer stands should be a minimum of 150 m across and managed as even-aged. For both food sub-models, WFSV and SFSV, only the aspen cover type required a modifying variable. Consequently, aspen tree height (Mod 8) was primarily responsible for reducing winter (Table 15) and spring food (Table 16) SI values.

The calculated HSI values indicate relatively poor to marginal habitat quality for elk in the evaluation areas examined (Table 10). However, the elk population has remained relatively stable within the forest over the last 10 years and has been growing steadily during this time across its entire range. There are several possible explanations for this apparent contradiction. First, the elk population may have a patchy distribution throughout the forest, and it is possible the evaluation areas were randomly located within pockets of poor habitat. Several of the aspen clear-cuts located centrally within evaluation areas experienced heavy browsing pressure which may contribute to poor quality habitat.

Secondly, the HSI model may not accurately reflect habitat quality. It is important to note that the Michigan elk HSI model has not been validated and this is the first attempt at application of the model. These data suggest that more research is needed to address the validity of the model and that some modifications may be warranted to refine the model.

Table 11. Optimum winter cover suitability index (SI) value, mean SI of modifying variables (standard error), and mean winter cover suitability index values (standard error) of landscapes surrounding 1-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan by cover type, age class, and management system.

Cover type	Age[a] class	Even-aged/ uneven-aged	Optimum SI	Mod 1[b]	Mod 2	Mod 3	Mod 4	Winter cover SI
Cedar	2	E	1.00	0.38 (0.02)	0.99 (0.01)	1.00 (0.00)	0.84 (0.16)	0.31 (0.04)
Cedar	2	U	1.00	0.33 (0.14)	0.91 (0.09)	0.26 (0.00)	NA	0.07 (0.02)
Cedar	3	E	1.00	0.67[c]	0.93	1.00	1.00	0.62
Swamp Conifer	2	E	1.00	0.65 (0.10)	0.88 (0.01)	1.00 (0.00)	1.00 (0.00)	0.59 (0.10)
Swamp Conifer	2	U	1.00	0.78 (0.11)	0.85 (0.15)	0.26 (0.00)	NA	0.17 (0.01)
Upland Conifer	2	E	0.5	0.80 (0.02)	0.82 (0.18)	1.00 (0.00)	0.95 (0.03)	0.62 (0.05)
Upland Conifer	2	U	0.5	0.44[c]	1.00	0.26	NA	0.06
Upland Conifer	3	E	0.5	1.00 (0.07)	0.96 (0.01)	1.00 (0.00)	0.95 (0.05)	0.91 (0.38)
Upland Conifer	3	U	0.5	1.00 (0.03)	0.77 (0.23)	0.26 (0.00)	NA	0.20 (0.02)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.

[b] Mod 1 = SI value for width of stand.
Mod 2 = SI value for percent canopy closure.
Mod 3 = SI value for management system (even- or uneven-aged stand).
Mod 4 = SI value for height of trees.

[c] Standard error not calculated (n = 1).

Table 12. Optimum winter cover suitability index (SI) value, mean SI of modifying variables (standard error), and mean winter cover suitability index values (standard error) of landscapes surrounding 2-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan by cover type, age class, and management system.

Cover type	Age[a] class	Even-aged/ uneven-aged	Optimum SI	Mod 1[b]	Mod 2	Mod 3	Mod 4	Winter cover SI
Cedar	2	U	1.00	0.80 (0.02)	1.00 (0.00)	0.26 (0.00)	NA	0.20 (0.01)
Swamp Conifer	2	E	1.00	0.46 (0.02)	1.00 (0.00)	1.00 (0.00)	0.70 (0.00)	0.32 (0.01)
Swamp Conifer	2	U	1.00	0.43[c]	1.00	0.26	NA	0.11
Swamp Conifer	3	E	1.00	0.35[c]	1.00	1.00	0.68	0.24
Upland Conifer	2	E	0.5	0.61 (0.14)	0.82 (0.08)	1.00 (0.00)	0.72 (0.10)	0.40 (0.00)
Upland Conifer	3	E	0.5	0.98[c]	1.00	1.00	0.30	0.29
Upland Conifer	3	U	0.5	0.71 (0.03)	0.90 (0.01)	0.26 (0.00)	NA	0.17 (0.00)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.

[b] Mod 1 = SI value for width of stand.
Mod 2 = SI value for percent canopy closure.
Mod 3 = SI value for management system (even- or uneven-aged stand).
Mod 4 = SI value for height of trees.

[c] Standard error not calculated (n = 1).

Table 13. Optimum winter cover suitability index (SI) value, mean SI of modifying variables (standard error), and mean winter cover suitability index values (standard error) of landscapes surrounding 1-year-old quaking aspen clear-cuts in Pigeon River Country Forest, Michigan by cover type, age class, and management system.

Cover type	Age[a] class	Even-aged/ uneven-aged	Optimum SI value	Mod 1[b]	Mod 2	Mod 3	Mod 4	Winter cover SI
Cedar	2	E	1.00	0.67 (0.23)	0.85 (0.08)	1.00 (0.00)	0.77 (0.22)	0.45 (0.26)
Cedar	3	E	1.00	0.67[c]	0.93	1.00	1.00	0.62
Swamp Conifer	2	E	1.00	0.62 (0.07)	0.89 (0.01)	1.00 (0.00)	0.92 (0.12)	0.55 (0.23)
Swamp Conifer	2	U	1.00	0.71 (0.18)	0.81 (0.10)	0.26 (0.00)	NA	0.14 (0.02)
Upland Conifer	2	E	0.5	0.76 (0.03)	0.64 (0.07)	1.00 (0.00)	0.88 (0.11)	0.20 (0.06)
Upland Conifer	2	U	0.5	1.00 (0.04)	0.94 (0.07)	0.26 (0.00)	NA	0.24 (0.01)
Upland Conifer	3	E	0.5	0.75 (0.22)	0.98 (0.02)	1.00 (0.00)	1.00 (0.00)	0.74 (0.10)
Upland Conifer	3	U	0.5	0.56 (0.32)	0.77 (0.22)	0.26 (0.00)	NA	0.11 (0.02)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.
[b] Mod 1 = SI value for width of stand.
Mod 2 = SI value for percent canopy closure.
Mod 3 = SI value for management system (even- or uneven-aged stand).
Mod 4 = SI value for height of trees.
[c] Standard error not calculated (n = 1).

Table 14. Optimum winter cover suitability index (SI) value, mean SI of modifying variables (standard error), and mean winter cover suitability index values (standard error) of landscapes surrounding 2-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan by cover type, age class, and management system.

Cover type	Age[a] class	Even-aged/ uneven-aged	Optimum SI	Mod 1[b]	Mod 2	Mod 3	Mod 4	Winter cover SI
Cedar	2	E	1.00	1.00 (0.15)	0.93 (0.07)	1.00 (0.00)	1.00 (0.00)	0.93 (0.18)
Cedar	2	U	1.00	0.57[c]	1.00	0.26	NA	0.15
Cedar	3	U	1.00	0.55[c]	0.91	0.26	NA	0.13
Swamp Conifer	2	E	1.00	0.46 (0.17)	0.50 (0.35)	1.00 (0.00)	0.51 (0.38)	0.27 (0.26)
Swamp Conifer	2	U	1.00	1.00 (0.06)	0.88 (0.08)	0.26 (0.00)	NA	0.20 (0.01)
Swamp Conifer	3	E	1.00	0.35[c]	1.00	1.00	0.68	0.24
Upland Conifer	2	E	0.5	0.77 (0.03)	0.63 (0.07)	1.00 (0.00)	0.74 (0.03)	0.36 (0.03)
Upland Conifer	2	U	0.5	0.96 (0.04)	0.94 (0.07)	0.26 (0.00)	NA	0.12 (0.01)
Upland Conifer	3	E	0.5	0.46 (0.46)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.23 (0.10)
Upland Conifer	3	U	0.5	1.00 (0.10)	1.00 (0.00)	0.26 (0.00)	NA	0.26 (0.01)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.
[b] Mod 1 = SI value for width of stand.
Mod 2 = SI value for percent canopy closure.
Mod 3 = SI value for management system (even- or uneven-aged stand).
Mod 4 = SI value for height of trees.
[c] Standard error not calculated (n = 1).

Table 15. Optimum winter food suitability index (SI) value, mean SI of the modifying variable (standard error), and mean winter food suitability index values (standard error) of landscapes surrounding 1- and 2-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan by cover type.

Clear-cut species	Clear-cut age	Cover type	Age class[a]	Optimum SI	Mod 8[b]	Winter food SI
Bigtooth	1	Aspen	1	1.00	0.39 (0.06)	0.39 (0.06)
Bigtooth	2	Aspen	1	1.00	0.34 (0.01)	0.34 (0.01)
Quaking	1	Aspen	1	1.00	0.50 (0.17)	0.50 (0.17)
Quaking	2	Aspen	1	1.00	0.43 (0.24)	0.43 (0.24)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.

[b] Mod 8 = SI value for aspen height.

Table 16. Optimum spring food suitability index (SI) value, mean SI of the modifying variable (standard error), and mean spring food suitability index values (standard error) of landscapes surrounding 1- and 2-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan by cover type.

Clear-cut species	Clear-cut age	Cover type	Age class[a]	Optimum SI	Mod 8[b]	Spring food SI
Bigtooth	1	Managed opening	0	1.00	NA	1.00
		Natural opening	0	0.70	NA	0.70
		Aspen	1	0.70	0.39 (0.06)	0.39 (0.06)
Bigtooth	2	Managed opening	0	1.00	NA	1.00
		Natural opening	0	0.70	NA	0.70
		Aspen	1	0.70	0.34 (0.01)	0.24 (0.01)
Quaking	1	Managed opening	0	1.00	NA	1.00
		Natural opening	0	0.70	NA	0.70
		Aspen	1	0.70	0.50 (0.17)	0.35 (0.12)
Quaking	2	Managed opening	0	1.00	NA	1.00
		Natural opening	0	0.70	NA	0.70
		Aspen	1	0.70	0.43 (0.24)	0.30 (0.17)

[a] Age class: 0 = non-stocked, 1 = MSFOI stocking class 1-3, 2 = MSFOI stocking class 4-6, 3 = MSFOI stocking class 7-9.

[b] Mod 8 = SI value for aspen height.

The first modification that could improve the accuracy of the model would be to assign the optimum SI values to age or stocking classes as well as to cover types. For example, based on the habitat attribute (tree height) that allows aspen stands to provide optimum winter and spring food, only young 1-6-year-old stands should be assigned optimum SI values rather than all stands of seedling-sapling age. Previous research has shown that suckers in aspen stands more than 6-years-old have grown out of the reach of ungulate species for normal browsing (Gaffney 1941, Aldous 1952, Alverson et al. 1988) and that elk prefer young 1- to 6-year-old clear-cuts (Campa 1989). Similarly, since only older, more mature conifer stands can provide optimum thermal cover, only stands of stocking class ≥ 4 should be assigned optimum SI values.

A second modification that may allow the model to more accurately reflect current habitat conditions is altering of the calculation of the sub-model suitability values. In the elk HSI model, stands that provide the highest potentially optimum habitat for 10 - 15% (depending on the sub-model) of the evaluation area are selected prior to sampling. The justification for this design is that managers can focus management efforts on only those cover types that potentially provide the most optimum habitat. While this can be a powerful landscape-wide planning tool for directing management objectives, it may not reflect actual habitat conditions. An alternative method of calculating sub-model suitability values would be to determine each stand's suitability first, and then select stands that represent the best habitat for 10 - 15% of the evaluation area. With this method, stands that have the structural attributes which provide the best winter cover (for example) would be included in the sub-model final value, rather than stands that are of potentially higher values but are actually of poorer quality. Although this method requires more extensive sampling, it may provide a more accurate representation of elk habitat quality.

Another complication with selecting the stands that provide the best 10-15% of habitat prior to sampling occurs when there is a larger proportion of the area within optimum cover types than necessary for that submodel. For example, 3 cover types provide optimum potential winter foraging habitat: aspen, maple, and cedar. In all evaluation areas > 15% of the areas were in the aspen cover type, so the winter foraging submodel can potentially be optimized by only considering this cover type.

The question then arises how to chose which proportion cover types to include in submodel SI calculation. The first option is to attempt to include an equal representation of each cover type when possible. However, typically equal representation is not possible due to a lack of area within one or more cover type. Another option may be to give priority to stands that provide potential optimum winter thermal cover and winter foraging cover. In this case cedar stands would be included first, followed by older maple stands, and finally by young maple or aspen stands. However, whether elk select foraging stands based on winter cover within those stands is dependent on factors such as temperature and wind speed, which vary annually. The selection of stands to include in submodel calculation and the proportions of these stands within various cover types is consequential because it can affect the submodel value and potentially the HSI value. For example, when WFSVs were recalculated using the above suggested alternative stand selection techniques, SI values ranged from 53% lower to 51% greater depending on the evaluation area. This illustrates the need to establish more detailed stand selection guidelines within the model.

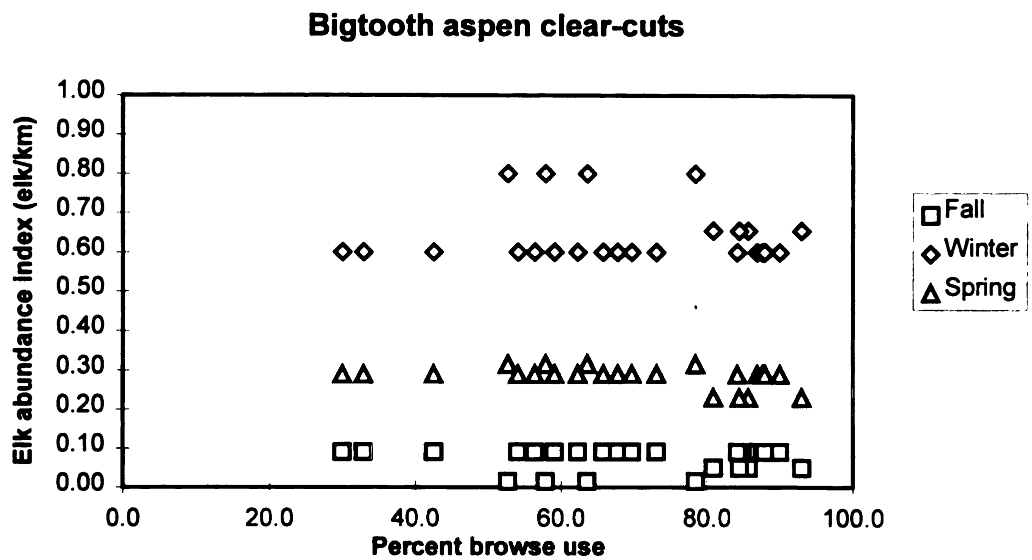
Association of browse use to elk abundance and HSI values

Correlation coefficients were not calculated to test the association of browse use to elk abundance and HSI values due to small sample sizes. Additional sampling is necessary before statistical association can be identified, however, potential trends may be highlighted.

Three seasonal indices of elk abundance were used to examine the potential trends between percent browsing (measured during spring 1995) and elk abundance. The fall index was calculated from November, 1994 drive surveys, while the spring index was calculated from both April and May, 1995 drive surveys. Elk abundances used for the winter index were provided by the MDNR elk population model (D. Whitcomb, MDNR, pers. comm.). Index values were calculated for 3 management units; all clear-cuts located within a management unit were assigned the same index value by season.

There were no apparent trends between percent browse use and elk abundance for any season on either bigtooth or quaking aspen clear-cuts (Figure 5). This apparent lack of relationship may be an artifact of the categorical assignment of elk abundance index values to clear-cuts with a wide range of percent browse use.

Since percent browse use declined with age (Table 5), there may be an association between abundance indices and browse use by clear-cut age, as well as by species, which could potentially explain any relationship between browse use and elk abundance. However, no trends were identified between elk abundance and browse use for any age of quaking aspen clear-cut. For bigtooth clear-cuts, only 2-year-old clear-cuts showed any



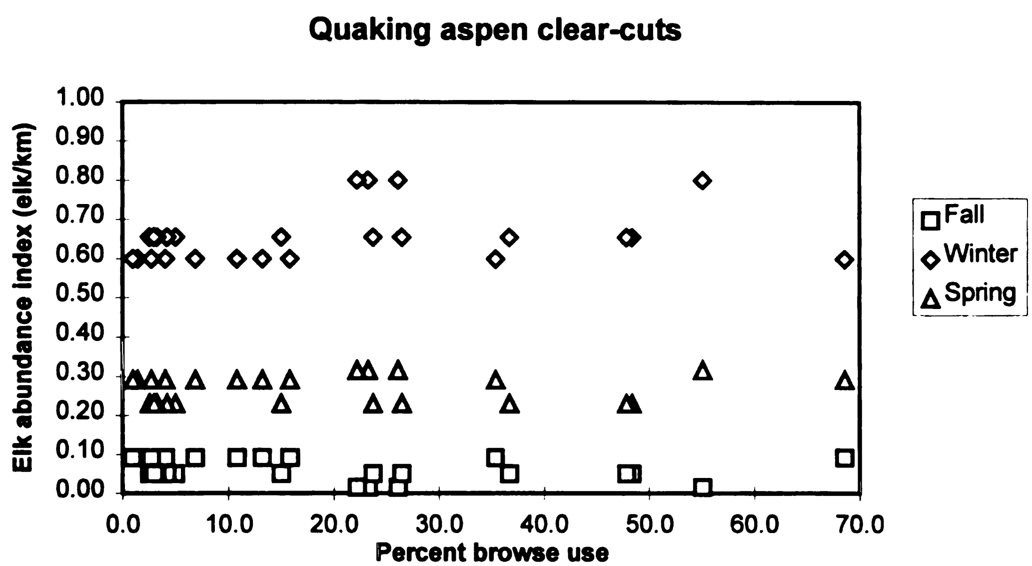


Figure 5. Mean percent browse use and elk abundance index (elk/km) by season of 1- to 3-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan.

potential trends (Figure 6). As browse use increased fall elk abundance increased, but winter and spring elk abundance tended to decrease. Again, no trends between browse use and elk abundance were seen when clear-cuts were pooled across age classes (Figure 5). The reason age specific trends may not reflect species specific trends may relate to the distribution of the sampled clear-cuts throughout the forest. For example, all 3-year-old bigtooth clear-cuts were located within elk management unit B and therefore all received the same elk abundance index values. Thus, unequal distribution of clear-cuts across management units may influence trend identification, particularly for smaller sample sizes.

No trends were identified between browse use and any HSI variables, including each sub-model suitability value, SI value of individual modifying variables, and final HSI value when samples were pooled by species. In contrast, for bigtooth aspen clear-cuts separately, several HSI variables increased as browse use increased: WCSV, SI Mod 1, SI Mod 4, SFSV, and HSI value (Figure 7). Likewise when only quaking aspen clear-cuts are considered, SFSV and HSI value seemed to increase as browse use increased, while WCSV and SI Mod 2 seemed to decrease (Figure 7).

Comparison of elk abundance indices to HSI values and sub-model values showed a few potential trends. No trends were identified between variables for pooled bigtooth and quaking aspen clear-cuts. However, when HSI values and elk abundance indices were examined for each species of clear-cut separately, several potential trends were identified. For bigtooth clear-cuts, as SFSV increased fall elk abundance seemed to decrease and winter elk abundance seemed to increase (Figure 8). For quaking aspen

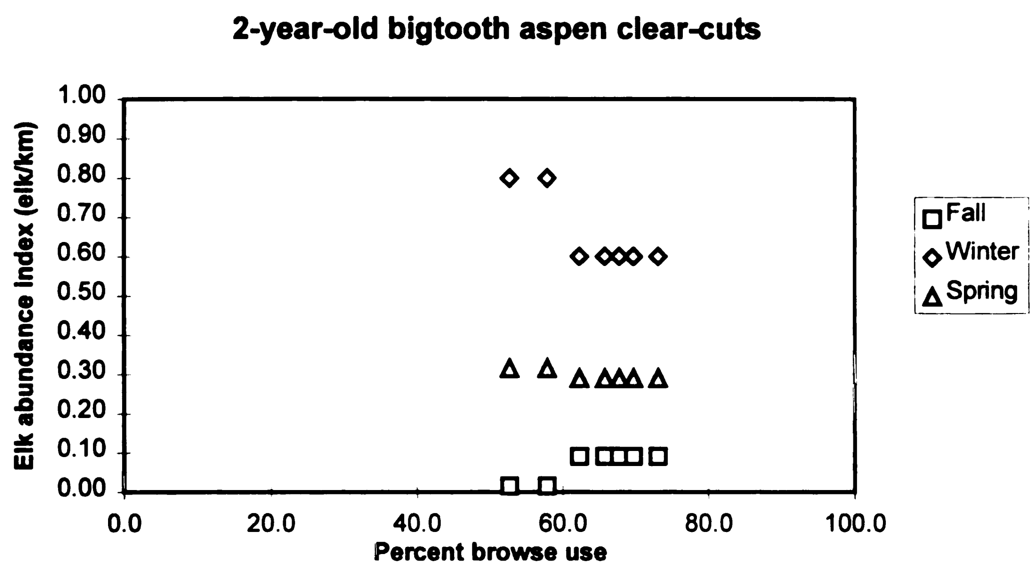
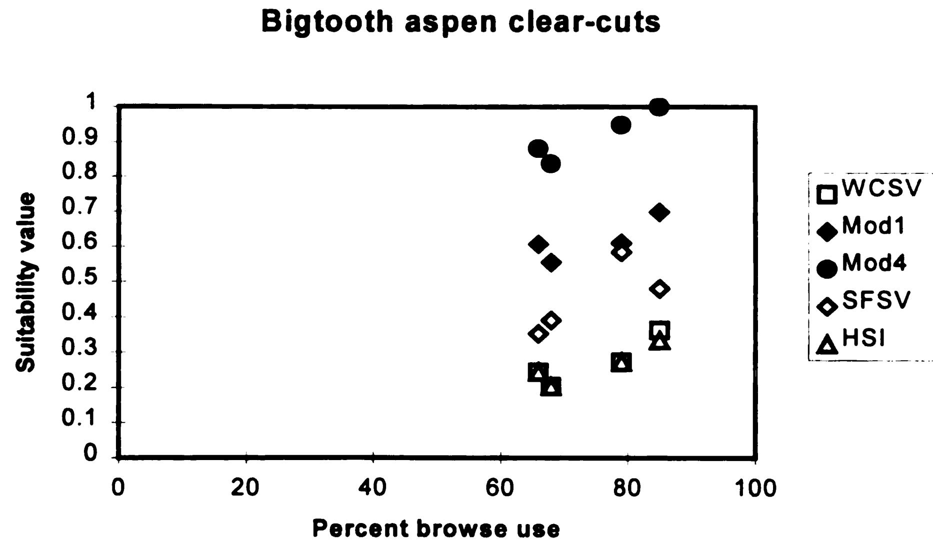


Figure 6. Mean percent browse use and elk abundance index (elk/km) by season of 2-year-old bigtooth clear-cuts in Pigeon River Country State Forest, Michigan.



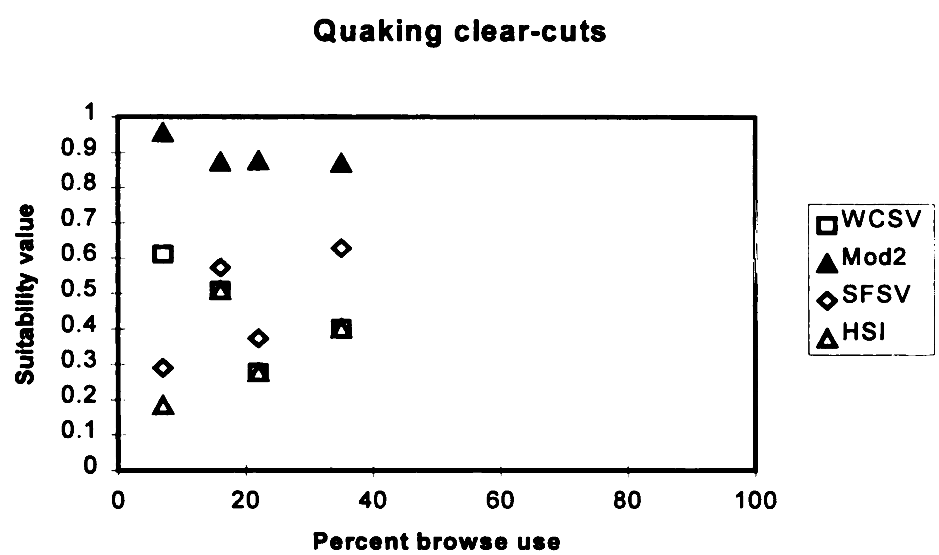
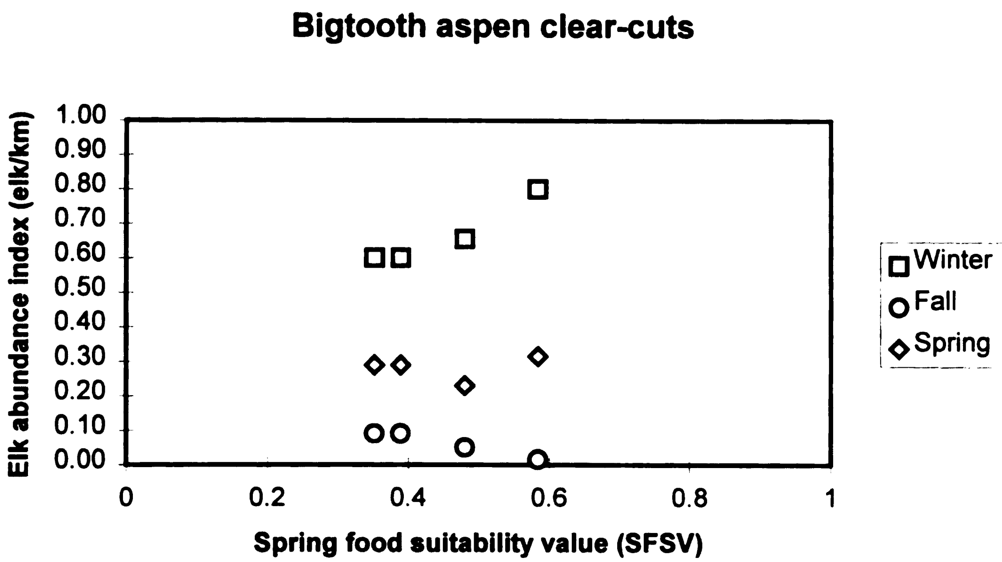


Figure 7. Mean percent browse use and elk HSI (Beyer 1987) suitability values for bigtooth and quaking aspen clear-cuts and surrounding landscapes in Pigeon River Country State Forest, Michigan. Where: WCSV = winter cover suitability value, Mod1 = stand width, Mod2 = percent canopy closure, Mod4 = tree height, SFSV = spring food suitability value, and HSI = final HSI value.



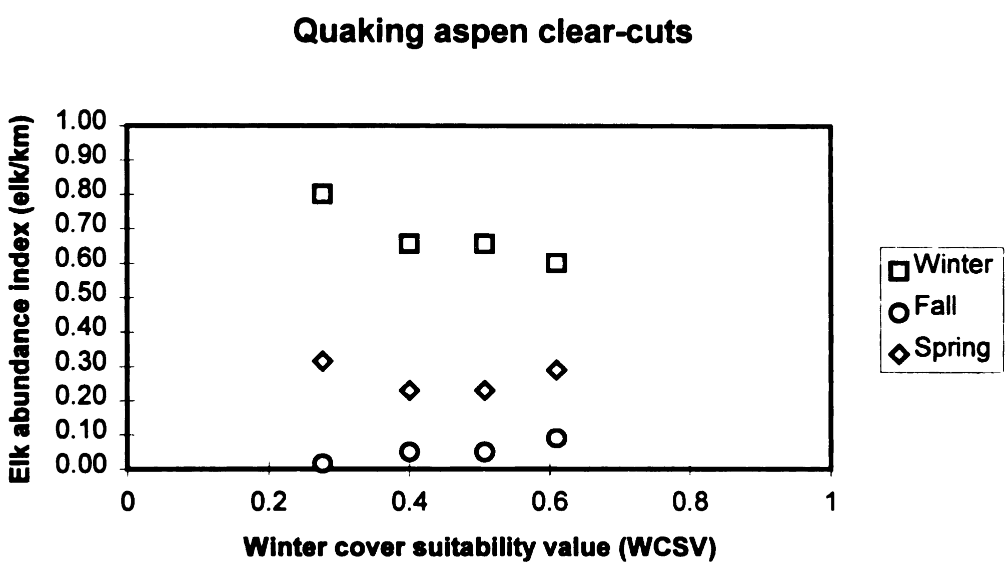


Figure 8. Elk abundance index (elk/km) by season and spring food suitability values for bigtooth aspen clear-cut evaluation areas, and elk abundance index and winter cover suitability values for quaking aspen clear-cut evaluation areas in Pigeon River Country State Forest, Michigan.

clear-cuts, as WCSV increased fall elk abundance seemed to decrease and spring elk abundance seemed to increase (Figure 8). In neither case was any trend apparent between the HSI variables and spring elk abundance. As with potential trends seen between browse use and HSI values, these trends should be viewed as indicators of possible relationships. However, additional sampling is required to identify whether any of these trends are associations between variables or artifacts of sample size.

EFFECTS OF UNGULATE BROWSING ON ASPEN STAND REGENERATION, STRUCTURE, AND COMPOSITION

Introduction

Aspen forests are a valuable natural resource for the wood products they produce and for the numerous wildlife species they support. Wood from aspen is used for various timber products from paper pulp to veneer. The PRCSF contains approximately 11,300 ha of aspen-dominated forest types, of which approximately 8,100 ha are potentially merchantable (> 30-years-old). The game species that rely on aspen for both food and cover, include white-tailed deer, elk, ruffed grouse, and woodcock. In Michigan, areas with the greatest production of white-tailed deer are typically aspen-dominated (Byelich et al. 1972). Regenerating aspen stands provide optimum winter foraging habitat for elk (Beyer 1987). It is not a coincidence that the native distribution of ruffed grouse coincides with the native range of aspen (Laidly 1990). Aspen stands of all ages provide habitat for numerous songbirds, black bear (*Ursus americanus*), beaver (*Castor canadensis*), various raptors, amphibians, and reptiles (DeGraff et al. 1980, DeGraff et al. 1981, DeGraff and Rudis 1981, Gullion 1985).

Since 1985, Michigan's elk population has remained relatively stable, with an estimated 9-year mean of 1,094 (±149) animals (D. Whitcomb, MDNR, pers. commun.). Currently, the herd is estimated at between 1,200 and 1,300 animals post-harvest, which is higher than the MDNR post-harvest management goal of 800-900 elk, stated in Michigan's Elk Management Plan (MDNR 1984). Approximately 30% of these animals reside within the Pigeon River Country State Forest, where elk densities range from 0.2-0.8 elk/km^2. Although total elk numbers have remained relatively constant, the distribution of elk throughout northern lower Michigan has changed. Since 1985, elk densities have increased in the northern portion of the forest and decreased in the southern portion. Deer densities have remained relatively low since the mid 1980's, ranging from approximately 7-10 deer/km^2. The impact of this altered distribution of elk on aspen regeneration, structure, and composition is uncertain.

Browsing on aspen by ungulates can have a number of immediate and long-term effects on individual trees and stands. Potential initial effects include reductions in total stem densities (Graham et al. 1963, Spiegel et al. 1963), modifications in the growth form of individual trees (Spiegel et al. 1963, DeByle 1979, Campa 1989), increases in pathogen infection rates (Graham et al. 1963, Marquis and Brenneman 1981, Perala 1990), and alterations in species composition (Graham et al. 1963, Spiegel et al. 1963, DeByle 1985, Tilghman 1989). Long-term effects of browsing include alterations in stand structure and composition, and reductions in merchantability and timber value (Tierson et al. 1966, Mueggler and Bartos 1977, Marquis and Brenneman 1981, and Tilghman 1989).

Previous research in Michigan has shown that aspen stem densities of young clear-cuts (≤ 3-years-old) were not affected by any level of browsing, but woody annual productivity, total available twigs, and tree height were reduced under high intensities of simulated browsing (> 50%) (Campa 1989). During the mid 1980's, browsing intensities in some stands within the PRCSF were >50% and therefore could cause changes in stand characteristics and plant composition within these stands. The changes observed in stand characteristics could impact aspen habitat quality for other wildlife species. Consequently, Campa (1989) also evaluated the effects of browsing on aspen stand characteristics and species composition in PRCSF by comparing areas open to browsing with paired areas protected from browsing. Exclosures were constructed on 1- and 2-year-old bigtooth and quaking aspen clear-cuts and vegetation characteristics were sampled yearly. By 1986, when these clear-cuts were 4- to 6-years-old, there was no evidence to suggest ungulate use had a negative impact on timber production. To date, the long-term (up to 30-40 years) effects of browsing on stand characteristics and merchantable timber production have not been evaluated. Since long-term effects may be confounded with successional changes, it is necessary that effects be evaluated at several intervals during stand development. Currently the aspen clear-cuts used in Campa's study (1989) are between 12- and 15-years-old, an ideal age for determining ungulate effects on sapling-successional-stage aspen stands due to their continued importance as elk habitat. Beyer (1987) found 11- to 15-year-old aspen stands are particularly important for bulls during the spring and winter and for cows during the summer and winter.

The MDNR objectives for the PRCSF provide for multiple uses of natural resources. Objectives include providing timber for harvesting, elk for consumptive and non-consumptive recreational opportunities, and quality habitat for a variety of other wildlife. To accomplish these objectives simultaneously both initial and long-term impacts of ungulate use on stand characteristics must be understood. To facilitate this understanding the objectives of this part of the study were: 1) to compare the effects of ungulate browse use on aspen stand characteristics of young (≤ 2 growing seasons) bigtooth and quaking aspen clear-cuts to historically observed levels and 2) to quantify the impacts of ungulate use on stand characteristics of older (12-15 growing seasons) bigtooth and quaking aspen clear-cuts.

Methods

Experimental design

To quantify the effects of ungulate browsing on bigtooth and quaking aspen stand characteristics, ungulate-proof exclosures were constructed on clear-cuts of each species during their first growing season. Clear-cuts were selected based on species, accessibility, and size. Stands with a species composition of at least 80% of a single species of aspen were chosen. Additionally, clear-cuts needed to be accessible to carry in equipment, and at least 4 ha in size. Within each clear-cut, a pair of sites were chosen that represented the composition and structure of the entire stand. For each clear-cut, 1 of the paired sites was randomly selected and a 20 x 20 x 2.1 m exclosure was constructed. Each exclosure was constructed of sixteen - 3.7 m cedar posts and heavy gauge, high tensile field fence. Six exclosures were built each year on 1-year-old aspen clear-cuts (3 on bigtooth cuts and 3 on quaking cuts) during late July and early August for 2 consecutive years for a total of 12 exclosures. Six additional exclosures will be built in 1996 for a 3rd age class. To facilitate comparisons between this research and prior data sets, this is the same experimental design used by Campa (1989). Eighteen exclosures were constructed by Campa during 1982 and 1983, also representing 3 age classes and 2 aspen species. To facilitate future long-term evaluation of stand characteristics, the wire of 3 exclosures constructed in 1982 and 1983 was replaced each year. New wire is expected to last until the stands are harvested.

Sampling methods

Effects of ungulates on aspen stand composition and structure were quantified using a variety of vegetation sampling techniques. All aspen stems were counted in exclosures and paired areas opened to browsing to determine stem densities. The DBH of each aspen stem was measured with a DBH tape and a Haga altimeter (Foresty Suppliers, Inc., Jackson, Miss.) was used to measured tree height a sample (n=10) of dominant and co-dominate aspen. A tree was defined as dominant if the majority of its crown received direct sunlight and co-dominant if only the top of its crown received direct sunlight. The densities of all other woody species were determined using randomly located 2 m x 15 m plots. Vertical cover was measured using the line intercept method (Canfield 1941). Ten 20 m line intercepts were systematically placed within exclosures and paired areas open to browsing to cover the entire 20 m x 20 m area. Three height strata (0-0.5 m, 0.5 m-2.0 m, >2.0 m) were used to quantify impacts of foraging on new shoots, grasses and forbs (0-0.5 m), plants within the optimal ungulate browsing range (0.5-2.0 m), and areas typically beyond the normal browsing capacity of large herbivores (>2.0 m) (Gaffney 1941, Graham et al. 1963, Moran 1973, Alverson et al. 1988). Horizontal cover was quantified using a randomly placed profile board read at a distance of 6 m (Gysel and Lyon 1980). Horizontal cover was estimated in 5 height strata (0-0.5 m, 0.5-1.0 m, 1.0-

1.5 m, 1.5-2.0 m, and 2.0-2.5 m). Frequencies of occurrence of herbaceous species were determined using randomly located 1 m x 1 m plots. The required number of plots was determined using a species area curve. Additionally, 35 mm slides were taken of the profile board at permanent points (southwest corner), previously established in 1983 within exclosures and areas open to browsing, to illustrate temporal and treatment differences in stand structure.

All vegetation sampling of the original exclosures and paired areas was conducted during June and July, and sampling within young (1- and 2-year-old) sites was done in August. Vegetation variables were measured on 1-year-old clear-cuts in 1994 and 1995, while 2-year-old clear-cuts were only available during 1995. Complete aspen counts, woody species plots, profile board, and line intercept transects were conducted on 12- to 15-year old clear-cuts in 1994 and 1995. Herbaceous plant species sampling was conducted in original exclosures and paired areas only during 1994. Sample sizes for vegetation variables were determined using Freese's formula (1978) with a 90% confidence interval and an allowable error of 10% of the mean.

Data analysis

To examine the impacts of ungulate browsing on the composition and structure of aspen stands, differences in vegetation characteristics of exclosures and paired areas open to browsing were compared using paired t-tests (Gill 1978). Between year differences were compared with the nonparametric Mann-Whitney U (Sokal and Rohlf 1995). The F-test was used to test equality of variances on non-paired data (Gill 1978). For parametric tests, percentage data were transformed with the arcsine function prior to statistical analysis (Steel and Torrie 1980). The minimum acceptable level of significance for all tests was set at $\alpha = 0.10$, and all tests were 2-tailed.

Results and Discussion

Structure and composition of 1-year-old clear-cuts

No significant differences ($P > 0.10$) in aspen stem densities were found in bigtooth clear-cuts between exclosures and browsed areas in either 1994 or 1995 (Table 17). In 1994, bigtooth aspen clear-cuts had mean aspen stem densities of 29,458 ± 3,940 stems/ha in exclosures and 26,642 ± 6,623 stems/ha in areas open to browsing. In 1995, stem densities were relatively lower with 18,892 ± 1,692 stems/ha in exclosures and 17,758 ± 3,638 stems/ha in areas open to browsing. Total stems/ha within exclosures and stems/ha in the 0.5-2.0 m strata within exclosures were significantly greater ($P < 0.10$) in 1994 than in 1995. Lower 1995 stems densities may be attributable to inherent site characteristics or weather. During this year, precipitation varied greatly from the long-term mean; June, a key month for sucker development, had lower than average precipitation (Figure 2).

In quaking aspen clear-cuts, exclosures had significantly greater ($P < 0.10$) stem densities than open areas in the 0-0.5 m strata in 1994 and the 0.5-2.0 m strata in 1995 (Table 17). There were no differences ($P > 0.10$) between treatments in other stratum in either year. The few treatment differences found were probably due to random chance, since no browsing had occurred on the sites. However, they should be considered when analyzing treatment differences as the clear-cuts age. Mean total aspen densities in 1994

Table 17. Mean stem densities per hectare (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m, and total) in exclosures and areas open to browsing on 1-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994 and 1995).

Stratum	Year	Exclosure	Browsed
		Bigtooth aspen	
0 - 0.5 m	1994	3,900(788)	5,575(1,819)
	1995	4,775(940)	3,233(393)
0.5 - 2.0 m	1994	25,558(3,503) *	21,067(5,034)
	1995	14,092(928)	14,492(3,272)
> 2.0 m	1994	0(0)	0(0)
	1995	25(14)	33(22)
Total	1994	29,458(3,940) *	26,642(6,623)
	1995	18,892(1,692)	17,758(3,638)
		Quaking aspen	
0 - 0.5 m	1994	11,808(3,109) A	10,108(2,942)
	1995	8,108(1,448)	6,358(1,122)
0.5 - 2.0 m	1994	30,983(7,727)	24,075(4,215)
	1995	23,683(2,346) A	18,558(3,387)
> 2.0 m	1994	8(8)	183(183)
	1995	0(0)	17(17)
Total	1994	42,800(6,255)	34,367(3,560)
	1995	31,791(906)	24,933(2,575)

A = Significantly different (P < 0.10) from browsed (paired t-test, Gill 1978).
* = Significantly different (P < 0.10) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

were 42,800 ± 6,255 stems/ha in exclosures and 34,367 ± 3,560 stems/ha in open areas. In 1995, quaking aspen clear-cuts had 31,791 ± 906 and 24,933 ± 2,575 stems/ha in exclosures and areas open to browsing, respectively. No significant differences ($P > 0.10$) in quaking aspen stem densities were found between 1994 and 1995.

In the Great Lakes region, initial stocking densities of aspen suckers after clear-cutting can vary considerably depending on geographical region, soil type, weather, and inherent site characteristics. Graham et al. (1963) reported that in Michigan, aspen stands can have regeneration of up to 148,100 stems/ha and average around 24,700 stems/ha. Eaton (1986) reported similar aspen stem densities from sixteen 1-year-old clear-cuts in PRCSF, around 32,000 stems/ha. Initial sucker densities in Wisconsin were found to be somewhat higher than Graham's reported average ranging from 39,500 - 44,000 stems/ha (Fralish 1972). Mean stem densities in Ontario approach the upper limit for Michigan at 98,800 stems/ha (Maini 1972). Aspen stem densities found on 1-year-old clear-cuts in 1994 and 1995 (Table 17) were similar to those reported within the PRCSF by Eaton (1986).

Many guidelines have been made developed for the minimum stocking density required to produce a merchantable timber stand. Graham et al. (1963) stated that 29,630 stems/ha is an ideal initial density (at age 1), while 14,800 stems/ha is a minimum. Stoeckler and Macon (1956) further explained that an initial density of 14,800 stems/ha would lead to 90% milacre stocking and 22,200 stems/ha would virtually assure 100% stocking in Wisconsin. Other estimates have not been based on initial densities. Westell (1954), for example, reported that clear-cuts with 25,000 stems/ha after 3 growing seasons could support substantial use by ungulates without suffering negative impacts. Recommendations from the western states typically include a minimum height recommendation to account for the slow growth rate of suckers (DeByle 1985). Sampson (1919) suggested a minimum of 6,200 stems/ha after 3 years (or ≥ 1 m) and DeByle (1985) indicated that if 1,000 aspen stems/ha reach 4 m, the stand will produce merchantable timber. In the PRCSF, initial stem densities within bigtooth aspen clear-cuts were 20-100% greater than the minimum density recommended by Graham et al. (1963). Likewise, initial stem densities on quaking aspen clear-cuts were 70-190% greater than Graham's (1963) recommended minimum stocking densities. However, this aspect alone may not necessarily predict that these clear-cuts will produce merchantable timber stands. Other factors, such as future browse use intensity, injury and infection rate, and current economics may play an important role in determining merchantability. Long-term investigation of the structure and composition of these stands is necessary to address this question adequately.

Few significant differences were found in vertical or horizontal cover between exclosures and areas open to browsing in 1-year-old clear-cuts in 1994 and 1995. There was significantly greater ($P < 0.05$) vertical cover in the 0.5-2.0 m strata in browsed areas of bigtooth clear-cuts in 1994 (Table 18). In 1995, quaking clear-cut exclosures had significantly greater ($P < 0.10$) vertical cover in the 0-0.5 m strata than browsed areas. However, no significant differences ($P > 0.10$) in vertical cover were found for any stratum in bigtooth clear-cuts in 1995 or quaking clear-cuts in 1994. Furthermore, only 1 significant difference in treatments was found between years. Vertical cover in the

Table 18. Mean percent vertical cover (standard error) by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m) in exclosures and areas open to ungulate browsing on 1-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994 and 1995).

Stratum	Year	Exclosure	Browsed
		Bigtooth aspen	
0 - 0.5 m	1994	67(15)	75(7) *
	1995	48(4)	48(1)
0.5 - 2.0 m	1994	36(11) B	46(12)
	1995	36(7)	41(6)
> 2.0 m	1994	1(1)	1(1)
	1995	3(2)	5(5)
		Quaking aspen	
0 - 0.5 m	1994	73(2)	67(14)
	1995	68(8) A	61(10)
0.5 - 2.0 m	1994	34(5)	24(5)
	1995	40(13)	40(19)
> 2.0 m	1994	0(0)	0(0)
	1995	0(0)	0(0)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
* = Significantly different ($P < 0.10$) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

0-0.5 m strata in browsed areas of bigtooth clear-cuts was significantly greater ($P < 0.10$) in 1994 than in 1995.

In quaking aspen clear-cuts, horizontal cover was significantly greater ($P < 0.05$) in browsed areas for the 0.5-1.0 m strata in 1994 (Table 19). No other significant differences ($P > 0.10$) were found between treatments for horizontal cover in any stratum in bigtooth or quaking aspen clear-cuts in either year. When horizontal cover was compared between years, no significant differences ($P > 0.10$) were detected in bigtooth or quaking clear-cuts for any stratum (Table 19).

The total number of woody species, other than aspen, found in bigtooth clear-cuts ranged from 10 in 1994 to 17 in 1995. The most common species were red maple (*Acer rubrum*), pin cherry (*Prunus pensylvanica*), black cherry (*P. serotina*), juneberry (*Amelanchier* spp.), and paper birch (*Betula papyrifera*). Mean stem densities of 50% of woody species tended to be greater in exclosures in 1994, and mean stem densities of 35% of the woody species tended to be greater in exclosures in 1995. No significant differences ($P > 0.10$) in woody stem densities were found between exclosures and areas open to browsing in either 1994 (Appendix Table 1) and 1995 (Appendix Table 2). Twenty woody species other than aspen were found in quaking aspen clear-cuts in 1994 and 19 species were found in 1995.

The most common species found in quaking aspen clear-cuts were red maple, black cherry, sugar maple (*A. saccharum*), white ash (*Fraxinus americana*), and juneberry. In 1994 60% of woody species tended to have greater stem densities in exclosures than in areas open to browsing, while in 1995 37% of woody species tended to have greater stem densities in exclosures. No significant differences ($P > 0.10$) in woody

Table 19. Mean percent horizontal cover (standard error) by height stratum (0-0.5 m, 0.5-1.0 m, 1.0-1.5 m, 1.5-2.0 m, 2.0-2.5 m) in exclosures and areas open to ungulate browsing on 1-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994 and 1995).

Stratum	Year	Exclosure	Browsed
		Bigtooth aspen	
0 - 0.5 m	1994	85(8)	85(8)
	1995	87(4)	86(4)
0.5 - 1.0 m	1994	39(10)	44(7)
	1995	36(10)	32(11)
1.0 - 1.5 m	1994	11(7)	16(7)
	1995	17(7)	11(9)
1.5 - 2.0 m	1994	5(4)	1(1)
	1995	5(3)	2(2)
> 2.0 m	1994	3(2)	0(0)
	1995	3(3)	0(0)
		Quaking aspen	
0 - 0.5 m	1994	83(4)	85(7)
	1995	77(11)	85(7)
0.5 - 1.0 m	1994	29(9) A	36(8)
	1995	43(18)	52(10)
1.0 - 1.5 m	1994	8(6)	9(6)
	1995	9(5)	16(11)
1.5 - 2.0 m	1994	1(1)	0(0)
	1995	0(0)	0(0)
> 2.0 m	1994	0(0)	0(0)
	1995	0(0)	0(0)

A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).

stem densities were found between treatments in quaking aspen clear-cuts in 1994 (Appendix Table 3) or in 1995 (Appendix Table 4).

Bigtooth clear-cuts supported 41 different herbaceous species in 1994 and 25 species in 1995. In 1994, the most frequent species found included various grass species, *Rubus* spp., bracken fern (*Pteridium aquilinum*), and common strawberry (*Fragaria virginiana*). In 1995, bracken fern, grass, checkberry (*Gaultheria procumbens*), sedge (*Carex* spp.), and *Rubus* spp. were the most frequently encountered herbaceous species. Approximately 20% the of species were unique to each treatment. Thirty-two different herbaceous species were identified in quaking clear-cuts in 1994, and 37 species in 1995. Bracken fern, grasses, *Rubus* spp., orange hawkweed (*Hieracium aurantiacium*), and sedges were the most frequently found species in 1994 and 1995. The percentage of unique species was relatively equal between treatments with approximately 20% in exclosures and 14% in areas open to browsing. Few significant differences ($P < 0.10$) in absolute and relative frequency of herbaceous species (Appendix Table 5 - Appendix Table 8) were found between treatments in either bigtooth or quaking aspen clear-cuts in either year.

The few treatment differences found in 1-year-old clear-cuts were probably due to random chance. Initial differences will be reviewed and compared in later years to explain future significant differences. Stem densities, vertical and horizontal cover, and species composition data demonstrate that exclosures and paired areas open to browsing were similar in all aspects at the beginning of the study. Thus, any differences found between treatments in the future may be attributed to browsing effects.

Structure and composition of 2-year-old clear-cuts

Bigtooth aspen clear-cuts had mean aspen densities of 22,750 ± 3,521 stems/ha in exclosures and 21,033 ± 3,772 stems/ha in areas open to browsing. Quaking aspen clear-cuts averaged 23,808 ± 1,378 stems/ha in exclosures and 22,216 ± 1,851 stems/ha in areas open to browsing. No significant differences ($P > 0.10$) in aspen stem densities were found in bigtooth clear-cuts between exclosures and browsed areas (Appendix Table 9). In quaking aspen clear-cuts, stem densities in the 0.5-2.0 m strata were significantly greater ($P < 0.05$) within exclosures than open areas (Appendix Table 10). At age 1, these quaking aspen clear-cuts showed significantly greater stem densities within exclosures in the 0-0.5 m strata. The presence of a significant difference between treatments within the 0.5-2.0 m strata in 1995 may be an artifact of this original difference. No significant differences ($P > 0.10$) were found between treatments in other stratum. Previous research by Campa (1989) in the PRCSF has shown that most significant differences in stem densities between exclosures and areas open to browsing occur around the 4th growing season after cutting. Thus, the relative lack of differences found on 2-year-old clear-cuts is not surprising.

Comparisons of stem densities found on 2-year-old clear-cuts to those found in the early 1980's, reveals few significant differences between current and historic data sets. Similar relative differences in stem densities between treatments were found in 1995 as were found in 1983 and 1984 (Haufler et al. 1984, Haufler et al. 1985) (Table 20 and Table 21). As in 1995, in 1983 and 1984 exclosures tended to have lower stem densities in the lowest strata and greater stem densities in the middle and upper strata. In

Table 20. Mean stem densities per hectare (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m) in exclosures and areas open to browsing, and the relative difference between treatments on 2-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1983, 1984, and 1995).

Stratum	Year	Exclosure	Relative difference	Browsed
0 - 0.5 m	1983[a]	4,033(1,575) A*	-11%	4,550(1,725)
	1984	750(25)	-10%	833(150)
	1995	508(188)	-64%	1,433(556)
0.5 - 2.0 m	1983	21,542(6,455)	14%	18,458(4,714)
	1984	22,308(5,056)	16%	18,633(4,443)
	1995	19,166(2,422)	-1%	19,283(3,434)
> 2.0 m	1983	50(50)	84%	8(8)
	1984	3,375(2,007) *	71%	958(397)
	1995	3,075(1,401)	90%	317(317)
Total	1983	25,625(6,494)	10%	23,017(6,106)
	1984	26,433(6,072) *	23%	20,425(4,394)
	1995	22,750(3,521)	8%	21,033(3,772)

[a] = Data from 1983 and 1984 2-year-old clear-cuts is from Haufler et al. (1984) and Haufler et al. (1985).
A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
* = Significantly different ($P < 0.10$) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

Table 21. Mean stem densities per hectare (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m) in exclosures and areas open to browsing, and the relative difference between treatments on 2-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1983, 1984, and 1995).

Stratum	Year	Exclosure	Relative difference	Browsed
0 - 0.5 m	1983[a]	6,250(825)	3%	6,012(138)
	1984	2,133(297) *	-13%	2,467(549)
	1995	583(338)	54%	1,275(499)
0.5 - 2.0 m	1983	23,000(925)	13%	20,113(5,513)
	1984	1,9214(3,164)	4%	18,474(647)
	1995	20,925(2,021) A	8%	19,208(2,231)
> 2.0 m	1983	13(13)	-85%	88(38)
	1984	1,206(385)	61%	473(190)
	1995	2,300(1,065)	75%	1,733(1,659)
Total	1983	19,508(9,754)	-85%	17,475(9,279)
	1984	22,554(3,356)	61%	21,414(231)
	1995	23,808(1,378)	75%	22,217(1,378)

[a] = Data from 1983 and 1984 2-year-old clear-cuts is from Haufler et al. (1984) and Haufler et al. (1985).
A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
* = Significantly different ($P < 0.10$) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

1995, the relative difference between treatments was greater within the lowest strata for bigtooth and quaking aspen clear-cuts than in either 1983 or 1984, however, only 1983 bigtooth clear-cuts showed a significant difference ($P < 0.05$) between treatments. Also, in most cases, the mean stems/ha found within exclosures and browsed areas was not different between years (Table 20 and Table 21). In 1983, relatively greater stem densities were in the lowest strata and relatively lower stem densities were present in the upper strata than in 1984 or 1995 in both bigtooth and quaking aspen clear-cuts (Table 20 and Table 21). Total stem densities were comparable between years indicating suckers within clear-cuts in 1983 may not have grown as quickly as in 1984 and 1995 possibly due to temperature, precipitation, or inherent site characteristics. The lack of significant differences between treatments within any year indicates that browsing did not significantly influenced aspen stem density in 2-year-old clear-cuts in either 1995 or the early 1980's.

Aspen stands can have very dense regeneration immediately following clear-cutting or fire. These newly established dense stands go through a 5-year natural thinning process due to intense competition (Graham et al. 1963). Jones (1976) reported that Arizona clear-cuts showed declines in aspen density of 40% within the first 4 years. Other estimates of mortality have been somewhat higher. Eaton (1986) reported aspen stem density reductions in Michigan of 17-37% each year for 3 years. Bartos and Mueggler (1982) found similar losses of 44% between years 2 and 3 in Utah. In the PRCSF, total aspen stem densities showed a reduction from year 1 of approximately 20% in bigtooth stands and 40% in quaking stands.

With exclosures there is the opportunity to study stocking densities and thinnint paterns under 2 distinct stand conditions, ungulate browsed and non-browsed. Compared to the thinning rate within the exclosures (20% in bigtooth aspen stands and 40% in quaking aspen stands), the loss of stems in browsed areas was slightly; 2% lower in bigtooth clear-cuts and 4% lower in quaking clear-cuts. This indicates that after 1 year of exposure to browsing the rate of stem loss in browsed areas is comparable to the thinning rate in non-browsed areas. However, browsing in consecutive years may have cumulative effects on the growth and structure of aspen suckers (Campa et al. 1992), and long-term damage, such as potentially higher rates of diseases infection due to browsing injuries, has not yet been quantified.

Likewise at age 2, there is no indication that browsed clear-cuts will not produce merchantable timber stands based on minimum stocking recommendations (Graham et al. 1963, Stoeckler and Macon 1956). Again, this conclusion is based on stem density reductions and does not consider other factors such as cumulative browse use and infection rate, that may be important in determining the final timber value of stands. Further long-term evaluation of stand structure and composition is necessary to adequately address this question.

In bigtooth clear-cuts, vertical cover in the 0-0.5 and >2.0 m stratum was significantly greater ($P < 0.10$) in exclosures than in browsed areas (Table 22). The difference in percent cover in the upper strata may be attributed to a greater number of aspen stems attaining heights above 2 m within the exclosures. Higher percent cover in the bottom strata may be due to the larger leaf sizes of mature leaves and greater biomass

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Table 22. Mean percent vertical cover (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m) in exclosures and areas open to browsing, and the relative difference between treatments on 2-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1983, 1984, and 1995).

Stratum	Year	Exclosure	Relative difference	Browsed
		Bigtooth aspen		
0 - 0.5 m	1983[a]	60(14)	10%	54(10) *
	1984	21(2) *	-19%	26(1) *
	1995	93(3) A	10%	84(2)
0.5 - 2.0 m	1983	47(14) B*	36%	30(8) *
	1984	56(3) *	13%	49(2)
	1995	84(5)	19%	68(7)
> 2.0 m	1983	0(0) *	0%	0(0)
	1984	22(2)	-4%	23(2)
	1995	7(3) A	85%	1(1)
		Quaking aspen		
0 - 0.5 m	1983	68(1)	24%	52(5)
	1984	14(1) A*	-33%	21(2)
	1995	83(7)	1%	82(8)
0.5 - 2.0 m	1983	38(9)	13%	33(6)
	1984	66(3) B	5%	63(4)
	1995	77(6)	17%	64(7)
> 2.0 m	1983	1(1)	0%	1(1)
	1984	8(3) B	88%	1(1)
	1995	3(2)	-25%	4(4)

[a] = Data from 1983 and 1984 2-year-old clear-cuts is from Haufler et al. (1984) and Haufler et al. (1985).
A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
C = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).
* = Significantly different ($P < 0.10$) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

of woody species. Quaking aspen clear-cuts showed the same general trends as the bigtooth clear-cuts. However, current browse pressure did not result in significant differences ($P > 0.10$) in mean percent cover for any strata (Table 22).

The relative differences between treatments found in vertical cover found in 1995 were similar to differences found by Haufler et al. (1984, 1985). For all years, most significant differences ($P < 0.10$) were found between treatments (exclosures > browsed) in bigtooth clear-cuts, while few significant differences between treatments were found in quaking aspen clear-cuts (Table 22). Relative differences ranged from -33% to 88%, and averaged 17% ± 10% and 10% ± 12% for bigtooth and quaking aspen clear-cuts, respectively. When comparing vertical cover by treatment among years, in most cases significantly greater ($P < 0.10$) cover was found in 1995 than in 1983 or 1984, particularly for bigtooth aspen clear-cuts (Table 22). This overall increase in cover may be related to browsing or differences in inherent site characteristics, weather variables, or timing of harvest.

In bigtooth aspen clear-cuts, horizontal cover was significantly greater ($P < 0.10$) in exclosures than in browsed areas for all but the 0.0-0.5 m strata (Table 23). In quaking aspen clear-cuts, exclosures had significantly greater ($P < 0.10$) horizontal cover only in the 0-0.5 m strata (Table 23). These differences indicate that the higher browsing pressure on bigtooth aspen clear-cuts (Table 5) created greater differences in horizontal cover than the relatively lower browsing pressure (39-54% lower) in quaking aspen clear-cuts.

Table 23. Mean percent horizontal cover (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m) in exclosures and areas open to browsing, and the relative difference between treatments on 2-year-old bigtooth and quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1983, 1984, and 1995).

Stratum	Year	Exclosure	Relative difference	Browsed
		Bigtooth aspen		
0 - 0.5 m	1983[a]	97(3)	1%	96(2)
	1984	99(1)	10%	89(11)
	1995	100(0)	2%	98(1)
0.5 - 1.0 m	1983	81(17)	33%	54(14) *
	1984	90(4)	34%	59(16)
	1995	95(1) A	11%	85(4)
1.0 - 1.5 m	1983	57(20)	54%	26(3) *
	1984	74(5) *	45%	41(10)
	1995	89(2) B	35%	58(7)
1.5 - 2.0 m	1983	30(9) *	33%	20(0)
	1984	47(11)	47%	25(4)
	1995	68(7) B	66%	23(8)
2.0 - 2.5 m	1983	20(0) *	0%	20(0)
	1984	35(9)	37%	22(2)
	1995	10(10) A	-9%	11(8)
		Quaking aspen		
0 - 0.5 m	1983	98(2)	2%	96(4)
	1984	98(1)	2%	96(1)
	1995	97(2) A	8%	89(3)
0.5 - 1.0 m	1983	85(13)	9%	78(14)
	1984	83(2) C	31%	57(3)
	1995	74(12)	32%	50(12)

Table 23 (cont.)

Stratum	Year	Exclosure	Relative difference	Browsed
1.0 - 1.5 m	1983	53(21)	26%	39(5)
	1984	59(1) C	49%	30(1)
	1995	54(17)	48%	28(13)
1.5 - 2.0 m	1983	28(8)	14%	24(2)
	1984	45(9)	51%	22(2)
	1995	34(17)	62%	13(7)
2.0 - 2.5 m	1983	20(0)	0%	20(0)
	1984	28(4)	25%	21(1) *
	1995	20(11)	65%	7(4)

[a] = Data from 1983 and 1984 2-year-old clear-cuts is from Haufler et al. (1984) and Haufler et al. (1985).
A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
C = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).
* = Significantly different ($P < 0.10$) from 1995 (Mann-Whitney U, Sokal and Rohlf 1995).

Relative treatment differences in horizontal cover found in 1995 were similar to differences found by Haufler et al. (1984, 1985). In all years, the greatest differences between treatments were in the middle 3 strata, while the greatest variation in relative differences was in the highest strata. Relative differences between treatments ranged from -9% to 66% and averaged 26% ± 6% for each species of aspen clear-cut. In all but 1 case (2.0-2.5 m strata in bigtooth aspen clear-cuts in 1995), cover tended to be greater in exclosures than in browsed areas. When comparing horizontal cover by treatment among years, all but the lowest strata (0-0.5 m) of bigtooth clear-cuts showed significantly greater ($P < 0.10$) cover in 1995 than in some earlier year (Table 23). There were few significant differences between years in quaking aspen clear-cuts. As with vertical cover, between year differences in cover may be related to browsing or to differences in inherent site characteristics, weather variables, or timing of harvest.

Twenty two woody species other than aspen were found within bigtooth clear-cuts. The most common species found include juneberry, hop-hornbeam (*Ostrya virginiana*), sugar maple, red maple, and black cherry. Twenty seven percent of the woody species were unique to exclosures and 14% were unique to browsed areas. No significant ($P > 0.10$) differences in woody stem densities were found between treatments in any strata (Appendix Table 9). However, in the 0-0.5 m strata, 67% of the woody species common to both treatments tended to have greater stem densities in browsed areas, while in the 0.5-2.0 m strata, 75% of woody species tended to have greater stem densities in exclosures. These results suggest that, by year 3, woody species protected from browsing may attain greater heights than those exposed to browsing. Only 4 woody species other than aspen had stems >2.0 m in height.

A total of 17 woody species other than aspen were found in quaking aspen clear-cuts. The most common species were red maple, white ash, black cherry, and juneberry. One woody species, American beech (*Fagus grandifolia*), was found in significantly ($P < 0.05$) greater densities in quaking clear-cut exclosures in the 0-0.5 m strata (Appendix Table 10). No other significant ($P > 0.10$) differences in woody stem densities were found between treatments. Approximately 60% of the woody species common to both treatments tended to have greater stem densities in exclosures than in browsed areas in the 0-0.5 and 0.5-2.0 m strata. No woody species other than aspen were present in the >2.0 m strata.

Forty five herbaceous species were present in bigtooth clear-cuts. The most frequently found species were *Rubus* spp., bracken fern, common strawberry, and orange hawkweed. Approximately 20% of the species were unique to exclosures and 22% were unique to browsed areas. Grasses, bracken fern, *Rubus* spp., and violet (*Viola* spp.) were the most frequently encountered species of 38 found in quaking aspen clear-cuts. The percentage of unique species was higher in browsed areas (18%) than in exclosures (8%) within quaking clear-cuts. After 1 year of exposure to browsing, a few differences in herbaceous species composition are found between exclosures and areas open to browsing (Appendix Table 11and Appendix Table 12). In bigtooth clear-cuts, the absolute frequency of *Aster* spp. was significantly greater ($P < 0.05$) in browsed areas than in exclosures. *Rubus* spp. and common strawberry showed significantly greater

(P < 0.10) relative frequencies in exclosures than in areas open to browsing. In quaking aspen clear-cuts, common dandelion (*Taraxacum officinale*) had greater (P < 0.10) absolute frequencies in browsed areas and grass had greater (P < 0.05) absolute frequencies in exclosures. Common dandelion also was significantly more frequent (P < 0.05) in quaking browsed areas, as was wood anemone (*Anemone quinquefolia*). Previous research has shown that the greatest number of differences between exclosures and open areas becomes apparent around 4 years after clear-cutting (Campa 1989).

Generally, it has been found that clear-cutting increases the amount of herbaceous and graminoid vegetation primarily due to increased available light and, initially, decreased competition from woody species (Mueggler and Bartos 1977, Bartos and Mueggler 1982). Furthermore, greater frequencies of herbaceous and graminoid species have been found in areas with heavy browsing because the open canopy created by clear-cutting is maintained for a longer period of time (Marquis and Brenneman 1981, Mueggler and Bartos 1982, Campa 1989). By year 2, several species typically found in open woodlands and grassy clearings - including aster, dandelion, and wood anemone - were found more frequently in browsed areas, probably due to the decrease in canopy density. Common strawberry and grass, plants frequently consumed during the summer by both deer and elk, were found more frequently in exclosures where they are protected from browsing. Tierson et al. (1966) found that *Rubus* spp. had greater stem densities in browsed areas because they were released from competition with woody species. Contrary to Tierson's findings, in the PRCSF *Rubus* spp. were more frequently found in exclosures than in browsed areas.

Browsing on 2-year-old clear-cuts has resulted in few significant differences in stem densities of woody species. Aspen stem densities and rates of stem loss were similar between treatments, although the rate of stem loss was greater in quaking aspen clear-cuts than in bigtooth clear-cuts. Few significant differences in herbaceous species frequencies were found between treatments regardless of aspen species. The most notable effect of browsing pressure between treatments was for vertical and horizontal cover in bigtooth clear-cuts. Cover within quaking aspen clear-cuts was less affected by browsing due to lower browse use by ungulates. Other structural and composition vegetation variables were similar between years.

When comparing current data to historical data, vertical and horizontal cover were significantly greater in bigtooth clear-cuts in 1995 than in the mid 1980's. This may be due to browsing, or to differences in inherent site characteristics, weather variables, or timing of harvest. Browse use of 2-year-old bigtooth clear-cuts was not significantly different in 1995 than in 1983-86 (Table 6), so between year differences in vegetation cover are not likely due to browsing effects. Inherent site characteristics, such as aspect, slope, soil type, and soil moisture, may contribute to the density of vegetation cover on those sites. However, sites chosen in the 1980's and 1990's encompass a range of these inherent characteristics and no individual sites stand out as largely different. Temperatures in 1983-84 (Campa 1989) and 1994-95 (Figure 2) did not vary from long-term averages (1940-69 and 1961-90, respectively). During the primary growth months (June-August) in 1983 and 1984, precipitation was lower than or equal to during June and July and higher than average in August. In 1994 and 1995 precipitation was higher than average in July as well as August. This relatively larger amount of precipitation during the growing season in 1994-95 may explain the development of greater amounts of vegetation cover during those years. Other contributing factors may relate to the timing of harvest and exclosure construction. During the 1980's, timber managers in PRCSF began to phase out growing season harvesting to conducting primarily dormant season cutting. By cutting only during the dormant season, aspen root systems are able to retain more stored energy, since nutrients have been transferred from the leaves before leaf senescence (Perala 1990). Some of the 1983-84 sites may have been cut during the growing season, which could potentially reduced their growth during the first few years. Another factor that may explain the significant difference present in vertical and horizontal cover between years, is the timing of exclosure building. In 1983, exclosures were constructed on 1-year-old and 2-year-old clear-cuts. Meaning that the 2-year-old clear-cuts had been exposed to 1 winter of ungulate browsing. Exclosures that were 2-years-old in 1984 had not had any previous exposure to ungulate browsing. This previous exposure to browsing may be a contributing factor to the lower cover values, but does not entirely explain the phenomenon. Likely, lower 1983 and 1984 values are a compilation of weather, timing of harvest, and timing of exclosure building.

Structure and composition of 12- to 15-year-old clear-cuts

Aspen stem densities on 12- to 15-year-old bigtooth clear-cuts ranged from 7,324 ± 669 to 10,308 ± 2,084 stems/ha in exclosures and from 4,216 ± 159 to 6,900 ± 2,214 stems/ha in areas open to browsing. Aspen stem densities on 12- to 15-year-old quaking clear-cuts ranged from 7,758 ± 1,164 to 10,192 ± 1,425 stems/ha in exclosures and from 3,917 ± 1,656 to 5,783 ± 2,624 stems/ha in open areas. Stem densities within clear-cuts of both species tended to be greater in exclosures in the >2.0 m strata and greater in browsed areas in the 0-0.5 m strata (Table 24 - Table 25). In the 0.5-2.0 m strata, bigtooth stem densities tended to be greater in browsed areas while quaking stem densities tended to be greater in exclosures. This may be attributed to a combination of browse use and growth rates. Bigtooth aspen stems are more heavily utilized than quaking stems (Table 5), thus, bigtooth aspen may have relatively lower recruitment rates into the upper height strata than quaking aspen. Quaking aspen, in comparison, can escape the browsing zone more quickly because of lower browse pressure and then are recruited into the overstory. Furthermore, although quaking aspen initially grows more slowly than bigtooth aspen (Laidly 1990), quaking aspen may have a greater likelihood for individual suckers to grow beyond the reach of herbivores due to the greater abundance of twigs within clear-cuts (Table 8). The opposite trend seen in exclosures may indicate that, when subdominant, bigtooth aspen stems die more quickly than quaking aspen stems.

Laidly (1990) stated that a merchantable aspen timber stand consists of 620-1235 stems per hectare at the end of rotation (30-40 years on poor sites, 50-60 years on good sites). Many estimates have been made of the initial number of aspen suckers required to produce this type of stand. However, due to the many factors that affect the growth and development of aspen stands between clear-cutting and harvest, these initial stocking estimates have been of limited value. Other estimates of minimum stocking density have been based on stem densities at a minimum height. In the western states, for example, DeByle (1985) indicated that if 1,000 aspen stems/ha reach 4 m the stand would produce merchantable timber. This may have limited application to Lake State stands where aspen suckers typically grow much faster (Perala 1990). Still other estimates have been

Table 24. Mean stem densities per hectare (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m, and total) in exclosures and areas open to browsing on 12-, 13-, 14-, and 15-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan.

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	171(65)	526(272)
		13	270(214)	83(45)
		14	79(79)	142(93)
	0.5 - 2.0 m	12	402(101)	1,345(683)
		13	208(47)	631(389)
		14	217(110)	326(102)
	> 2.0 m	12	8,519(1,421) B	989(393)
		13	9,831(2,068)	6,187(2,635)
		14	8,605(1,030)	4,216(275)
	Total	12	10,183(1,635) A	6,025(2,703)
		13	10,308(2,084)	6,900(2,214)
		14	8,900(1,037) B	4,683(94)
1995	0 - 0.5 m	13	25(14)	1,058(532)
		14	25(25)	75(75)
		15	8(8)	0(0)
	0.5 - 2.0 m	13	233(88)	3,258(1,647)
		14	92(33)	283(197)
		15	108(58)	58(30)

Table 24 (cont.)

Year	Stratum	Age class	Exclosure	Browsed
	> 2.0 m	13	8,300(1,121) C	1,942(661)
		14	8,417(1,417)	5,483(2,206)
		15	7,208(669) B	4,216(159)
	Total	13	8,558(1,194)	6258(2,594)
		14	8,533(1,510)	5842(1,937)
		15	7,324(669) B	4,216(159)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
C = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

Table 25. Mean stem densities per hectare (standard error) of aspen by height stratum (0-0.5 m, 0.5-2.0 m, >2.0 m, and total) in exclosures and areas open to browsing on 12-, 13-, 14-, and 15-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan.

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	34(34)	564(285)
		13	0(0)	33(33)
		14	147(119)	368(368)
	0.5 - 2.0 m	12	198(112)	402(223)
		13	342(115) A	138(94)
		14	147(119)	0(0)
	> 2.0 m	12	9,863(1,517)	4,817(3,061)
		13	9,600(1,247) C	4,913(1,286)
		14	8,898(1,899)	4,182(2,197)
	Total	12	10,192(1,425)	5,783(2,624)
		13	9,942(1,180) C	5,083(1,242)
		14	9,192(1,947)	4,550(1,942)
1995	0 - 0.5 m	13	0(0)	433(269)
		14	8(8)	58(58)
		15	8(8)	317(317)
	0.5 - 2.0 m	13	58(46)	117(65)
		14	175(175)	117(36)
		15	108(96)	17(17)

Table 25 (cont.)

Year	Stratum	Age class	Exclosure	Browsed
	> 2.0 m	13	8,317(1,183)	3,758(2,044)
		14	8,292(880) B	4,075(159)
		15	7,642(1,593)	3,583(1,898)
	Total	13	8,375(1,155)	4,308(1,719)
		14	8,475(729) B	4,250(1,670)
		15	7,758(1,644)	3,917(1,656)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
C = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

based on minimum density after the 1st period of natural thinning, and thus, may be somewhat more reliable indicators of merchantability. For instance, for a Lake State 11-year-old aspen stand, Zehngraff (1949) found that 5,460 stems/ha were more than enough to produce a fully stocked stand. Based on Zehngraff's (1949) recommendation, at age 11 browsed areas and exclosures in the PRCSF had approximately 10% and 68% more stems/ha respectively than required for minimum stocking.

The mean DBH of trees in 12- to 15-year-old clear-cuts ranged from 2.9-4.7 cm (Table 26). Quaking aspen clear-cuts tended to have greater mean DBHs than bigtooth clear-cuts. For both species, trees within browsed areas tended to have greater mean DBHs than trees within exclosures. The larger DBHs found in browsed areas is likely due to several physiological factors. The density of trees is typically lower in browsed areas, allowing each individual tree access to more space and nutrients. Also, lower tree density means individual trees received less support by neighboring trees resulting in larger DBH growth for mechanical stability. Mean tree heights of dominant and co-dominant aspen ranged from 7.1-9.0 m and tended to be greater in exclosures than in browsed areas (Table 27). As with DBH, quaking aspen clear-cuts tended to have greater mean tree heights than bigtooth aspen clear-cuts.

Zazada (1972), a Minnesota forester, defined a well stocked aspen stand as having a large number of evenly spaced trees with similar diameters at the time of harvest. He further detailed expected stocking rates and sizes of aspen during the development of stands. At age 11, aspen stands should be comprised mainly of trees 2.5-5.0 cm in diameter and 7.5 m in height at a density of 7,400 stems per hectare (Zazada 1972). By age 20, there should be 4,200 aspen stems per hectare of approximately 5.0-10.0 cm in

Table 26. Mean DBH in centimeters (standard error) of aspen in exclosures and areas open to browsing on 12-, 13-, and 14-year-old clear-cuts in Pigeon River Country State Forest, Michigan (1994).

Age	Exclosures	Browsed
	Bigtooth aspen	
12	3.5(0.2)	3.1(1.7)
13	2.9(0.2)	3.5(0.3)
14	3.7(0.1)	4.3(0.5)
	Quaking aspen	
12	3.6(0.4)	3.6(0.2)
13	3.4(0.2)	3.8(0.5)
14	3.9(0.2) A	4.7(0.5)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

Table 27. Mean tree height in meters (standard error) of dominant and co-dominant aspen in exclosures and areas open to browsing on 12-, 13-, and 14-year-old clear-cuts in Pigeon River Country State Forest, Michigan (1994).

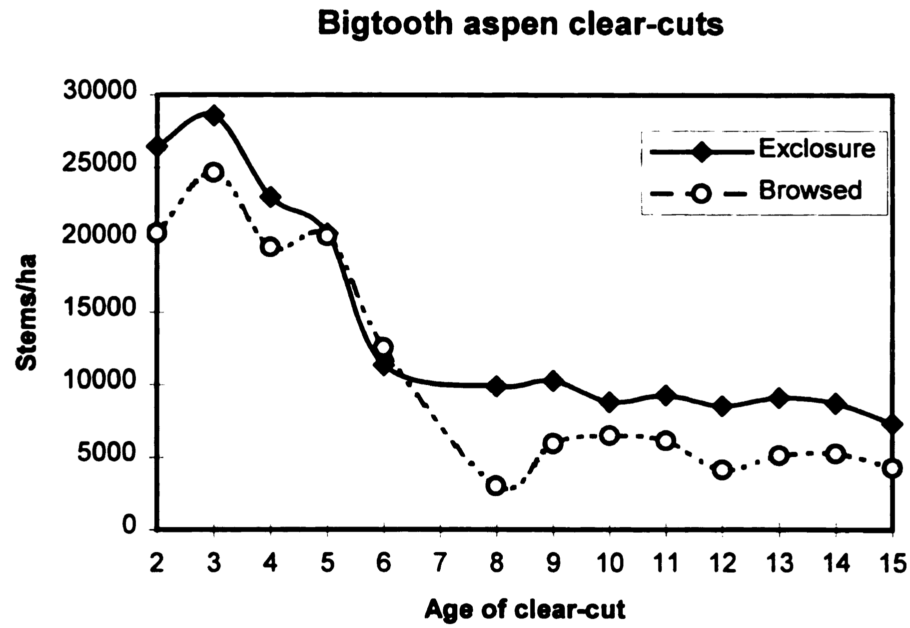
Age	Exclosures	Browsed
	Bigtooth aspen	
12	7.5(0.5) B	5.7(0.5)
13	7.1(0.2)	6.9(0.3)
14	9.2(0.4)	8.0(0.3)
	Quaking aspen	
12	7.8(0.5)	7.2(0.6)
13	9.0(0.5)	7.7(0.5)
14	8.6(0.6) A	8.0(1.1)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

diameter and 12 m in height. The mean DBH of trees in 12- to 15-year-old PRCSF clear-cuts fell within the range of 11-year-old stands (Table 26), indicating that, according to Zazada (1972), Pigeon River stands are developing DBHs typical of quality stands regardless of treatment. Likewise, tree heights for both treatments fell between Zazada's 11- and 20-year-old values (Table 27), indicating merchantable stand development. Stem densities in 12- to 15-year-old PRCSF exclosures closely matched values for 11-year-old stands, while browsed area stem densities were more similar to the 20-year-old stand values. This suggests that browsed areas may not support the minimum recommended stocking densities by age 20, and that exclosures may be overstocked. However, these conclusions should be viewed with caution because they are based on comparisons to 2 fixed point estimates and do not consider factors such as mortality and growth rates which will effect stocking density, DBH, and height.

It is important to examine stocking densities during stand development to determine thinning rates and predict future conditions. Two distinct conditions, aspen stands that have developed with and without the influence of ungulates, can be examined for potential differences in thinning rates and stocking densities due to ungulate use. Differences in stocking patterns can also be examined between aspen species. The following discussion and graphs of thinning rates and patterns incorporate data from the original set of 18 exclosures. Data have been pooled by age class from all available years.

In bigtooth clear-cuts, browsed areas showed a slightly greater increase in stem density than exclosures during the 3rd growing season (Figure 9). However, mean stem density was greater in exclosures than in browsed areas for most years of the study.



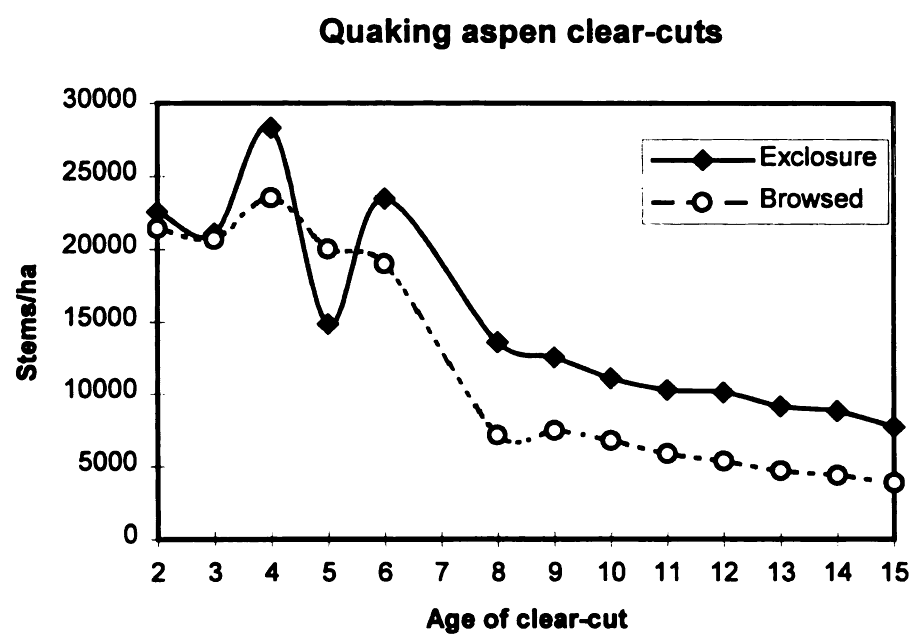
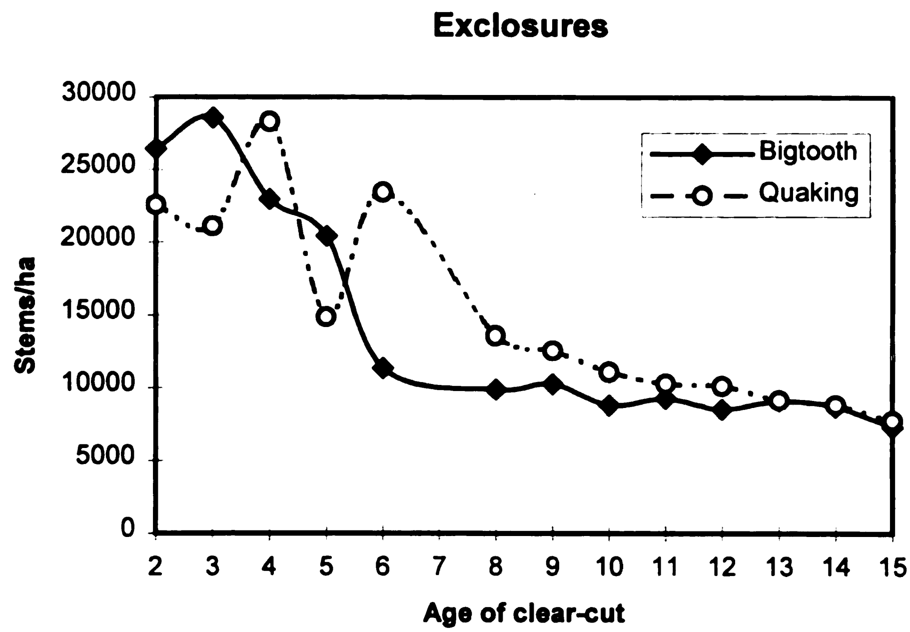


Figure 9. Mean aspen stem density per hectare on bigtooth and quaking aspen clear-cuts in exclosures and areas open to browsing from ages 2 to 15 in Pigeon River Country State Forest, Michigan, monitored from 1983-1995.

Exclosures experienced a 3 year period of natural thinning between the ages of 3 and 6. In browsed areas, the thinning duration was extended to 5 years (ages 3-8). Rates of stem loss were similar in exclosures and browsed areas during the later years, ages 9-15 (4% and 5% per year, respectively). By age 15, bigtooth clear-cuts contained fewer stems per hectare in browsed areas than in exclosures. Unlike bigtooth clear-cuts, browsed areas and exclosures in quaking clear-cuts began the 2nd year with a similar number of stems per hectare (Figure 9). Between the 3rd and 4th year there was a much greater increase in stems within exclosures than within browsed areas. Similar thinning rates were present in exclosures and browsed areas from ages 4 to 15. The rate of thinning in browsed areas was similar to the rate of thinning in exclosures for ages 9-15 (8% and 6% per year, respectively). However, because exclosures experienced a greater increase in stem density during the 3rd growing season, 15-year-old quaking aspen exclosures contain higher stem densities than browsed areas (Figure 9).

When comparing thinning rates between species, stems densities were initially greater in bigtooth aspen exclosures than in quaking exclosures and declined rapidly for 3 years (ages 3-6) (Figure 10). Stems per hectare remained relatively stable in bigtooth exclosures with little loss between ages 6 and 15. Quaking aspen exclosures began with fewer stems per hectare, but increased to the level found in bigtooth exclosure year 4. Stem density decline was less rapid and continued until age 8. By age 15, bigtooth and quaking aspen exclosures contained approximately equal numbers of stems per hectare. Similarly, in browsed areas, stem density peaked later in quaking aspen clear-cuts than in bigtooth aspen clear-cuts, but densities were similar in maximum value (Figure 10). The majority of thinning lasted 3 years and occurred approximately 2 years later in quaking



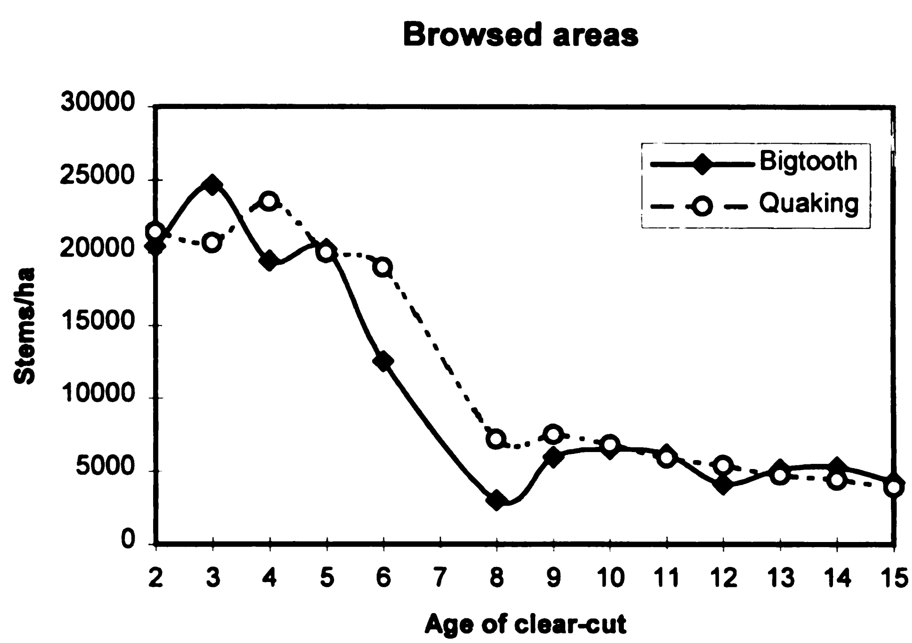


Figure 10. Mean aspen stem density per hectare in exclosures and areas open to browsing on bigtooth and quaking aspen clear-cuts from ages 2 to 15 in Pigeon River Country State Forest, Michigan monitored from 1983-1995.

clear-cuts than in bigtooth clear-cuts. Declines in stem densities were slow beyond age 8, and by age 15, bigtooth and quaking browsed areas contained similar numbers of stems per hectare (Figure 10). For both species, years 1-6 were a critical period for changes in stem density. These are also the ages when clear-cuts experience the greatest browse utilization by ungulates, particularly ages 1-3 (Campa 1989). These data support the idea that reducing or minimizing browsing on young clear-cuts may be important to sustain timber production within these areas. Furthermore, the lower stem densities present at age 15 in browsed areas than exclosures may indicate a potential long-term effect on timber production.

Theoretically, since the rate of thinning within browsed areas and exclosures is relatively equal after age 8, the stocking densities at age 40 can be projected from stem densities of 7- to 8-year-old stands regardless of browsing observed. For example, at age 40, bigtooth stands will contain 1,186 stems/ha based on the more conservative observed thinning rate from 9- to 15-year-old browsed bigtooth areas (5% stem loss per year). Quaking aspen stands will contain 487 stems/ha based on the thinning rate of 8% stems/year observed in browsed areas or 834 stems/ha based on the observed exclosure thinning rate of 6%. When these figures are compared figures to Laidly's (1990) recommendation of 620-1,235 stems/ha at the end of rotation (40 years), bigtooth stands will support merchantable timber regardless of ungulate browse use. In contrast, when using the conservative thinning rate, quaking aspen stands contain fewer stems than recommended, therefore browse use may be impacting the long-term merchantability within these stands. However, these numbers are only predictions of possible stocking densities, long-term evaluation of browsing effects on aspen stand composition and structure are necessary to determine final merchantability of PRCSF stands.

Significant differences in vertical cover were mostly found between treatments in the >2.0 m strata (Table 28 and Table 29). Exclosures tended to have greater vertical cover in the upper strata than browsed areas for bigtooth and quaking aspen clear-cuts. The largest difference found between treatments was in the >2.0 m strata in 13-year-old bigtooth clear-cuts: 60% more cover in exclosures than in browsed areas. Exclosures with greater vertical cover in the upper strata also tended to have greater stem densities than browsed areas. There were no recognizable trends in bigtooth clear-cuts concerning vertical cover treatment differences in the 0-0.5 m and 0.5-2.0 m strata. Quaking clear-cuts tended to have greater percent cover in exclosures for all strata (Table 29).

Although there tended to be greater percent vertical cover within exclosures for both species, there were few significant differences between treatments (Table 28 and Table 29). Haufler et al. (1985) reported many significant differences in vertical cover between treatments for these clear-cuts at ages 2-4. This suggests that while protection from ungulate browsing allows greater percent vertical cover to develop in exclosures, the differences between treatments peak by age 4. This indicates that by ages 12-15 clear-cuts may be recovering from the initial impacts of browsing on vertical cover. Furthermore, because bigtooth aspen clear-cuts still show significant differences between treatments, there is evidence that bigtooth clear-cuts may recover more slowly than quaking aspen clear-cuts. Likely, recovery rates are related to the degree of browse utilization within clear-cuts when they are young. Bigtooth clear-cuts may recover more slowly than quaking clear-cuts because they experience heavier browsing pressure.

Table 28. Significant differences in vertical cover by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) between exclosures and areas open to browsing on bigtooth aspen clear-cuts of various age classes in Pigeon River Country State Forest, Michigan (1994 and 1995).

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	65(14)	82(1)
		13	71(11)	68(10)
		14	41(8)	40(14)
	0.5 - 2.0 m	12	63(4)	61(8)
		13	65(11)	68(1)
		14	76(3)	71(4)
	> 2.0 m	12	67(19)	30(1)
		13	77(10)	71(19)
		14	86(2) B	68(5)
1995	0 - 0.5 m	13	76(6) A	90(0)
		14	77(4)	63(4)
		15	63(7)	61(13)
	0.5-2.0 m	13	73(3)	75(6)
		14	69(4)	69(1)
		15	78(4)	79(3)
	> 2.0 m	13	91(6) B	31(3)
		14	82(8)	71(19)
		15	95(1) B	82(4)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).

Table 29. Significant differences in vertical cover by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) between exclosures and areas open to browsing on quaking aspen clear-cuts of various age classes in Pigeon River Country State Forest, Michigan (1994 and 1995).

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	64(12)	82(4)
		13	81(5)	84(11)
		14	90(5)	88(5)
	0.5 - 2.0 m	12	44(7)	33(8)
		13	67(8)	64(14)
		14	65(9)	60(14)
	> 2.0 m	12	87(3)	64(21)
		13	81(7)	72(12)
		14	89(4)	60(24)
1995	0 - 0.5 m	13	58(10)	70(6)
		14	76(9)	66(12)
		15	82(7)	80(9)
	0.5-2.0 m	13	49(12)	32(9)
		14	74(10)	56(12)
		15	69(5)	80(9)
	> 2.0 m	13	88(5)	64(23)
		14	91(7) A	73(13)
		15	94(3)	62(26)

A = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

However, it is unlikely that recovery rates are effected by only browse use, many other factors may be involved such as soil type, soil moisture, topography, aspect, and disease.

Few significant differences were found in horizontal cover between exclosures and areas opened to browsing for 12- to 15-year-old clear-cuts (Table 30 and Table 31). In bigtooth clear-cuts, horizontal cover tended to be greater in browsed areas in the 0-0.5 m strata and greater in exclosures in the 1.0-1.5 m, 1.5-2.0 m, and 2.0-2.5 m strata (Table 30). Thus, the relatively more open canopy in browsed areas allowed greater herbaceous development while the relatively more shaded exclosures had greater development of shrubs and saplings. Similar trends were present in the quaking aspen clear-cuts (Table 31). These trends are reminiscent of the significant differences found when the clear-cuts were between 4 and 6-years-old (Campa 1989). This suggests that aspen clear-cuts may be able to recover from the initial impacts of browsing and provide similar structure for hiding cover as non-browsed stands.

The total number of woody species, other than aspen, tended to be greater in quaking aspen clear-cuts than in bigtooth clear-cuts. Quaking clear-cuts had from 19-24 species, depending on age class, while bigtooth clear-cuts had from 7-17 species. Few significant differences ($P < 0.10$) were found in mean stem densities of woody species between treatments in 12- to 15-year-old bigtooth and quaking aspen clear-cuts (Appendix Table 13 - Appendix Table 24).

The most abundant species, other than bigtooth aspen, found in bigtooth clear-cuts were black cherry, red maple, juneberry, and red oak (*Quercus rubra*). Within the >2.0 m strata, 70-100% of the species common to both treatments had greater stem densities within exclosures. Thus, protection from browsing has allowed greater stems/ha of most

Table 30. Significant differences in horizontal cover by height stratum (0-0.5 m, 0.5-1.0 m, 1.0-1.5 m, 1.5-2.0 m, and 2.0-2.5 m) between exclosures and areas open to browsing on bigtooth aspen clear-cuts of various age classes in Pigeon River Country State Forest, Michigan (1994 and 1995).

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	86(4)	95(8)
		13	91(4)	99(8)
		14	95(1)	97(6)
	0.5 - 1.0 m	12	50(6)	55(5)
		13	64(7)	73(7)
		14	68(10)	68(9)
	1.0 - 1.5 m	12	43(8)	29(7)
		13	48(8)	34(7)
		14	38(12)	25(10)
	1.5 - 2.0 m	12	44(9) C	25(8)
		13	39(8)	29(7)
		14	32(11)	23(9)
	2.0 - 2.5 m	12	45(8)	36(7)
		13	50(10)	29(9)
		14	31(11)	20(10)
1995	0 - 0.5 m	13	93(1) A	94(5)
		14	87(1)	90(4)
		15	96(0)	97(2)

Table 30 (cont.)

Year	Stratum	Age class	Exclosure	Browsed
	0.5-1.0 m	13	62(10)	64(10)
		14	61(7)	61(4)
		15	85(3)	80(6)
	1.0-1.5 m	13	42(13)	37(11)
		14	35(7)	36(4)
		15	61(2)	33(13)
	1.5-2.0 m	13	38(12)	28(13)
		14	25(2)	38(6)
		15	56(4)	23(7)
	2.0 - 2.5 m	13	39(14) B	33(11)
		14	25(8)	31(6)
		15	61(2) B	29(17)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).
C = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

Table 31. Significant differences in horizontal cover by height stratum (0-0.5 m, 0.5-1.0 m, 1.0-1.5 m, 1.5-2.0 m, and 2.0-2.5 m) between exclosures and areas open to browsing on quaking aspen clear-cuts of various age classes in Pigeon River Country State Forest, Michigan (1994 and 1995).

Year	Stratum	Age class	Exclosure	Browsed
1994	0 - 0.5 m	12	70(8)	67(7)
		13	98(2)	94(4)
		14	95(2)	96(6)
	0.5 - 1.0 m	12	48(4)	40(3)
		13	86(8) A	75(7)
		14	67(12)	64(12)
	1.0 - 1.5 m	12	31(9)	24(6)
		13	63(8) A	44(5)
		14	41(12)	31(10)
	1.5 - 2.0 m	12	28(7)	18(6)
		13	49(7) A	30(5)
		14	23(7)	27(6)
	2.0 - 2.5 m	12	33(9)	17(7)
		13	54(11) A	24(8)
		14	28(7)	25(7)
1995	0 - 0.5 m	13	76(14)	58(14)
		14	83(11)	77(17)
		15	80(8)	83(4)

Table 31 (cont.)

Year	Stratum	Age class	Exclosure	Browsed
	0.5-1.0 m	13	52(14)	26(18)
		14	71(8)	43(23)
		15	59(16)	39(11)
	1.0-1.5 m	13	41(14)	23(16)
		14	52(19)	33(22)
		15	30(15)	16(10)
	1.5-2.0 m	13	33(14)	13(10)
		14	47(16)	24(16)
		15	25(15)	9(5)
	2.0 - 2.5 m	13	41(18)	16(10)
		14	38(25)	24(17)
		15	26(17)	11(7)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

species to be recruited into the canopy. However, some species, such as hawthorn (*Crataegus* spp.), witch-hazel (*Hamamelis virginiana*), hop-hornbeam, and white oak (*Q. alba*), had higher stem densities in the upper strata in browsed areas. Browsing pressure has served to release these less common species from competition, allowing greater numbers of stems/ha to grow to >2.0 m in browsed areas than in exclosures. No trends in abundance of woody species were identified in the lower 2 strata.

The most abundant species found in 12- to 15-year-old quaking aspen clear-cuts were red maple, black cherry, juneberry, and sugar maple. Of the species common to both treatments, an average of 78% of the species >2.0 m in height were more frequent within exclosures than in browsed areas. These species were primarily juneberry, black cherry, red maple, dogwood (*Cornus* spp.), and beaked hazelnut (*Corylus americana*). Because they have been protected from browsing, a greater number of stems/ha of these species have been recruited into the canopy layer. Species found more frequently in the upper strata of browsed areas were white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), hawthorn, witch-hazel, and red oak. These species were released from competition by browsing which has allowed larger numbers to grow to >2.0 m in height in browsed areas. The greater abundance of conifers in browsed areas may allow these stands to provide better hiding cover for other wildlife species such as the ruffed grouse. According to the Michigan grouse habitat model (Hammill and Moran 1986), conifer stems provide 4 times the amount of cover provided by aspen stems, thus the presence of even a few conifer stems/ha can compensate for lower aspen stem densities. As with bigtooth clear-cuts, no trends in abundance of woody species were identified in the lower 2 strata. These data on the composition of woody species within sapling stage aspen clear-cuts supports the theory that ungulate browsing can alter the composition of stands (Mueggler and Bartos 1977, Marquis and Brenneman 1981, Tilghman 1989) either through direct utilization or indirectly by altering competitive interactions.

Sakai et al. (1985) studied successional changes in mature aspen stands (55- to 65-years-old) in northern lower Michigan between 1974 and 1981. They found that the overstory of mature aspen stands typically consisted of bigtooth aspen, red maple, and quaking aspen while the understory was composed of sugar maple, red maple, and American beech. Sakai et al. considered red maple more dominant than sugar maple in both the overstory and understory with rapid turnover and recruitment into gaps. Sugar maple and American beech were present in smaller diameter classes and likely would become more dominant in the stand much later. Roberts and Richardson (1985), who followed community succession in aspen forests for 41 years (ages 19-60), reported that in northern lower Michigan mature aspen forests on dry mesic sites are typically succeeded by red maple and red oak, while aspen on mesic sites are typically succeeded by American beech, sugar maple, and red maple.

Currently, the species other than aspen dominant in 12- to 15-year-old bigtooth and quaking aspen clear-cuts are red maple and black cherry (Appendix Table 13 - Appendix Table 24). Only the youngest cohort of bigtooth aspen clear-cuts (12 years old in 1994, 13 years old in 1995) have, at any time, supported the late successional hardwoods sugar maple and American beech. In these clear-cuts, all sugar maple present in browsed areas at age 4 have died, while only 28% of the sugar maple present at age 4 in the 0.5-2.0 m strata have been recruited in the >2.0 m strata. American beech are relatively rare and have only begun seeding into the youngest cohort of bigtooth exclosures at age 13. Sugar maple and American beech are relatively rare in 12- to 15-year-old quaking aspen clear-cuts as well. Sugar maple was common at only 1 of 9 quaking aspen sites, but was beginning to seed into both the exclosures and browsed areas of other sites. The American beech present in some sites at younger ages (5 and 6) had largely died out, but some seedlings were present in both treatments.

These composition data suggest that, if not harvested, both bigtooth and quaking aspen sites will likely succeed to stands dominated red maple and black cherry. This type of successional pathway is in agreement with those found by Roberts and Richardson (1985) and Sakai et al. (1985). While some authors have suggested that browsing may promote black cherry within stands (Tilghman 1989, Yahner 1995), in the PRCSF black cherry was relatively equally dominant in exclosures and browsed areas. Although red maple and black cherry were the most common species other than aspen in 12- to 15-year-old clear-cuts, this does not preclude the possibility that sugar maple and American beech may become important succeeding hardwood species. These species generally exhibit a delayed dominance strategy (Robert and Richardson 1985) and are currently present in small numbers in clear-cuts.

Few differences in herbaceous species composition were found between exclosures and areas open to browsing in bigtooth or quaking clear-cuts (Appendix Table 25 - Appendix Table 30). Bigtooth aspen clear-cuts supported between 25 and 36 herbaceous species while quaking aspen typically supported 35-54 species. Exclosures and browsed areas each tended to have approximately 5-10 unique species. Browsed areas of 14-year-old quaking aspen clear-cuts contained 23 unique herbaceous species, the highest number for either species or treatment. The most frequently encountered species within both species of clear-cuts were bracken fern, grasses, *Rubus* spp., aster spp., and common strawberry. For bigtooth clear-cuts, wild lettuce (*Lactura canadensis*), sheep sorrel (*Rumex acetosella*), and low sweet blueberry (*Vaccinium corymbosum*) were found more commonly in browsed areas while checkberry (*Gaultheria procumbens*), wood-betony (*Pedicularis canadensis*), *Pyrola* spp., smooth rose (*Rosa blanda*), and highbush blueberry (*V. corymbosum*) were found more frequently in exclosures. In quaking aspen clear-cuts the species most frequently found in browsed areas were common strawberry, grass, orange hawkweed, wild lettuce, partridgeberry (*Mitchella repens*), sweet cicely (*Osmorhiza claytoni*), bracken fern, *Pyrola* spp., and goldenrod (*Solidago* spp.). Species found most frequently in quaking aspen exclosures include wild sarsaparilla (*Aralia nudicaulis*), bunchberry (*Cornus canadensis*), Canada mayflower (*Maianthemum canadense*), fringed polygola (*Polygola paucifolia*), large-flowered trillium (*Trillium grandiflorum*), and aster (*Aster* spp.). Species found more frequently in exclosures tended to be species that prefer growing in a more shaded microclimate, while species found more frequently in browsed areas tended to be species that prefer growing in a more open environment. Some herbaceous species considered sensitive to browsing, such as trillium and lilies (Rogers et al. 1981, Nelson and Leege 1982), were found almost exclusively in exclosures. Between 20 and 50% of the species found more frequently in exclosures are forage species for elk or white-tailed deer, while 0-50% of the species more frequent in browsed areas are elk or white-tailed deer forage plants (Rogers et al. 1981, Nelson and Leege 1982). The proportion of forage plants is similar between treatments, suggesting that any significant differences in herbaceous frequencies may not be directly caused by feeding activity but rather related to browsing effects on stand characteristics such as vertical cover, and overstory and shrub stem densities.

Similar species were common to clear-cuts at ages 12-14 as were common to them at ages 4-6. When younger, herbaceous species common to clear-cuts included bracken fern, violet, grasses, *Carex*, common strawberry, *Rubus*, and orange hawkweed (Campa 1989). Additional species common to 12- to 14-year-old clear-cuts were aster and blueberry, both of which were present when the sites were younger. However, many more species (40-70% more in bigtooth aspen clear-cuts, 50-80% more in quaking aspen clear-cuts) were found within these stands at older ages than when younger. The greatest difference between clear-cuts across the years has been the accumulation of species within stands and greater numbers of species unique to each treatment. Many of these accumulated species are considered residents in mature aspen stands. For example, blueberry, checkberry, bracken fern, and strawberry are common herbaceous species in the bigtooth aspen forest type (Laidly 1990) while *Rubus*, *Ribes*, *Viburnum*, aster, wild sarsaparilla, aster, Canada mayflower, bedstraw, sweet fern, bracken fern, *Carex*, and *Solidago* are common to the quaking aspen forest type (Perala 1990). These species, typical of mature aspen stands, are frequently found in 12- to 14-year-old clear-cuts. The accumulation of species across time is an artifact of successional changes, however, species that appear more frequently or uniquely within either exclosures or open areas are probably a result of both successional changes and browsing effects.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Most 1- to 3-year-old bigtooth aspen stands in the PRCSF currently experience high (> 50%) browse use intensities, in contrast to quaking aspen clear-cuts. Bigtooth aspen clear-cuts were browsed significantly ($P < 0.01$) more than quaking aspen clear-cuts across all age classes and browsing decreased significantly ($P < 0.01$) with age since harvest. No significant differences ($P > 0.10$) were found between current and historic levels (1983-1986) of browsing on any age of bigtooth aspen clear-cut. Two and 3-year-old quaking clear-cuts showed significantly ($P < 0.10$) lower intensities of browsing in 1995 than in the pooled years 1983 through 1986.

Calculated HSI values indicated relatively poor to marginal (0.20 - 0.51) habitat quality for elk within the 8 evaluation areas examined. The HSI value for an evaluation area, as described by Beyer (1987), is the minimum of 3 sub-model SI values: winter cover suitability value (WCSV), winter food suitability value (WFSV), and spring food suitability value (SFSV). Seventy five percent of the HSI values were determined by the WCSV, while the remainder were determined by the WFSV. In most cases, the dominating factor that led to low HSI values was inadequate area in optimum cover types. The minimum areas required in optimum cover types are 10% winter cover, 15% winter food, and 10% spring food.

Although elk use throughout the PRCSF is prevelent, elk HSI values were relatively low, suggesting that the HSI model may not accurately reflect habitat quality. Some modifications are warranted to refine the model, such as assigning optimum SI values by age or stocking classes within cover types and altering the selection process for including stands for evaluation. Additionally, further research is needed to address the validity of the model. Few significant ($P < 0.10$) correlations were found between elk abundance, HSI values, and browse use, however, sample sizes were extremely small.

The few differences in vegetation characteristics between exclosures and browsed areas found in 1-year-old clear-cuts in 1994 and 1995 were probably due to random chance. Stem densities, vertical and horizontal cover, and species composition data demonstrate that exclosures and paired areas open to browsing were similar in all aspects at the beginning of the study. Thus, any differences found between treatments in the future may be attributed to browsing effects.

Browsing on 2-year-old clear-cuts resulted in few significant differences in stem densities of woody species. Aspen stem densities and rates of stem loss were similar between treatments for both species of clear-cuts. Furthermore, few significant differences in herbaceous species frequencies were found between treatments regardless of aspen species. The most notable effect of browsing pressure between treatments was for vertical and horizontal cover in bigtooth clear-cuts. Cover within quaking aspen clear-cuts was less affected by browsing due to lower browse use by ungulates. When comparing current data (1995) to historical data (1983-1985), relative differences between treatments for aspen stem densities and cover were similar across years. However, when comparing individual treatments between years, vertical and horizontal cover was significantly ($P < 0.10$) greater in bigtooth clear-cuts in 1995 than in the mid 1980's. These differences may be due to browsing, or differences in inherent site characteristics and weather variables, or timing of harvest and exclosure construction. Other structural and composition vegetation variables were similar among years.

Longer term impacts (12-15 year) of browsing include reductions in stem density, tree height, vertical and horizontal cover, increases in DBH, and alteration of species composition. Although visual differences between exclosures and browsed areas can be observed in aspen stem densities and cover, evidence suggests that stem densities within 12- to 15-year-old clear-cuts are adequate to produce merchantable timber stands. However, further research is necessary to determine the impacts browse use may produce in timber volume or quality. Furthermore, browsing-induced changes may have significant impact on the ability of aspen stands to provide habitat components for other wildlife species. For example, the greater percent vertical cover present in the lowest strata (0-0.5 m) of browsed areas may reduce habitat quality for woodcock by interfering with foraging access to the ground surface (Cade 1985). Lower aspen densities within browsed areas may result in less hiding cover for ruffed grouse, but the greater stem densities of conifers found within browsed areas may compensate (Hammill and Moran 1986).

The woody species other than aspen dominant in 12- to 15-year-old bigtooth and quaking aspen clear-cuts were red maple and black cherry. Other late successional hardwoods, such as sugar maple and American beech, were relatively rare. The data suggests that, if not harvested, both bigtooth and quaking aspen sites will likely succeed to stands dominated by red maple and black cherry. This is typical for aspen sites in northern lower Michigan (Roberts and Richardson 1985, Sakai et al. 1985). Total number of herbaceous species increased across the years, and current species composition included herbs typical of mature aspen stands (Laidly 1990, Perala 1990). Differences in herbaceous composition between exclosures and browsed areas is likely a combination of succession and browsing effects.

Currently in the PRCSF there is no differentiation between bigtooth and quaking aspen when classifying cover types or contracting timber sales, because no distinction is made at the market level. Incidental information is available for some stands, however, throughout most of the forest stands of each species are recorded only as containing "aspen". Nevertheless, significant differences in ungulate use of each species can lead to localized regeneration problems, and altered stand composition and structure, particularly within bigtooth clear-cuts. Thus, while the species of aspen may not be important at the market level, distinguishing between the 2 species may prove valuable in multiple use and landscape-level planning efforts in the Pigeon River Country State Forest.

Browse use within clear-cuts is a function of food quality, cover, and human access (Lyon and Ward 1982). Not only is bigtooth aspen more nutritional than quaking aspen (Campa et al. 1992), but also high browse use (> 50%) primarily occurs within bigtooth clear-cuts. Therefore, the following recommendations on reducing browse use are targeted for bigtooth clear-cuts. The relationship of cover to clear-cut use is a function of the size of the cut and the presence of security cover at the edges. Lyon and Ward (1982) found that in areas where tree cover is almost continuous, elk prefer openings and clear-cuts of ≤ 16.2 ha (40 acres). In Wyoming, Boyce (1989) found elk prefer openings that are a maximum of 400 m across (13 ha (32 acre) circle). Thus, cutting bigtooth aspen stands in blocks that are larger and wider than these preferred dimensions may reduce mean percent browse use within those areas. Only approximately 25% of clear-cuts in PRCSF in 1993-1995 were ≥ 13 ha. Clear-cuts of this size and greater may be beneficial to some wildlife. Back (1982), for example, found that song bird diversity increased with clear-cut size in Minnesota. However clear-cuts of this size may be detrimental to other species, such as showshoe hare (*Lepus americanus*), that prefer smaller 2-4 ha clear-cuts (Gullion 1985).

Cutting larger blocks of bigtooth aspen may only reduce browsing pressure in the center, or core area, of the stand. Elk will still feed along the edges of stands near security cover, but avoid areas of the stand distant from cover, essentially reducing the available size of the clear-cut. Thus the same number of clear-cuts may be needed to provide equivalent feeding area. Total hectares of harvested aspen per year would increase if the size clear-cuts is uniformly increased. Alternatively, if increases in harvested hectares of aspen is not desired, the number of clear-cuts should be reduced to compensate for increases in individual cut size. In this case, alternative food resources should be provided and aspen clear-cut distribution throughout the forest may be more critical. Optimum alternative winter food sources are northern hardwoods and cedar stands with dense regeneration (Beyer 1987).

Another factor that affects the browse use of openings and clear-cuts is human and vehicle access by roads (Knight 1975, Lyon and Jenson 1980, Lyon and Ward 1982, Grover and Thompson 1986). Ungulate use of openings has been negatively correlated with road access into or near the opening. Currently, logging roads are diligently closed immediately after clear-cutting is completed due to the potential negative impacts on the elk population through poaching and on the wild character of the PRCSF. Delaying road closures into bigtooth aspen clear-cuts for up to 3 years could potentially reduce browsing pressure by allowing human disturbance within those areas. However, increased access to secluded areas could potentially lead to increased poaching intensity. Illegal kills are second only to legal kills as the leading cause of elk mortality in northern lower Michigan (Campa et al. 1995). Alternatively, for clear-cuts near established roads increasing the proportion of the cut visible from the road may reduce ungulate use within that stand. However, clear-cuts visible on main roads may be negatively received by the public, particularly during their first several growing seasons. To reduce public negativity concerning clear-cut visibility, signs with information on the role of clear-cutting in elk management could be placed at prominent clear-cuts. Also, brochures could be made available at the PRCSF headquarters for public use.

Browsing pressure within aspen stands may also be reduced by providing greater numbers of hectares and more even distribution of optimum foraging cover types. The 8 randomly located HSI evaluation areas all had less than optimum proportions of optimum spring foraging cover types (desired minimum = 10%). Optimum spring foraging cover types include managed wildlife openings and cultivated winter wheat, while aspen only provides a potential suitability of 0.7. The proportions of evaluation areas within optimum cover types ranged from only 0 - 2% of total area, indicating a substantial lack of optimum foraging area. Additional managed wildlife openings may reduce browsing pressure within clear-cuts during the spring by providing forage of higher nutritional value to elk. Newly created openings should be placed in areas where clear-cutting is underway or future clear-cutting is planned to maximize potential benefits from this technique.

The MDNR currently creates managed openings and young clear-cuts as a part of their elk management plan. However, even distribution of these areas throughout the forest is often lacking. It has been theorized that single, isolated clear-cuts (especially bigtooth aspen clear-cuts) may experience high levels of browsing due to the limited availability of foraging areas in the surrounding landscape. Consequently, since the late 1980's Pigeon River foresters have planned aspen clear-cuts in multiple units as an attempt to reduce browsing pressure within any one unit. However, there have been no significant reductions in percent browse use in bigtooth clear-cuts since the mid 1980's, nor has there been an substantial increase in elk numbers within the State Forest. Furthermore, for bigtooth aspen clear-cuts, the preferred aspen species, there is some evidence that clumping may lead to higher levels of browsing by attracting elk to an area with increased foraging opportunities. Therefore, when planning an aspen clear-cut, its location relative to other clear-cuts, must be considered as well as its location relative to managed openings and hardwood thinnings.

Rather than focusing on the spatial arrangement of individual bigtooth clear-cut units, the foraging potential in the surrounding area should be considered. If other cover types that provide optimum winter and spring foods are managed in conjunction with bigtooth stands, browse use may be reduced in those areas. For example, creating more managed openings, interspersed with new or proposed clear-cuts, will increase forage potential in areas surrounding clear-cuts and potentially reduce browsing pressure within those cuts. Likewise, locating selective thinnings of hardwoods near or adjacent to bigtooth clear-cuts will provide alternative foraging areas for elk.

These management recommendations focus on habitat manipulation as a mechanism to control browsing pressure. However, population manipulation may also be useful for addressing browsing concerns. To potentially reduce the total number of animals within an area that can contribute to browsing, more licenses could be issued for management units with young bigtooth clear-cuts or potential browsing problems. This would permit hunters to reduce abundances of elk and white-tailed deer in target areas prior to or during the first browsing season. Currently, PRCSF spans 3 management units that range from 385-640 km^2. Attempts to remove local animals that cause damage may be more effective if management unit size and shape were based on the demographic patterns of elk causing depredation problems, Size and location of these units should be based on elk distribution, and would allow for more finely-turned herd manipulations.

Another potential tool for population manipulation is to allow hunting within the primary elk range during September hunts. Currently, September hunting occurs only in outlying areas in an effort to reduce potential elk/agriculture conflicts. Allowing September hunting within the PRCSF could increase the effectiveness of local herd reduction. However, opening the primary elk range for hunting in September may result in reduced hunting pressure in outlying areas and conflict with elk viewing opportunities.

Habitat management has greater potential than population manipulation for adequately addressing the issue of high localized browse use due to elk grouping behavior. Browsing pressure within any one stand seems to be largely due to concentration of animals in that area. Once the majority of accessible stems and twigs are browsed within a clear-cut, animals typically move to a different location and concentrate foraging efforts within that area. Population manipulation is a broad-scale technique that increases or reduces numbers of animals over a large area. Even when the total number of elk is reduced, individual elk exhibit the same social behaviors, again leading to concentrated use of clear-cuts in localized areas. Extreme herd reduction may reduce browsing even in localized areas, but the tradeoff of fewer elk for potentially greater timber production must be considered. Thus, altering stand characteristics and distribution may have more potential for reducing browsing pressure within individual clear-cuts.

Because browsing tends to be problematic on a local scale, habitat manipulations and herd reductions may not decrease browsing pressure within every bigtooth or quaking aspen stand in the PRCSF. In fact, reducing browsing pressure to levels that do not alter stand structure and composition may not be desirable in every stand. Managers may chose to accept browsing induced changes within some clear-cuts to provide unique habitat components for the wildlife species that rely on less densely stocked stands with greater understory development, such as snowshoe hare, red fox, black-capped chickadee, and a number other songbirds. By managing for stands with a range of browse use, aspen stands will provide a variety of habitat structures and unique species compositions to potentially support a wider diversity of plant and animal species.

Although ungulate browsing of aspen affects initial and potentially long-term stand structure and composition, evidence suggests that stem densities are adequate to produce merchantable timber stands. Young aspen clear-cuts should continue to be monitored for percent browse use to predict future stand conditions. Evaluation of long-term vegetation response to browsing should continue until stands are harvested. The management of the aspen resource has implications for multiple economic and recreational uses. The effects of ungulate use on aspen stands should be considered when setting habitat and population management goals to maintain multiple use benefits within the PRCSF.

APPENDIX

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Appendix Table 1. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 1-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994). No significant differences (P > 0.10) (paired t-test, Gill 1978).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	3,900(788)	5,575(1,819)
Populus grandidentata	0.5-2.0	25,558(3,503)	21,067(5,034)
	>2.0	0(0)	0(0)
Quaking aspen	0-0.5	283(202)	325(325)
Populus tremuloides	0.5-2.0	2,992(2,880)	1,917(1,867)
	>2.0	0(0)	0(0)
Red maple	0-0.5	1,806(1,485)	1,083(96)
Acer rubrum	0.5-2.0	28(28)	83(48)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	2,778(1,588)	1,861(1,108)
Acer saccharum	0.5-2.0	28(28)	56(56)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	1,139(431)	1,695(628)
Amelanchier spp.	0.5-2.0	306(111)	667(585)
	>2.0	28(28)	0(0)
Paper birch	0-0.5	889(848)	3,056(3,056)
Betula papyrifera	0.5-2.0	278(278)	778(778)
	>2.0	0(0)	111(111)
Alternate leaf dogwood	0-0.5	195(195)	28(28)
Cornus alternifolia	0.5-2.0	28(28)	0(0)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	111(111)	0(0)
Elaeagnus umbellata	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Black ash	0-0.5	806(482)	945(674)
Fraxinus nigra	0.5-2.0	56(56)	111(111)
	>2.0	0(0)	0(0)

Appendix Table 1 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Pin cherry	0-0.5	2,611(1,651)	3,222(2,935)
Prunus pensylvanica	0.5-2.0	417(210)	722(641)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	1,167(301)	1,250(488)
Prunus serotina	0.5-2.0	722(348)	528(121)
	>2.0	0(0)	0(0)
Basswood	0-0.5	556(556)	167(96)
Tilia americana	0.5-2.0	500(459)	195(195)
	>2.0	0(0)	0(0)

Appendix Table 2. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 1-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995). No significant differences (P > 0.10) (paired t-test, Gill 1978).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	4,775(940)	3,233(393)
Populus grandidentata	0.5-2.0	14,092(928)	14,492(3,272)
	>2.0	25(14)	33(22)
Balsam fir	0-0.5	93(93)	130(81)
Abies balsamea	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red maple	0-0.5	6,963(592)	11,111(2,111)
Acer rubrum	0.5-2.0	74(37)	167(85)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	722(722)	56(56)
Acer saccharum	0.5-2.0	148(148)	0(0)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	1,519(438)	1,481(419)
Amelanchier spp.	0.5-2.0	222(170)	222(116)
	>2.0	0(0)	0(0)
Paper birch	0-0.5	333(231)	1,444(1,123)
Betula papyrifera	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	426(426)	111(85)
Cornus alternifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	148(98)	389(195)
Corylus cornuta	0.5-2.0	0(0)	93(49)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	19(19)	0(0)
Crataegus spp.	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 2 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Autumn-olive	0-0.5	37(37)	37(37)
Elaeagnus umbellata	0.5-2.0	0(0)	74(74)
	>2.0	0(0)	0(0)
American beech	0-0.5	74(49)	93(67)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	852(852)	741(713)
Ostrya virginiana	0.5-2.0	241(241)	260(260)
	>2.0	0(0)	0(0)
White pine	0-0.5	0(0)	74(49)
Pinus strobus	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	1,741(815)	1,407(946)
Prunus pensylvanica	0.5-2.0	56(32)	111(64)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	1,315(1,068)	1,315(565)
Prunus serotina	0.5-2.0	241(241)	556(294)
	>2.0	0(0)	0(0)
Choke cherry	0-0.5	130(67)	185(185)
Prunus virginiana	0.5-2.0	19(19)	0(0)
	>2.0	0(0)	0(0)
Red oak	0-0.5	493(312)	389(170)
Quercus rubra	0.5-2.0	37(19)	19(19)
	>2.0	0(0)	0(0)
Smooth sumac	0-0.5	19(19)	37(37)
Rhus glabra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

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Appendix Table 3. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 1-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Quaking aspen	0-0.5	11,808(3,104) A	10,108(2,942)
Populus tremuloides	0.5-2.0	30,983(7,727)	24,975(4,215)
	>2.0	0(0)	0(0)
Bigtooth aspen	0-0.5	400(243)	1,450(739)
Populus grandidentata	0.5-2.0	967(773)	1,033(592)
	>2.0	8(8)	0(0)
Balsam fir	0-0.5	389(348)	56(28)
Abies balsamea	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red maple	0-0.5	8,778(3,675)	6,611(3,004)
Acer rubrum	0.5-2.0	639(321)	56(56)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	222(111)	195(195)
Acer saccharum	0.5-2.0	28(28)	28(28)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	1,195(389)	945(484)
Amelanchier spp.	0.5-2.0	278(56)	445(445)
	>2.0	0(0)	0(0)
Yellow birch	0-0.5	28(28)	0(0)
Betula alleghaniensis	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Paper birch	0-0.5	1,139(1,139)	1,083(1,001)
Betula papyrifera	0.5-2.0	472(472)	83(83)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	139(100)	389(155)
Cornus alternifolia	0.5-2.0	28(28)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 3 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Flowering dogwood	0-0.5	28(28)	28(28)
Cornus florida	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
American beech	0-0.5	0(0)	83(48)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	917(917)	1,667(1,667)
Fraxinus americana	0.5-2.0	195(155)	333(333)
	>2.0	0(0)	0(0)
Witch-hazel	0-0.5	56(56)	167(167)
Hamamelis virginiana	0.5-2.0	28(28)	28(28)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	56(56)	0(0)
Ostrya virginiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White pine	0-0.5	222(182)	139(139)
Pinus strobus	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Balsam popular	0-0.5	56(56)	0(0)
Populus balsamifera	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	1,028(1,028)	195(195)
Prunus pensylvanica	0.5-2.0	306(306)	0(0)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	2,778(837)	2,611(925)
Prunus serotina	0.5-2.0	972(667)	1,417(1,417)
	>2.0	0(0)	0(0)
Choke cherry	0-0.5	56(56)	56(56)
Prunus virginiana	0.5-2.0	28(28)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 3 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Red oak	0-0.5	28(28)	0(0)
Quercus rubra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	222(222)	222(222)
Tilia americana	0.5-2.0	28(28)	111(111)
	>2.0	0(0)	0(0)
American elm	0-0.5	0(0)	306(306)
Ulmus americana	0.5-2.0	0(0)	28(28)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

Appendix Table 4. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 1-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Quaking aspen	0-0.5	8,108(1,447)	6,358(1,122)
Populus tremuloides	0.5-2.0	23,683(2,345) A	18,558(3,387)
	>2.0	0(0)	17(17)
Balsam fir	0-0.5	19(19)	56(56)
Abies balsamea	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red maple	0-0.5	13,000(6,366)	3,852(2,663)
Acer rubrum	0.5-2.0	148(98)	19(19)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	4,722(4,639)	3,741(3,603)
Acer saccharum	0.5-2.0	444(444)	74(74)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	593(337)	1,815(612)
Amelanchier spp.	0.5-2.0	333(210)	722(402)
	>2.0	0(0)	19(19)
Paper birch	0-0.5	19(19)	56(32)
Betula papyrifera	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	389(195)	241(214)
Cornus alternifolia	0.5-2.0	19(19)	37(37)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	74(74)	185(93)
Corylus cornuta	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	19(19)	37(37)
Crataegus spp.	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

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Appendix Table 4 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
American beech	0-0.5	185(134)	297(148)
Fagus grandifolia	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
White ash	0-0.5	1,537(952)	2,222(2,004)
Fraxinus americana	0.5-2.0	741(686)	426(426)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	296(269)	352(352)
Ostrya virginiana	0.5-2.0	389(389)	19(19)
	>2.0	19(19)	0(0)
White pine	0-0.5	0(0)	0(0)
Pinus strobus	0.5-2.0	19(19)	0(0)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	1,519(1,104)	741(582)
Prunus pensylvanica	0.5-2.0	204(204)	130(130)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	815(437)	2,204(1,464)
Prunus serotina	0.5-2.0	370(370)	1,296(1,269)
	>2.0	0(0)	0(0)
Choke cherry	0-0.5	319(236)	93(93)
Prunus virginiana	0.5-2.0	37(37)	74(74)
	>2.0	0(0)	0(0)
Red oak	0-0.5	0(0)	19(19)
Quercus rubra	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Alder buckthorn	0-0.5	0(0)	0(0)
Rhamnus alnifolia	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Smooth sumac	0-0.5	574(574)	0(0)
Rhus glabra	0.5-2.0	0(0)	926(926)
	>2.0	0(0)	0(0)

Appendix Table 4(cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Basswood	0-0.5	241(241)	463(409)
Tilia americana	0.5-2.0	37(37)	19(19)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

Appendix Table 5. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 1-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994). No significant differences (P > 0.10) (paired t-test, Gill 1978).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Agrimonia *Agrimonia* spp.	3(3)	1(1)	0(0)	0(0)
Pearly everlasting *Anaphalis margaritacea*	0(0)	0(0)	3(3)	1(1)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	3(3)	1(1)
Wild sarsaparilla *Aralia nudicaulis*	0(0)	0(0)	3(3)	1(1)
Aster *Aster* spp.	17(5)	3(1)	35(15)	7(3)
Grape fern *Botrychium* spp.	0(0)	0(0)	3(3)	1(1)
Sedge *Carex* spp.	31(16)	5(3)	47(25)	9(5)
Field chickweed *Cerastium arvense*	3(3)	1(1)	3(3)	1(1)
Daisy *Erigeron* spp.	13(13)	3(3)	4(4)	1(1)
Leafy spurge *Euphorbia esula*	3(3)	1(1)	11(11)	2(2)
Common strawberry *Fragaria virginiana*	40(18)	7(3)	49(23)	8(3)
Bedstraw *Galium* spp.	17(10)	3(2)	11(8)	2(1)

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Appendix Table 5 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Checkberry *Gaultheria procumbens*	33(33)	7(7)	33(33)	7(7)
Wild geranium *Geranium maculatum*	4(4)	1(1)	0(0)	0(0)
Grass spp.	83(10)	15(2)	78(22)	14(4)
Orange-hawkweed *Hieracium aurantiacium*	13(3)	2(1)	20(16)	3(2)
Hawkweed *Hieracium* spp.	6(6)	1(1)	3(3)	1(1)
Rough hawkweed *Hieracium scabrum*	4(4)	1(1)	0(0)	0(0)
Wild lettuce *Lactura canadensis*	0(0)	0(0)	4(4)	1(1)
Honeysuckle *Lonicera* spp.	6(3)	1(1)	6(3)	1(1)
Ground cedar *Lycopodium* spp.	4(4)	1(1)	0(0)	0(0)
Canada mayflower *Maianthemum canadense*	14(10)	2(2)	22(22)	5(5)
Mint *Mentha* spp.	3(3)	1(1)	0(0)	0(0)
Partridgeberry *Mitchella repens*	3(3)	1(1)	0(0)	0(0)
Bracken fern *Pteridium aquilinum*	64(32)	12(6)	61(31)	11(6)

Appendix Table 5 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wintergreen *Pyrola* spp.	4(4)	1(1)	0(0)	0(0)
Ribes spp.	6(6)	1(1)	6(6)	1(1)
Rubus spp.	72(24)	13(4)	53(27)	9(5)
Basil *Satureja vulgaris*	0(0)	0(0)	3(3)	1(1)
Goldenrod *Solidago* spp.	3(3)	1(1)	8(5)	1(1)
Common dandelion *Taraxacum officinale*	3(3)	1(1)	14(7)	3(2)
Starflower *Trientalis borealis*	0(0)	0(0)	3(3)	1(1)
Red clover *Trifolium pratense*	8(8)	1(1)	11(7)	2(1)
Low sweet blueberry *Vaccinium angustifolium*	13(13)	3(3)	8(8)	2(2)
Common mullein *Verbascum thapsus*	39(20)	7(4)	36(28)	5(4)
Viburnum spp.	3(3)	1(1)	3(3)	1(1)
Violet *Viola* spp.	8(5)	2(1)	8(5)	1(1)

Appendix Table 6. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 1-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995). No significant differences (P > 0.10) (paired t-test, Gill 1978).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	4(4)	1(1)	7(7)	1(1)
Wood anemone *Anemone quinquefolia*	3(3)	3(3)	0(0)	0(0)
Wild sarsaparilla *Aralia nudicaulis*	4(4)	1(1)	0(0)	0(0)
Aster *Aster* spp.	11(11)	2(2)	3(3)	1(1)
Sedge *Carex* spp.	53(22)	11(5)	41(26)	8(5)
Canada thistle *Cirsium arvense*	4(4)	1(1)	0(0)	0(0)
Sweet-fern *Comptonia pergrina*	14(14)	2(2)	22(22)	4(4)
Daisy *Erigeron* spp.	14(14)	2(2)	7(7)	1(1)
Common strawberry *Fragaria virginiana*	8(8)	2(2)	10(10)	2(2)
Checkberry *Gaultheria procumbens*	61(31)	17(11)	39(31)	13(12)
Grass spp.	76(13)	18(2)	78(11)	19(3)
Orange-hawkweed *Hieracium aurantiacium*	0(0)	0(0)	3(3)	1(1)

Appendix Table 6 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Wild lettuce *Lactura canadensis*	3(3)	0(0)	0(0)	0(0)
Honeysuckle *Lonicera* spp.	0(0)	0(0)	3(3)	1(1)
Cow wheat *Melampyrum lineare*	3(3)	0(0)	0(0)	0(0)
Rough-fruited cinquefoil *Potentilla recta*	0(0)	0(0)	3(3)	1(1)
White lettuce *Prenanthes alba*	0(0)	0(0)	3(3)	1(1)
Bracken fern *Pteridium aquilinum*	88(13)	22(7)	100(0)	25(6)
Rubus spp.	39(22)	8(5)	50(20)	11(3)
Goldenrod *Solidago* spp.	4(4)	1(1)	0(0)	0(0)
Common dandelion *Taraxacum officinale*	8(8)	1(1)	3(3)	1(1)
Low sweet blueberry *Vaccinium angustifolium*	18(12)	4(2)	22(22)	4(4)
Highbush blueberry *Vaccinium corymbosum*	11(11)	2(2)	0(0)	0(0)
Common mullein *Verbascum thapsus*	17(17)	4(4)	20(20)	4(4)
Viburnum spp.	6(6)	1(1)	14(14)	3(3)

Appendix Table 6 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Violet *Viola* spp.	0(0)	0(0)	3(3)	1(1)

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Appendix Table 7. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 1-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994). No significant differences (P > 0.10) (paired t-test, Gill 1978).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	4(4)	1(1)
Wild sarsaparilla *Aralia nudicaulis*	8(8)	1(1)	8(4)	2(1)
Aster *Aster* spp.	42(29)	7(5)	50(7)	10(2)
Hoary alyssum *Berteroa incana*	4(4)	1(1)	4(4)	1(1)
Sedge *Carex* spp.	25(25)	4(4)	0(0)	0(0)
Common strawberry *Fragaria virginiana*	29(23)	5(3)	33(27)	5(3)
Bedstraw *Galium* spp.	38(19)	6(3)	21(11)	3(2)
Checkberry *Gaultheria procumbens*	33(33)	8(8)	13(7)	3(2)
Grass spp.	75(0)	14(2)	71(15)	14(4)
Orange-hawkweed *Hieracium aurantiacum*	8(8)	1(1)	25(25)	3(3)
Yellow-hawkweed *Hieracium pratense*	0(0)	0(0)	4(4)	1(1)
Lily *Lilium* spp.	4(4)	1(1)	4(4)	1(1)

Appendix Table 7 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Honeysuckle *Lonicera* spp.	13(13)	2(2)	13(7)	3(2)
Ground cedar *Lycopodium* spp.	0(0)	0(0)	8(4)	2(1)
Canada mayflower *Maianthemum canadense*	33(11)	7(3)	38(22)	10(6)
Cow wheat *Melampyrum lineare*	0(0)	0(0)	4(4)	1(1)
Sweet cicely *Osmorhiza claytoni*	21(21)	4(4)	8(8)	2(2)
Virginia creeper *Parthenocissus* spp.	4(4)	1(1)	0(0)	0(0)
White lettuce *Prenanthes alba*	4(4)	1(1)	4(4)	1(1)
Bracken fern *Pteridium aquilinum*	92(8)	17(4)	88(7)	18(5)
Wintergreen *Pyrola* spp.	0(0)	0(0)	8(8)	2(2)
Ribes spp.	4(4)	1(1)	8(8)	1(1)
Rubus spp.	42(17)	7(2)	38(26)	6(3)
Basil *Satureja vulgaris*	0(0)	0(0)	4(4)	1(1)
Goldenrod *Solidago* spp.	0(0)	0(0)	4(4)	1(1)

Appendix Table 7 (cont.)

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Common dandelion *Taraxacum officinale*	4(4)	1(1)	8(8)	1(1)
Red clover *Trifolium pratense*	8(8)	1(1)	17(17)	3(3)
Low sweet blueberry *Vaccinium angustifolium*	4(4)	1(1)	0(0)	0(0)
Common mullein *Verbascum thapsus*	29(29)	4(4)	21(21)	3(3)
Viburnum spp.	4(4)	1(1)	0(0)	0(0)
Violet *Viola* spp.	38(13)	7(2)	33(4)	7(2)
Other	8(8)	1(1)	0(0)	0(0)

Appendix Table 8. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 1-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Yarrow *Achillea millefolium*	3(3)	0(0)	0(0)	0(0)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	7(7)	1(1)	0(0)	0(0)
Wood anemone *Anemone quinquefolia*	3(3)	0(0)	3(3)	0(0)
Wild sarsaparilla *Aralia nudicaulis*	8(8)	1(1)	18(11)	3(2)
Aster *Aster* spp.	57(22)	8(2)	36(32)	5(5)
Sedge *Carex* spp.	69(19) A	10(3)	25(7)	4(1)
Field chickweed *Cerastium arvense*	3(3)	0(0)	0(0)	0(0)
Bunchberry *Cornus canadensis*	23(23)	3(3)	3(3)	0(0)
Daisy *Erigeron* spp.	22(13)	3(2)	0(0)	0(0)
Indian strawberry *Duchesnea indica*	8(8)	1(1)	0(0)	0(0)
Common strawberry *Fragaria virginiana*	28(11)	4(2)	18(9)	3(2)
Bedstraw *Galium* spp.	26(16)	3(2)	39(25)	6(3)

Appendix Table 8 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Checkberry *Gaultheria procumbens*	3(3)	0(0)	7(7)	1(1)
Grass spp.	71(13)	10(2) A	82(11)	14(3)
Orange-hawkweed *Hieracium aurantiacium*	49(11)	7(2)	40(20)	7(4)
Yellow-hawkweed *Hieracium pratense*	10(10)	2(2)	7(7)	1(1)
Common St. Johnswort *Hypericum perforatum*	17(17)	3(3)	7(7)	1(1)
Wild lettuce *Lactura canadensis*	3(3)	0(0)	3(3)	1(1)
Honeysuckle *Lonicera* spp.	19(10)	3(1)	13(9)	2(2)
Ground cedar *Lycopodium* spp.	16(12)	2(1)	13(9)	2(1)
Canada mayflower *Maianthemum canadense*	23(23)	3(3)	31(24)	4(3)
Cow wheat *Melampyrum lineare*	10(10)	2(2)	3(3)	1(1)
Partridgeberry *Mitchella repens*	3(3)	0(0)	13(13)	2(2)
Sweet cicely *Osmorhiza claytoni*	0(0)	0(0)	3(3)	1(1)
Silverweed *Potentilla anserina*	3(3)	0(0)	0(0)	0(0)

Appendix Table 8 (cont.)

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Fringed polygola *Polygola paucifolia*	5(5)	1(1)	0(0)	0(0)
Rough-fruited cinquefoil *Potentilla recta*	10(10)	2(2)	5(5)	1(1)
Bracken fern *Pteridium aquilinum*	67(33)	9(5)	77(23)	13(4)
Poison ivy *Rhus radicans*	5(5)	1(1)	0(0)	0(0)
Rubus spp.	55(20)	8(3)	69(19)	12(4)
Basil *Satureja vulgaris*	0(0)	0(0)	6(3)	1(1)
Goldenrod *Solidago* spp.	13(9)	2(1)	10(10)	2(2)
Twisted-stalk *Streptopus amplexifolius*	5(5)	1(1)	3(3)	0(0)
Common dandelion *Taraxacum officinale*	26(16)	4(2)	19(7)	3(1)
Starflower *Trientalis borealis*	3(3)	0(0)	13(13)	2(2)
Red clover *Trifolium pratense*	21(17)	3(3)	23(19)	4(3)
Common mullein *Verbascum thapsus*	8(8)	1(1)	9(1)	1(0)
Violet *Viola* spp.	26(19)	3(2)	23(13)	4(2)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

Appendix Table 9. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 2-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995). No significant differences (P > 0.10) (paired t-test, Gill 1978).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	508(188)	1,433(556)
Populus grandidentata	0.5-2.0	19,166(2,422)	19,283(3,434)
	>2.0	3,075(1,401)	317(317)
Balsam fir	0-0.5	19(19)	0(0)
Abies balsamea	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red maple	0-0.5	2,019(1,664)	1,704(784)
Acer rubrum	0.5-2.0	296(74)	148(67)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	2,093(1,219)	2,167(1,320)
Acer saccharum	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	1,760(1,537)	1,407(67)
Amelanchier spp.	0.5-2.0	611(56)	667(340)
	>2.0	222(111)	0(0)
Paper birch	0-0.5	19(19)	56(32)
Betula papyrifera	0.5-2.0	185(93)	0(0)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	185(185)	111(111)
Cornus alternifolia	0.5-2.0	222(111)	0(0)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	37(27)	241(214)
Corylus cornuta	0.5-2.0	185(93)	93(67)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	74(74)	0(0)
Crataegus spp.	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 9 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Autumn-olive	0-0.5	0(0)	0(0)
Elaeagnus umbellata	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
American beech	0-0.5	0(0)	0(0)
Fagus grandifolia	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
White ash	0-0.5	352(182)	1,056(747)
Fraxinus americana	0.5-2.0	593(296)	259(259)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	444(242)	2,167(2,002)
Ostrya virginiana	0.5-2.0	482(241)	1,482(1,345)
	>2.0	0(0)	37(19)
Red pine	0-0.5	0(0)	19(19)
Pinus resinosa	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White pine	0-0.5	19(19)	222(222)
Pinus strobus	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	870(661)	2,907(1,971)
Prunus pensylvanica	0.5-2.0	2,519(1,260)	593(538)
	>2.0	185(93)	0(0)
Black cherry	0-0.5	685(658)	1,204(710)
Prunus serotina	0.5-2.0	760(130)	389(64)
	>2.0	185(93)	0(0)
Choke cherry	0-0.5	130(49)	74(19)
Prunus virginiana	0.5-2.0	500(167)	74(74)
	>2.0	0(0)	0(0)
Alder buckthorn	0-0.5	93(49)	0(0)
Rhamnus alnifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 9 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Smooth sumac	0-0.5	0(0)	19(19)
Rhus glabra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red-berried elder	0-0.5	0(0)	0(0)
Sambucus pubens	0.5-2.0	37(19)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	148(98)	130(81)
Tilia americana	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
American elm	0-0.5	74(74)	0(0)
Ulmus americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 10. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 2-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Quaking aspen	0-0.5	583(338)	1,275(499)
Populus tremuloides	0.5-2.0	20,925(2,021) A	19,208(2,231)
	>2.0	2,300(1,065)	1,733(1,659)
Balsam fir	0-0.5	185(185)	148(121)
Abies balsamea	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Red maple	0-0.5	7,093(1,715)	6,481(1,957)
Acer rubrum	0.5-2.0	704(648)	260(113)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	278(278)	297(121)
Acer saccharum	0.5-2.0	56(56)	74(49)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	500(347)	1,111(449)
Amelanchier spp.	0.5-2.0	204(152)	1,111(1,029)
	>2.0	0(0)	0(0)
Paper birch	0-0.5	37(37)	1,704(1,704)
Betula papyrifera	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	0(0)	1,870(1,622)
Cornus alternifolia	0.5-2.0	0(0)	167(167)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	56(56)	407(165)
Corylus cornuta	0.5-2.0	93(93)	204(177)
	>2.0	0(0)	0(0)
American beech	0-0.5	204(37) A	37(37)
Fagus grandifolia	0.5-2.0	37(37)	37(37)
	>2.0	0(0)	0(0)

Appendix Table 10 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
White ash	0-0.5	0(0)	4,278(4,084)
Fraxinus americana	0.5-2.0	1,667(1,667)	1,667(1,611)
	>2.0	982(982)	0(0)
Witch-hazel	0-0.5	0(0)	19(19)
Hamamelis virginiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	0(0)	1,278(972)
Ostrya virginiana	0.5-2.0	0(0)	204(130)
	>2.0	0(0)	0(0)
White pine	0-0.5	148(148)	111(111)
Pinus strobus	0.5-2.0	74(49)	0(0)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	19(19)	630(427)
Prunus pensylvanica	0.5-2.0	19(19)	74(49)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	1,222(841)	2,222(819)
Prunus serotina	0.5-2.0	1,722(868)	2,407(1,836)
	>2.0	0(0)	93(93)
Choke cherry	0-0.5	167(116)	648(445)
Prunus virginiana	0.5-2.0	260(260)	241(241)
	>2.0	0(0)	0(0)
Basswood	0-0.5	0(0)	444(444)
Tilia americana	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
American elm	0-0.5	0(0)	889(889)
Ulmus americana	0.5-2.0	0(0)	297(297)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).

Appendix Table 11. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 2-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	4(4)	1(1)
Wood anemone *Anemone quinquefolia*	15(10)	2(1)	11(11)	1(1)
Burdock *Arctium* spp.	3(3)	0(0)	3(3)	0(0)
Green rock cress *Arabis missouriensis*	6(6)	1(1)	0(0)	0(0)
Wild sarsaparilla *Aralia nudicaulis*	0(0)	0(0)	8(8)	1(1)
Aster *Aster* spp.	13(7) A	2(1)	24(6)	3(1)
Sedge *Carex* spp.	39(27)	6(4)	50(25)	6(3)
Field chickweed *Cerastium arvense*	3(3)	0(0)	3(3)	0(0)
Field bindweed *Convolvulus arvensis*	3(3)	0(0)	0(0)	0(0)
Daisy *Erigeron* spp.	8(8)	2(2)	13(7)	2(1)
Leafy spurge *Euphorbia esula*	6(6)	1(1)	19(19)	2(2)
Common strawberry *Fragaria virginiana*	67(27)	10(4) A	58(30)	7(4)

Appendix Table 11 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Bedstraw *Galium* spp.	18(11)	3(2)	3(3)	0(0)
Checkberry *Gaultheria procumbens*	33(33)	6(6)	33(33)	6(6)
Grass spp.	100(0)	16(1)	100(0)	14(2)
Orange-hawkweed *Hieracium aurantiacium*	28(10)	5(2)	44(19)	7(3)
Yellow-hawkweed *Hieracium pratense*	0(0)	0(0)	22(8)	4(2)
Common St. Johnswort *Hypericum perforatum*	6(6)	1(1)	0(0)	0(0)
Wild lettuce *Lactura canadensis*	0(0)	0(0)	4(4)	1(1)
Honeysuckle *Lonicera* spp.	3(3)	0(0)	4(4)	1(1)
Ground cedar *Lycopodium* spp.	3(3)	0(0)	10(5)	1(1)
Canada mayflower *Maianthemum canadense*	22(12)	3(2)	17(17)	2(2)
Cow wheat *Melampyrum lineare*	0(0)	0(0)	13(13)	2(2)
Partridgeberry *Mitchella repens*	3(3)	0(0)	0(0)	0(0)
Common evening-primrose *Oenothera biennis*	0(0)	0(0)	3(3)	0(0)

Appendix Table 11 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wood-betony *Pedicularis canadensis*	0(0)	0(0)	3(3)	0(0)
Fringed polygola *Polygola paucifolia*	8(8)	2(2)	0(0)	0(0)
Rough-fruited cinquefoil *Potentilla recta*	0(0)	0(0)	3(3)	0(0)
White lettuce *Prenanthes alba*	0(0)	0(0)	4(4)	1(1)
Bracken fern *Pteridium aquilinum*	67(33)	11(6)	63(32)	10(5)
Wintergreen *Pyrola* spp.	13(13)	2(2)	0(0)	0(0)
Ribes spp.	4(4)	1(1)	0(0)	0(0)
Sheep sorrel *Rumex acetosella*	8(4)	1(1)	7(4)	1(1)
Rubus spp.	68(28)	10(4) A	64(32)	8(4)
Basil *Satureja vulgaris*	3(3)	0(0)	15(11)	2(1)
Balsam ragwort *Senecio robbinsii*	4(4)	1(1)	0(0)	0(0)
Goldenrod *Solidago* spp.	8(8)	1(1)	22(12)	3(2)
Twisted-stalk *Streptopus amplexifolius*	0(0)	0(0)	3(3)	0(0)

Appendix Table 11 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Common dandelion *Taraxacum officinale*	11(11)	2(2)	10(5)	1(1)
Starflower *Trientalis borealis*	0(0)	0(0)	6(6)	1(1)
Red clover *Trifolium pratense*	3(3)	0(0)	13(13)	2(2)
Low sweet blueberry *Vaccinium angustifolium*	25(25)	4(4)	8(8)	2(2)
Common mullein *Verbascum thapsus*	25(14)	3(2)	47(24)	6(3)
Viburnum spp.	4(4)	1(1)	0(0)	0(0)
Violet *Viola* spp.	7(4)	1(1)	19(10)	2(1)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).

Appendix Table 12. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 2-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wood anemone *Anemone quinquefolia*	0(0)	0(0) A	8(4)	1(0)
Wild sarsaparilla *Aralia nudicaulis*	8(8)	2(2)	22(12)	4(2)
Sullivant's milkweed *Asclepias sullivantii*	0(0)	0(0)	4(4)	0(0)
Aster *Aster* spp.	47(22)	7(3)	53(22)	7(3)
Sedge *Carex* spp.	17(17)	2(2)	24(20)	3(2)
Field chickweed *Cerastium arvense*	8(8)	1(1)	8(8)	1(1)
Field bindweed *Convolvulus arvensis*	0(0)	0(0)	3(3)	1(1)
Bunchberry *Cornus canadensis*	3(3)	1(1)	6(6)	1(1)
Daisy *Erigeron* spp.	8(8)	1(1)	8(4)	1(0)
Common strawberry *Fragaria virginiana*	38(26)	4(3)	33(33)	3(3)
Bedstraw *Galium* spp.	29(15)	4(2)	42(22)	4(2)
Checkberry *Gaultheria procumbens*	31(31)	6(6)	19(19)	4(4)

Appendix Table 12 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Grass spp.	93(4) A	13(2)	89(11)	11(1)
Orange-hawkweed *Hieracium aurantiacium*	25(25)	3(3)	32(28)	3(3)
Yellow-hawkweed *Hieracium pratense*	21(21)	3(3)	17(17)	2(2)
Wild lettuce *Lactura canadensis*	13(7)	1(1)	8(8)	1(1)
Twin flower *Linnaea borealis*	3(3)	1(1)	0(0)	0(0)
Honeysuckle *Lonicera* spp.	14(7)	2(1)	11(11)	2(2)
Ground cedar *Lycopodium* spp.	6(6)	1(1)	3(3)	1(1)
Canada mayflower *Maianthemum canadense*	33(22)	6(4)	57(29)	8(5)
Partridgeberry *Mitchella repens*	3(3)	1(1)	4(4)	1(1)
Sweet cicely *Osmorhiza claytoni*	25(25)	3(3)	36(32)	4(4)
Fringed polygola *Polygola paucifolia*	3(3)	1(1)	19(16)	2(2)
Rough-fruited cinquefoil *Potentilla recta*	0(0)	0(0)	8(8)	1(1)
White lettuce *Prenanthes alba*	8(8)	1(1)	13(13)	1(1)

Appendix Table 12 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Bracken fern *Pteridium aquilinum*	75(19)	11(4)	100(0)	13(3)
Wintergreen *Pyrola* spp.	11(7)	2(1)	0(0)	0(0)
Ribes spp.	13(13)	1(1)	4(4)	0(0)
Rubus spp.	46(15)	6(1)	33(33)	3(3)
Basil *Satureja vulgaris*	8(8)	1(1)	8(8)	1(1)
Goldenrod *Solidago* spp.	29(18)	4(3)	13(7)	1(1)
Twisted-stalk *Streptopus amplexifolius*	3(3)	1(1)	8(8)	1(1)
Common dandelion *Taraxacum officinale*	0(0) A	0(0) A	13(7)	1(1)
Starflower *Trientalis borealis*	0(0)	0(0)	3(3)	1(1)
Red clover *Trifolium pratense*	8(8)	1(1)	17(17)	2(2)
Low sweet blueberry *Vaccinium angustifolium*	6(6)	1(1)	0(0)	0(0)
Common mullein *Verbascum thapsus*	17(17)	2(2)	17(17)	2(2)
Viburnum spp.	0(0)	0(0)	8(8)	1(1)

Appendix Table 12 (cont.)

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Violet *Viola* spp.	28(17)	4(3)	60(21)	7(2)

A = Significantly different (P < 0.10) from browsed (paired t-test, Gill 1978).

Appendix Table 13. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 12-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	171(65)	526(272)
Populus grandidentata	0.5-2.0	402(101)	1,345(683)
	>2.0	8,519(1,421) A	989(394)
Quaking aspen	0-0.5	36(36)	1,092(663)
Populus tremuloides	0.5-2.0	36(36)	1,439(666)
	>2.0	1,019(1,019)	632(586)
Red maple	0-0.5	1,111(642)	556(193)
Acer rubrum	0.5-2.0	445(340)	630(98)
	>2.0	1,222(778)	482(37)
Sugar maple	0-0.5	0(0)	0(0)
Acer saccharum	0.5-2.0	0(0)	0(0)
	>2.0	185(185)	0(0)
Speckled alder	0-0.5	74(37)	0(0)
Alnus rugosa	0.5-2.0	333(193)	0(0)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	1,852(546)	1,000(509)
Amelanchier spp.	0.5-2.0	1,667(321)	1,667(612)
	>2.0	111(64)	0(0)
Paper birch	0-0.5	0(0)	741(741)
Betula papyrifera	0.5-2.0	37(37)	74(74)
	>2.0	74(37)	0(0)
Beaked hazelnut	0-0.5	0(0)	37(37)
Corylus cornuta	0.5-2.0	0(0)	259(259)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	148(148)	74(74)
Crataegus spp.	0.5-2.0	74(74)	111(111)
	>2.0	0(0)	0(0)

Appendix Table 13 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Witch-hazel	0-0.5	296(196)	259(259)
Hamamelis virginiana	0.5-2.0	408(206)	556(556)
	>2.0	37(37)	74(74)
Hop-hornbeam	0-0.5	74(74)	296(296)
Ostrya virginiana	0.5-2.0	259(259)	408(408)
	>2.0	0(0)	74(74)
White pine	0-0.5	74(37)	74(37)
Pinus strobus	0.5-2.0	37(37)	185(134)
	>2.0	0(0)	74(74)
Pin cherry	0-0.5	0(0)	0(0)
Prunus pensylvanica	0.5-2.0	74(74)	0(0)
	>2.0	111(111)	0(0)
Black cherry	0-0.5	482(196)	1,741(1,413)
Prunus serotina	0.5-2.0	1,593(376)	2,778(1,094)
	>2.0	445(333)	0(0)
Choke cherry	0-0.5	0(0)	37(37)
Prunus virginiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Red oak	0-0.5	630(162) A	1,185(206)
Quercus rubra	0.5-2.0	148(37)	333(128)
	>2.0	296(148)	0(0)
Basswood	0-0.5	0(0)	37(37)
Tilia americana	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)

A = Significantly different (P < 0.05) from browsed (paired t-test, Gill 1978).

Appendix Table 14. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 12-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Balsam fir	0-0.5	74(74)	0(0)
Abies balsamea	0.5-2.0	0(0)	74(74)
	>2.0	0(0)	0(0)
Red maple	0-0.5	7,995(3,780)	4,249(3,339)
Acer rubrum	0.5-2.0	2143(1103)	572(572)
	>2.0	0(0)	0(0)
Sugar maple	0-0.5	2,741(2,630)	3,683(3,683)
Acer saccharum	0.5-2.0	1,810(1,810)	2,699(2,699)
	>2.0	952(952)	952(952)
Speckled alder	0-0.5	0(0)	37(37)
Alnus rugosa	0.5-2.0	0(0)	111(111)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	381(137)	577(382)
Amelanchier spp.	0.5-2.0	143(40)	302(163)
	>2.0	37(37)	0(0)
Paper birch	0-0.5	0(0)	185(185)
Betula papyrifera	0.5-2.0	0(0)	111(111)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	64(64)	0(0)
Cornus alternifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Flowering dogwood	0-0.5	0(0)	32(32)
Cornus florida	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	0(0)	0(0)
Elaeagnus umbellata	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)

Appendix Table 14 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
American beech	0-0.5	32(32)	0(0)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	37(37)	0(0)
Fraxinus americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	0(0)	508(508)
Ostrya virginiana	0.5-2.0	0(0)	349(349)
	>2.0	0(0)	0(0)
Red pine	0-0.5	0(0)	0(0)
Pinus resinosa	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
White pine	0-0.5	37(37)	185(185)
Pinus strobus	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Pin cherry	0-0.5	64(64)	95(95)
Prunus pensylvanica	0.5-2.0	0(0)	159(159)
	>2.0	32(32)	32(32)
Black cherry	0-0.5	1,413(477)	1,677(770)
Prunus serotina	0.5-2.0	804(258) A	2,175(395)
	>2.0	397(247)	392(262)
Choke cherry	0-0.5	111(111)	74(74)
Prunus virginiana	0.5-2.0	296(296)	0(0)
	>2.0	222(222)	0(0)
Red oak	0-0.5	37(37)	0(0)
Quercus rubra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	137(69)	254(208)
Tilia americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 14 (cont.)

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
American elm	0-0.5	185(185)	0(0)
Ulmus americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

A = Significantly different (P < 0.10) from browsed (paired t-test, Gill 1978).

Appendix Table 15. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 13-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994). No significant (P > 0.10) differences (paired t-test, Gill 1978).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	270(214)	83(45)
Populus tremuloides	0.5-2.0	208(47)	631(389)
	>2.0	9,831(2,068)	6,187(2,635)
Balsam fir	0-0.5	0(0)	0(0)
Abies balsamea	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Red maple	0-0.5	1,741(259)	1,926(741)
Acer rubrum	0.5-2.0	1,889(714)	2,963(1,322)
	>2.0	852(797)	482(427)
Juneberry	0-0.5	852(515)	852(37)
Amelanchier spp.	0.5-2.0	1,482(162)	1,185(582)
	>2.0	74(37)	0(0)
Beaked hazelnut	0-0.5	74(74)	0(0)
Corylus cornuta	0.5-2.0	111(111)	0(0)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	74(74)	296(243)
Crataegus spp.	0.5-2.0	111(64)	482(243)
	>2.0	0(0)	111(111)
Autumn-olive	0-0.5	37(37)	111(64)
Elaeagnus umbellata	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	0(0)	0(0)
Ostrya virginiana	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
White pine	0-0.5	37(37)	0(0)
Pinus strobus	0.5-2.0	0(0)	37(37)
	>2.0	185(98)	74(37)

Appendix Table 15 (cont.)

Species	Stratum (m)	Treatments: Exclosure	Treatments: Browsed
Pin cherry	0-0.5	0(0)	0(0)
Prunus pensylvanica	0.5-2.0	0(0)	0(0)
	>2.0	37(37)	0(0)
Black cherry	0-0.5	2,889(2,226)	2,556(1,667)
Prunus serotina	0.5-2.0	3,408(1,185)	3,037(802)
	>2.0	630(196)	74(37)
Choke cherry	0-0.5	0(0)	148(148)
Prunus virginiana	0.5-2.0	0(0)	74(74)
	>2.0	0(0)	0(0)
White oak	0-0.5	148(98)	445(340)
Quercus alba	0.5-2.0	222(222)	259(259)
	>2.0	0(0)	111(111)
Red oak	0-0.5	1,148(582)	1,519(760)
Quercus rubra	0.5-2.0	482(376)	333(193)
	>2.0	370(196)	111(111)

Appendix Table 16. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 13-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	8(8)	458(235)
Populus grandidentata	0.5-2.0	183(44)	1,567(735)
	>2.0	7,383(1,126) A	1,317(849)
Trembling aspen	0-0.5	17(16)	600(303)
Populus tremuloides	0.5-2.0	50(50)	1,692(1,027)
	>2.0	917(904)	625(501)
Red maple	0-0.5	3,000(1,487)	648(49)
Acer rubrum	0.5-2.0	630(218)	500(255)
	>2.0	519(177)	444(32)
Sugar maple	0-0.5	93(93)	0(0)
Acer saccharum	0.5-2.0	37(37)	0(0)
	>2.0	56(56)	0(0)
Juneberry	0-0.5	1,222(347)	852(353)
Amelanchier spp.	0.5-2.0	1,741(744)	778(242)
	>2.0	37(37)	0(0)
Paper birch	0-0.5	19(19)	19(19)
Betula papyrifera	0.5-2.0	19(19)	37(37)
	>2.0	56(32)	0(0)
Beaked hazelnut	0-0.5	148(37)	315(145)
Corylus cornuta	0.5-2.0	556(170)	815(214)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	0(0)	19(19)
Elaeagnus umbellata	0.5-2.0	56(56)	0(0)
	>2.0	19(19)	0(0)
American beech	0-0.5	19(19)	0(0)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 16 (cont.)

Species	Stratum (m)	Treatments Exclosure	Browsed
Witch-hazel	0-0.5	130(103)	37(373)
Hamamelis virginiana	0.5-2.0	167(96)	130(130)
	>2.0	37(37)	56(56)
Hop-hornbeam	0-0.5	37(37)	0(0)
Ostrya virginiana	0.5-2.0	19(19)	185(185)
	>2.0	19(19)	93(93)
White pine	0-0.5	0(0)	19(19)
Pinus strobus	0.5-2.0	0(0)	93(49)
	>2.0	37(19)	130(81)
Pin cherry	0-0.5	74(37)	19(19)
Prunus pensylvanica	0.5-2.0	278(195)	0(0)
	>2.0	93(49)	0(0)
Black cherry	0-0.5	352(81)	648(437)
Prunus serotina	0.5-2.0	1,500(446)	2,574(1,031)
	>2.0	222(85)	0(0)
Choke cherry	0-0.5	19(19)	111(111)
Prunus virginiana	0.5-2.0	74(74)	37(37)
	>2.0	0(0)	0(0)
Red oak	0-0.5	1000(289)	889(263)
Quercus rubra	0.5-2.0	111(56)	537(182)
	>2.0	222(140)	37(37)
Common buckthorn	0-0.5	19(19)	0(0)
Rhamnus cathartica	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

Appendix Table 17. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 13-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Quaking aspen	0-0.5	0(0)	33(33)
Populus tremuloides	0.5-2.0	342(115) A	138(94)
	>2.0	9,600(1,247) B	4,913(1,286)
Balsam fir	0-0.5	0(0)	185(185)
Abies balsamea	0.5-2.0	259(259)	667(667)
	>2.0	704(704)	704(704)
Red maple	0-0.5	1,889(484)	2,296(854)
Acer rubrum	0.5-2.0	1,259(437)	593(303)
	>2.0	1,074(617)	0(0)
Sugar maple	0-0.5	1,333(1,333)	1,704(1,704)
Acer saccharum	0.5-2.0	815(815)	370(370)
	>2.0	185(185)	0(0)
Juneberry	0-0.5	1,778(723)	1,445(706)
Amelanchier spp.	0.5-2.0	2,408(1,101)	482(427)
	>2.0	296(296)	0(0)
Yellow birch	0-0.5	185(185)	778(778)
Betula alleghaniensis	0.5-2.0	148(148)	296(296)
	>2.0	37(37)	37(37)
Alternate leaf dogwood	0-0.5	111(111)	0(0)
Cornus alternifolia	0.5-2.0	148(148)	0(0)
	>2.0	111(111)	0(0)
Flowering dogwood	0-0.5	0(0)	37(37)
Cornus florida	0.5-2.0	0(0)	185(185)
	>2.0	0(0)	0(0)
Gray dogwood	0-0.5	408(408)	1,926(1,926)
Cornus foemina	0.5-2.0	1,889(1889)	1,852(1,852)
	>2.0	37(37)	0(0)

Appendix Table 17 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Hawthorn	0-0.5	0(0)	0(0)
Crataegus spp.	0.5-2.0	148(98)	0(0)
	>2.0	0(0)	0(0)
American beech	0-0.5	0(0)	37(37)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	148(148)	296(296)
Fraxinus americana	0.5-2.0	333(333)	889(889)
	>2.0	296(296)	111(111)
Witch-hazel	0-0.5	222(222)	148(148)
Hamamelis virginiana	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	37(37)	1,148(1,148)
Ostrya virginiana	0.5-2.0	74(74)	1,222(1,222)
	>2.0	37(37)	0(0)
Jack pine	0-0.5	0(0)	0(0)
Pinus banksiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	37(37)
White spruce	0-0.5	0(0)	0(0)
Picea glauca	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Red pine	0-0.5	0(0)	37(37)
Pinus resinosa	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	37(37)
White pine	0-0.5	37(37)	74(37)
Pinus strobus	0.5-2.0	37(37)	111(111)
	>2.0	0(0)	111(111)
Black cherry	0-0.5	1,370(704)	482(225)
Prunus serotina	0.5-2.0	1,593(1,372)	852(643)
	>2.0	1,074(862)	333(333)

Appendix Table 17 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Choke cherry	0-0.5	185(185)	222(222)
Prunus virginiana	0.5-2.0	667(559)	370(370)
	>2.0	74(74)	0(0)
Red oak	0-0.5	408(408)	630(630)
Quercus rubra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Alder buckthorn	0-0.5	0(0)	0(0)
Rhamnus alnifolia	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
Meadowsweet	0-0.5	148(148)	0(0)
Spiraea alba	0.5-2.0	1,889(1,889)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	0(0)	0(0)
Tilia americana	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
American elm	0-0.5	0(0)	0(0)
Ulmus americana	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.10$) from browsed (paired t-test, Gill 1978).
B = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

Appendix Table 18. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 13-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

Species	Stratum (m)	Treatments: Exclosure	Treatments: Browsed
Quaking aspen	0-0.5	0(0)	433(269)
Populus tremuloides	0.5-2.0	58(46)	117(65)
	>2.0	8,317(1,183)	3,758(2,044)
Balsam fir	0-0.5	16(16)	0(0)
Abies balsamea	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	19(19)
Red maple	0-0.5	5,087(2,416)	1,148(454)
Acer rubrum	0.5-2.0	3,527(1,764)	444(294)
	>2.0	174(97)	278(140)
Sugar maple	0-0.5	2,198(1,950)	0(0)
Acer saccharum	0.5-2.0	1,738(1,656)	0(0)
	>2.0	444(444)	0(0)
Speckled alder	0-0.5	0(0)	93(93)
Alnus rugosa	0.5-2.0	0(0)	148(148)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	500(255)	370(134)
Amelanchier spp.	0.5-2.0	350(193)	537(361)
	>2.0	111(111)	0(0)
Paper birch	0-0.5	0(0)	19(19)
Betula papyrifera	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	0(0)	0(0)
Cornus alternifolia	0.5-2.0	16(16)	0(0)
	>2.0	16(16)	0(0)
Beaked hazelnut	0-0.5	130(130)	130(103)
Corylus cornuta	0.5-2.0	148(148)	574(355)
	>2.0	0(0)	0(0)

Appendix Table 18 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Autumn-olive	0-0.5	0(0)	0(0)
Elaeagnus umbellata	0.5-2.0	0(0)	37(37)
	>2.0	37(37)	0(0)
American beech	0-0.5	53(3) A	0(0)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	19(19)	0(0)
Fraxinus americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	79(79)	0(0)
Ostrya virginiana	0.5-2.0	32(32)	185(185)
	>2.0	16(16)	93(93)
White pine	0-0.5	71(50)	0(0)
Pinus strobus	0.5-2.0	0(0)	0(0)
	>2.0	19(19)	56(56)
Pin cherry	0-0.5	0(0)	19(19)
Prunus pensylvanica	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	773(172)	889(432)
Prunus serotina	0.5-2.0	976(108)	2,241(1,111)
	>2.0	394(284)	333(333)
Choke cherry	0-0.5	0(0)	148(98)
Prunus virginiana	0.5-2.0	32(32)	37(37)
	>2.0	16(16)	0(0)
Red oak	0-0.5	74(49)	463(291)
Quercus rubra	0.5-2.0	37(37)	463(241)
	>2.0	0(0)	37(37)
Steeplebush spirea	0-0.5	0(0)	37(37)
Spirea tomentosa	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 18 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Basswood	0-0.5	0(0)	0(0)
Tilia americana	0.5-2.0	0(0)	16(16)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.01$) from browsed (paired t-test, Gill 1978).

Appendix Table 19. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 14-year-old bigtooth clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	789(79)	142(93)
Populus grandidentata	0.5-2.0	217(110)	326(102)
	>2.0	8,605(1,030) A	4,216(275)
Red maple	0-0.5	1,630(413)	1,852(715)
Acer rubrum	0.5-2.0	1,222(193)	1,926(1214)
	>2.0	778(333)	296(196)
Juneberry	0-0.5	1,926(704)	1,889(449)
Amelanchier spp.	0.5-2.0	1,704(427)	1,482(707)
	>2.0	148(98)	37(37)
Hawthorn	0-0.5	74(74)	0(0)
Crataegus spp.	0.5-2.0	222(222)	0(0)
	>2.0	0(0)	0(0)
Bush-honeysuckle	0-0.5	111(111)	0(0)
Diervilla lonicera	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Jack pine	0-0.5	37(37)	0(0)
Pinus banksiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	74(74)
Black cherry	0-0.5	2,222(778)	2,815(1,873)
Prunus serotina	0.5-2.0	3,778(612)	4,667(2,694)
	>2.0	370(162)	259(148)
Red oak	0-0.5	3,222(1,429)	3,000(1,060)
Quercus rubra	0.5-2.0	296(243)	74(74)
	>2.0	111(111)	0(0)

A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).

Appendix Table 20. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 14-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995). No significant (P > 0.10) differences (paired t-test, Gill 1978).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Bigtooth aspen	0-0.5	25(25)	75(75)
Populus grandidentata	0.5-2.0	92(33)	283(197)
	>2.0	8,417(1,471)	5,483(2,206)
Quaking aspen	0-0.5	0(0)	25(25)
Populus tremuloides	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Balsam fir	0-0.5	0(0)	0(0)
Abies balsamea	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Black maple	0-0.5	0(0)	0(0)
Acer nigrum	0.5-2.0	0(0)	0(0)
	>2.0	56(56)	0(0)
Red maple	0-0.5	3,907(561)	4,778(2,135)
Acer rubrum	0.5-2.0	2,019(158)	1,759(902)
	>2.0	259(232)	296(176)
Sugar maple	0-0.5	19(19)	0(0)
Acer saccharum	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	2,037(1,159)	1,352(334)
Amelanchier spp.	0.5-2.0	1,704(288)	1,056(402)
	>2.0	185(98)	0(0)
Paper birch	0-0.5	0(0)	0(0)
Betula papyrifera	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	56(32)	56(56)
Corylus cornuta	0.5-2.0	0(0)	241(241)
	>2.0	0(0)	0(0)

Appendix Table 20 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Hawthorn	0-0.5	37(191)	167(116)
Crataegus spp.	0.5-2.0	56(32)	56(32)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	0(0)	185(185)
Elaeagnus umbellata	0.5-2.0	0(0)	204(204)
	>2.0	0(0)	0(0)
White ash	0-0.5	0(0)	19(19)
Fraxinus americana	0.5-2.0	19(19)	56(56)
	>2.0	0(0)	0(0)
White pine	0-0.5	37(19)	37(37)
Pinus strobus	0.5-2.0	19(19)	56(56)
	>2.0	204(121)	56(32)
Pin cherry	0-0.5	0(0)	0(0)
Prunus pensylvanica	0.5-2.0	37(19)	0(0)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	2,851(2,160)	2,407(1,446)
Prunus serotina	0.5-2.0	3,630(1,980)	3,241(1,056)
	>2.0	315(152)	204(152)
Choke cherry	0-0.5	56(56)	204(204)
Prunus virginiana	0.5-2.0	56(56)	167(167)
	>2.0	0(0)	0(0)
White oak	0-0.5	1,907(1,907)	1,148(885)
Quercus alba	0.5-2.0	296(296)	241(188)
	>2.0	0(0)	37(37)
Red oak	0-0.5	1,426(735)	2,111(1,058)
Quercus rubra	0.5-2.0	796(522)	167(0)
	>2.0	74(74)	0(0)
American elm	0-0.5	0(0)	0(0)
Ulmus americana	0.5-2.0	0(0)	0(0)
	>2.0	111(111)	0(0)

Appendix Table 21. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 14-year-old quaking clear-cuts in Pigeon River Country State Forest, Michigan (1994).

		Treatments	
Species	Stratum (m)	Exclosure	Browsed
Quaking aspen	0-0.5	147(119)	370(370)
Populus tremuloides	0.5-2.0	147(119)	0(0)
	>2.0	8,898(1,899)	4,182(2,197)
Balsam fir	0-0.5	222(170)	74(74)
Abies balsamea	0.5-2.0	630(575)	408(225)
	>2.0	37(37)	74(37)
Red maple	0-0.5	3,148(2,818) A	3,963(2,801)
Acer rubrum	0.5-2.0	2,148(1,927)	2,148(1,984)
	>2.0	3,963(2,492)	0(0)
Sugar maple	0-0.5	0(0)	0(0)
Acer saccharum	0.5-2.0	111(111)	0(0)
	>2.0	0(0)	0(0)
Speckled alder	0-0.5	0(0)	37(37)
Alnus rugosa	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Juneberry	0-0.5	556(449)	630(267)
Amelanchier spp.	0.5-2.0	1,259(825)	815(606)
	>2.0	482(482)	0(0)
Paper birch	0-0.5	0(0)	0(0)
Betula papyrifera	0.5-2.0	0(0)	111(111)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	370(317)	37(37)
Cornus alternifolia	0.5-2.0	74(74)	37(37)
	>2.0	37(37)	0(0)
Beaked hazelnut	0-0.5	37(37)	37(37)
Corylus cornuta	0.5-2.0	741(451)	37(37)
	>2.0	37(37)	0(0)

Appendix Table 21 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Flowering dogwood	0-0.5	0(0)	185(185)
Cornus florida	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	0(0)	556(556)
Crataegus spp.	0.5-2.0	0(0)	111(111)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	0(0)	0(0)
Elaeagnus umbellata	0.5-2.0	37(37)	0(0)
	>2.0	37(37)	0(0)
American beech	0-0.5	0(0)	0(0)
Fagus grandifolia	0.5-2.0	74(74)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	0(0)	0(0)
Fraxinus americana	0.5-2.0	148(148)	0(0)
	>2.0	0(0)	0(0)
Black ash	0-0.5	0(0)	37(37)
Fraxinus nigra	0.5-2.0	0(0)	0(0)
	>2.0	37(37)	0(0)
Witch-hazel	0-0.5	0(0)	222(128)
Hamamelis virginiana	0.5-2.0	0(0)	185(134)
	>2.0	0(0)	37(37)
Hop-hornbeam	0-0.5	0(0)	0(0)
Ostrya virginiana	0.5-2.0	0(0)	74(74)
	>2.0	0(0)	0(0)
White spruce	0-0.5	0(0)	0(0)
Picea glauca	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	37(37)
White pine	0-0.5	37(37)	37(37)
Pinus strobus	0.5-2.0	333(333)	482(376)
	>2.0	37(37)	185(98)

Appendix Table 21 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Black cherry	0-0.5	556(257)	1,667(804)
Prunus serotina	0.5-2.0	926(437)	1,667(849)
	>2.0	296(162)	74(37)
White oak	0-0.5	111(111)	0(0)
Quercus alba	0.5-2.0	37(37)	0(0)
	>2.0	111(111)	0(0)
Red oak	0-0.5	408(353)	593(482)
Quercus rubra	0.5-2.0	185(185)	704(704)
	>2.0	370(370)	0(0)
Alder buckthorn	0-0.5	0(0)	0(0)
Rhamnus alnifolia	0.5-2.0	0(0)	74(74)
	>2.0	0(0)	0(0)
Basswood	0-0.5	37(37)	0(0)
Tilia americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
American elm	0-0.5	0(0)	519(519)
Ulmus americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

A = Significantly different ($P < 0.005$) from browsing (paired t-tests, Gill 1978).

Appendix Table 22. Mean stem densities per hectare (standard error) of trees by height strata (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 14-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1995).

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Quaking aspen	0-0.5	8(8)	58(58)
Populus tremuloides	0.5-2.0	175(175)	117(36)
	>2.0	8,292(880) A	4,075(159)
Balsam fir	0-0.5	111(111)	370(370)
Abies balsamea	0.5-2.0	426(426)	926(926)
	>2.0	519(519)	870(815)
Red maple	0-0.5	1,833(945)	3,519(2,824)
Acer rubrum	0.5-2.0	1,130(693)	1,167(536)
	>2.0	293(134)	278(140)
Sugar maple	0-0.5	1,482(1,482)	2,352(2,251)
Acer saccharum	0.5-2.0	1,148(1,148)	370(370)
	>2.0	185(185)	0(0)
Juneberry	0-0.5	926(787)	407(97)
Amelanchier spp.	0.5-2.0	1,944(1,103)	574(334)
	>2.0	93(49)	0(0)
Paper birch	0-0.5	0(0)	19(19)
Betula papyrifera	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	185(185)	0(0)
Cornus alternifolia	0.5-2.0	130(80)	0(0)
	>2.0	56(56)	0(0)
Silky dogwood	0-0.5	56(56)	0(0)
Cornus amomum	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	111(85)	222(85)
Corylus cornuta	0.5-2.0	370(209)	630(312)
	>2.0	37(37)	0(0)

Appendix Table 22 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Red-osier dogwood	0-0.5	0(0)	37(37)
Cornus stolonifera	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)
Hawthorn	0-0.5	37(37)	0(0)
Crataegus spp.	0.5-2.0	333(255)	0(0)
	>2.0	0(0)	0(0)
American beech	0-0.5	0(0)	56(56)
Fagus grandifolia	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
White ash	0-0.5	130(130)	130(130)
Fraxinus americana	0.5-2.0	611(611)	1,204(1204)
	>2.0	278(278)	204(204)
Witch-hazel	0-0.5	93(93)	0(0)
Hamamelis virginiana	0.5-2.0	74(74)	0(0)
	>2.0	0(0)	0(0)
Winterberry	0-0.5	19(19)	0(0)
Ilex verticillata	0.5-2.0	130(130)	0(0)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	222(222)	722(722)
Ostrya virginiana	0.5-2.0	259(232)	889(632)
	>2.0	130(130)	93(93)
White spruce	0-0.5	0(0)	0(0)
Picea glauca	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
White pine	0-0.5	74(49)	0(0)
Pinus strobus	0.5-2.0	37(37)	56(56)
	>2.0	19(19)	37(37)
Pin cherry	0-0.5	0(0)	19(19)
Prunus pensylvanica	0.5-2.0	0(0)	19(19)
	>2.0	0(0)	0(0)

Appendix Table 22 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Black cherry	0-0.5	315(214)	537(481)
Prunus serotina	0.5-2.0	1,148(600)	1,852(1,311)
	>2.0	537(83)	0(0)
Choke cherry	0-0.5	19(19)	111(111)
Prunus virginiana	0.5-2.0	444(257)	56(32)
	>2.0	19(19)	0(0)
Red oak	0-0.5	463(463)	482(277)
Quercus rubra	0.5-2.0	0(0)	444(281)
	>2.0	0(0)	37(37)
Smooth sumac	0-0.5	0(0)	3,056(3,056)
Rhus glabra	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Broadleaf spirea	0-0.5	93(93)	0(0)
Spiraea latifolia	0.5-2.0	370(370)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	0(0)	0(0)
Tilia americana	0.5-2.0	19(19)	0(0)
	>2.0	19(19)	0(0)

A = Significantly different (P < 0.05) from browsed (paired t-test, Gill 1978).

Appendix Table 23. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 15-year-old bigtooth clear-cuts in Pigeon River Country State Forest, Michigan (1995).

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Bigtooth aspen	0-0.5	8(8)	0(0)
Populus grandidentata	0.5-2.0	108(58)	58(30)
	>2.0	7,208(669) A	4,216(159)
Red maple	0-0.5	1,111(434)	2,093(534)
Acer rubrum	0.5-2.0	1,722(594)	2,667(1343)
	>2.0	741(323)	537(289)
Juneberry	0-0.5	1,519(490)	1,963(433)
Amelanchier spp.	0.5-2.0	1,537(328)	1,685(514)
	>2.0	37(19)	19(19)
Hawthorn	0-0.5	185(185)	19(19)
Crataegus spp.	0.5-2.0	315(315)	19(19)
	>2.0	0(0)	0(0)
Jack pine	0-0.5	0(0)	0(0)
Pinus banksiana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	74(74)
White pine	0-0.5	0(0)	0(0)
Pinus strobus	0.5-2.0	19(19)	0(0)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	1,407(681)	2,556(2,111)
Prunus serotina	0.5-2.0	4,074(691)	4,296(2,560)
	>2.0	3,537(277)	407(152)
Red oak	0-0.5	2,778(1,649)	3,037(1,037)
Quercus rubra	0.5-2.0	519(409)	278(85)
	>2.0	56(56)	19(19)
Smooth sumac	0-0.5	0(0)	0(0)
Rhus glabra	0.5-2.0	0(0)	1,111(756)
	>2.0	0(0)	19(19)

A = Significantly different ($P < 0.05$) from browsed (paired t-test, Gill 1978).

Appendix Table 24. Mean stem densities per hectare (standard error) of trees by height stratum (0-0.5 m, 0.5-2.0 m, and >2.0 m) in exclosures and areas open to browsing on 15-year-old quaking clear-cuts in Pigeon River Country State Forest, Michigan (1995). No significant (P > 0.10) differences (paired t-test, Gill 1978).

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Quaking aspen	0-0.5	8(8)	317(317)
Populus tremuloides	0.5-2.0	108(96)	17(17)
	>2.0	7,642(1,593)	3,583(1,898)
Balsam fir	0-0.5	167(85)	259(161)
Abies balsamea	0.5-2.0	648(621)	537(298)
	>2.0	278(278)	74(74)
Red maple	0-0.5	6,222(4,546)	611(85)
Acer rubrum	0.5-2.0	2,389(2,223)	482(267)
	>2.0	852(372)	278(140)
Sugar maple	0-0.5	130(130)	0(0)
Acer saccharum	0.5-2.0	19(19)	0(0)
	>2.0	93(93)	19(19)
Juneberry	0-0.5	685(520)	389(116)
Amelanchier spp.	0.5-2.0	944(752)	630(298)
	>2.0	315(315)	0(0)
White birch	0-0.5	93(67)	19(19)
Betula papyrifera	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Alternate leaf dogwood	0-0.5	204(204)	0(0)
Cornus alternifolia	0.5-2.0	56(56)	0(0)
	>2.0	0(0)	0(0)
Flowering dogwood	0-0.5	19(19)	0(0)
Cornus florida	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Beaked hazelnut	0-0.5	130(81)	148(93)
Corylus cornuta	0.5-2.0	926(926)	574(355)
	>2.0	19(19)	0(0)

Appendix Table 24 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Hawthorn	0-0.5	19(19)	241(241)
Crataegus spp.	0.5-2.0	0(0)	37(37)
	>2.0	0(0)	0(0)
Autumn-olive	0-0.5	56(56)	0(0)
Elaeagnus umbellata	0.5-2.0	37(37)	37(37)
	>2.0	56(56)	0(0)
American beech	0-0.5	111(111)	0(0)
Fagus grandifolia	0.5-2.0	56(56)	0(0)
	>2.0	37(37)	0(0)
White ash	0-0.5	0(0)	0(0)
Fraxinus americana	0.5-2.0	37(19)	0(0)
	>2.0	19(19)	0(0)
Black ash	0-0.5	19(19)	0(0)
Fraxinus nigra	0.5-2.0	37(37)	0(0)
	>2.0	0(0)	0(0)
Witch-hazel	0-0.5	0(0)	37(37)
Hamamelis virginiana	0.5-2.0	0(0)	111(111)
	>2.0	0(0)	0(0)
Hop-hornbeam	0-0.5	37(37)	0(0)
Ostrya virginiana	0.5-2.0	93(93)	204(177)
	>2.0	37(37)	93(93)
White pine	0-0.5	0(0)	19(19)
Pinus strobus	0.5-2.0	222(222)	74(49)
	>2.0	222(222)	130(81)
Pin cherry	0-0.5	0(0)	19(19)
Prunus pensylvanica	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)
Black cherry	0-0.5	519(352)	815(419)
Prunus serotina	0.5-2.0	796(483)	2,870(1,046)
	>2.0	259(161)	0(0)

Appendix Table 24 (cont.)

Species	Stratum (m)	Treatments	
		Exclosure	Browsed
Choke cherry	0-0.5	0(0)	111(111)
Prunus virginiana	0.5-2.0	0(0)	74(37)
	>2.0	19(19)	0(0)
Red oak	0-0.5	315(288)	463(291)
Quercus rubra	0.5-2.0	315(148)	463(241)
	>2.0	0(0)	37(37)
Alder buckthorn	0-0.5	0(0)	0(0)
Rhamnus alnifolia	0.5-2.0	19(19)	0(0)
	>2.0	0(0)	0(0)
Basswood	0-0.5	19(19)	0(0)
Tilia americana	0.5-2.0	0(0)	0(0)
	>2.0	0(0)	0(0)

Appendix Table 25. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 12-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	4(4)	1(1)
Columbine *Aquilegia canadensis*	0(0)	0(0)	4(4)	1(1)
Green rock cress *Arabis missouriensis*	0(0)	0(0)	4(4)	1(1)
Aster *Aster* spp.	96(5)	14(2)	63(13)	9(2)
Sweet-fern *Comptonia pergrina*	16(16)	2(2)	30(30)	4(4)
Upright bindweed *Convolvulus spithamaeus*	0(0)	0(0)	8(8)	1(1)
Daisy *Erigeron* spp.	8(8)	1(1)	21(15)	4(3)
Common strawberry *Fragaria virginiana*	49(7)	7(0)	67(22)	9(3)
Checkberry *Gaultheria procumbens*	72(10)	10(2)	29(23)	5(4)
Grass spp.	81(10)	11(1)	100(0)	14(2)
Orange-hawkweed *Hieracium aurantiacium*	17(17)	2(2)	50(13)	8(2)
Panicled hawkweed *Hieracium paniculatum*	4(4)	1(1)	21(21)	3(3)

Appendix Table 25 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Yellow-hawkweed *Hieracium pratense*	32(16)	4(2)	13(13)	2(2)
Rattlesnake-weed *Hieracium venosum*	0(0)	0(0)	8(4)	1(1)
Common St. Johnswort *Hypericum perforatum*	0(0)	0(0)	4(4)	1(1)
Wild lettuce *Lactura canadensis*	2(2)	0(0)	17(17)	2(2)
Honeysuckle *Lonicera* spp.	7(7)	1(1)	0(0)	0(0)
Canada mayflower *Maianthemum canadense*	2(2)	0(0)	0(0)	0(0)
Cow wheat *Melampyrum lineare*	8(8)	1(1)	0(0)	0(0)
Wood-betony *Pedicularis canadensis*	13(7)	2(1)	0(0)	0(0)
Fringed polygola *Polygola paucifolia*	0(0)	0(0)	17(17)	2(2)
White lettuce *Prenanthes alba*	19(11)	4(1)	4(4)	1(1)
Bracken fern *Pteridium aquilinum*	100(0)	14(2)	96(4)	14(1)
Wintergreen *Pyrola* spp.	13(7)	2(1)	0(0)	0(0)
Smooth rose *Rosa blanda*	5(5)	1(1)	0(0)	0(0)

Appendix Table 25 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Sheep sorrel *Rumex acetosella*	2(2)	0(0)	21(21)	3(3)
Rubus spp.	70(9)	10(2)	42(11)	6(1)
Basil *Satureja vulgaris*	0(0)	0(0)	4(4)	1(1)
Goldenrod *Solidago* spp.	2(2)	0(0)	0(0)	0(0)
Common dandelion *Taraxacum officinale*	11(6)	2(1)	21(8)	3(2)
Starflower *Trientalis borealis*	8(4)	1(1)	0(0)	0(0)
Low sweet blueberry *Vaccinium angustifolium*	40(14)	6(2)	42(8)	6(2)
Highbush blueberry *Vaccinium corymbosum*	7(7)	1(1)	4(4)	1(1)
Viburnum spp.	13(7)	2(1)	4(4)	1(1)
Violet *Viola* spp.	17(4)	3(1)	8(8)	1(1)
Other	2(2)	0(0)	8(8)	1(1)

Appendix Table 26. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 12-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Yarrow *Achillea millefolium*	0(0)	0(0)	6(3)	6(3)
Wild sarsaparilla *Aralia nudicaulis*	4(4)	1(1)	0(0)	0(0)
Aster *Aster* spp.	63(32)	8(4)	35(7)	5(1)
Bunchberry *Cornus canadensis*	4(4)	1(1)	0(0)	0(0)
Daisy *Erigeron* spp.	0(0)	0(0)	12(7)	2(1)
Common strawberry *Fragaria virginiana*	46(25)	6(3)	81(7)	12(1)
Bedstraw *Galium* spp.	21(21)	3(3)	24(24)	3(3)
Checkberry *Gaultheria procumbens*	13(13)	2(2)	8(8)	1(1)
Grass spp.	75(19)	12(1)	98(2)	15(2)
Orange-hawkweed *Hieracium aurantiacium*	29(18)	7(5)	67(33)	11(6)
Yellow-hawkweed *Hieracium pratense*	29(29)	4(4)	30(24)	4(3)
Wild lettuce *Lactura canadensis*	0(0)	0(0)	4(4)	1(1)

Appendix Table 26 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Honeysuckle *Lonicera* spp.	8(8)	1(1)	2(2)	0(0)
Ground cedar *Lycopodium* spp.	25(13)	5(3)	25(13)	4(2)
Canada mayflower *Maianthemum canadense*	17(4)	3(1)	10(10)	1(1)
Cow wheat *Melampyrum lineare*	8(8)	2(2)	4(4)	1(1)
Partridgeberry *Mitchella repens*	8(4)	2(1)	20(4)	3(1)
Sweet cicely *Osmorhiza claytoni*	13(13)	2(2)	14(14)	2(2)
Wood-betony *Pedicularis canadensis*	21(21)	3(3)	0(0)	0(0)
Fringed polygola *Polygola paucifolia*	25(25)	3(3)	13(13)	2(2)
Bracken fern *Pteridium aquilinum*	63(32)	12(7)	65(30)	11(5)
Wintergreen *Pyrola* spp.	4(4)	1(1)	8(4)	1(1)
Ribes spp.	4(4)	1(1)	0(0)	0(0)
Sheep sorrel *Rumex acetosella*	4(4)	1(1)	6(3)	1(1)
Rubus spp.	67(15)	12(4)	37(27)	5(3)

Appendix Table 26 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
False Solomon's-seal *Smilacina racemosa*	4(4)	1(1)	2(2)	0.3(0.3)
Goldenrod *Solidago* spp.	4(4)	1(1)	20(15)	3.1(2.2)
Common dandelion *Taraxacum officinale*	21(21)	3(3)	30(24)	3.8(2.9)
Starflower *Trientalis borealis*	8(8)	1(1)	18(6)	3(1)
Large-flowered trillium *Trillium grandiflorum*	17(11)	2(2)	0(0)	0(0)
Low sweet blueberry *Vaccinium angustifolium*	4(4)	1(1)	21(21)	3(3)
Highbush blueberry *Vaccinium corymbosum*	0(0)	0(0)	8(8)	1(1)
Violet *Viola* spp.	17(17)	2(2)	12(12)	2(2)

Appendix Table 27. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 13-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Pearly everlasting *Anaphalis margaritacea*	0(0)	0(0)	4(4)	4(4)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	8(8)	8(8)
Aster *Aster* spp.	58(22)	9(3)	88(13)	88(13)
Sweet-fern *Comptonia pergrina*	8(4)	1(1)	0(0)	0(0)
Upright bindweed *Convolvulus spithamaeus*	4(4)	1(1)	0(0)	0(0)
Daisy *Erigeron* spp.	17(11)	4(3)	25(25)	25(25)
Common strawberry *Fragaria virginiana*	42(30)	6(3)	21(4)	21(4)
Checkberry *Gaultheria procumbens*	46(17)	7(2)	38(7)	38(7)
Grass spp.	100(0)	19(5)	100(0)	100(0)
Orange-hawkweed *Hieracium aurantiacium*	25(25)	3(3)	8(8)	8(8)
Yellow-hawkweed *Hieracium pratense*	8(4)	2(1)	54(29)	54(29)
Rattlesnake-weed *Hieracium venosum*	4(4)	1(1)	0(0)	0(0)

Appendix Table 27 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wild lettuce *Lactura canadensis*	0(0)	0(0)	4(4)	4(4)
Honeysuckle *Lonicera* spp.	21(11)	3(1)	4(4)	4(4)
Canada mayflower *Maianthemum canadense*	25(13)	3(2)	29(18)	29(18)
Cow wheat *Melampyrum lineare*	13(7)	2(1)	4(4)	4(4)
Wood-betony *Pedicularis canadensis*	25(25)	3(3)	0(0)	0(0)
Fringed polygola *Polygola paucifolia*	4(4)	1(1)	0(0)	0(0)
White lettuce *Prenanthes alba*	0(0)	0(0)	4(4)	4(4)
Bracken fern *Pteridium aquilinum*	100(0)	19(5)	96(4)	96(4)
Wintergreen *Pyrola* spp.	8(8)	1(1)	0(0)	0(0)
Smooth rose *Rosa blanda*	4(4)	1(1)	0(0)	0(0)
Sheep sorrel *Rumex acetosella*	4(4)	1(1)	8(8)	8(8)
Rubus spp.	38(22)	5(3)	58(30)	58(30)
Basil *Satureja vulgaris*	0(0)	0(0)	13(13)	13(13)

Appendix Table 27 (cont.)

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Common dandelion *Taraxacum officinale*	0(0)	0(0)	13(7)	13(7)
Low sweet blueberry *Vaccinium angustifolium*	33(17)	5(2)	46(25)	46(25)
Violet *Viola* spp.	42(30)	5(3)	46(4)	46(4)

Appendix Table 28. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 13-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wild sarsaparilla *Aralia nudicaulis*	21(21)	3(3)	4(4)	1(1)
Blunt-leaved milkweed *Asclepias amplexicaulis*	4(4)	1(1)	0(0)	0(0)
Aster *Aster* spp.	53(14)	7(2)	50(22)	6(3)
Canada thistle *Cirsium arvense*	0(0)	0(0)	4(4)	1(1)
Bunchberry *Cornus canadensis*	33(33)	3(3)	23(23)	3(3)
Upright bindweed *Convolvulus spithamaeus*	0(0)	0(0)	4(4)	1(1)
Trailing arbutus *Epigaea repens*	3(3)	1(1)	0(0)	0(0)
Daisy *Erigeron* spp.	3(3)	1(1)	4(4)	(1)
Common strawberry *Fragaria virginiana*	35(8)	4(1)	65(8)	8(1)
Bedstraw *Galium* spp.	20(15)	3(2)	17(17)	2(2)
Checkberry *Gaultheria procumbens*	33(33)	4(4)	37(32)	5(4)
White avens *Geum canadense*	30(30)	3(3)	10(10)	1(1)

Appendix Table 28 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wild geranium *Geranium maculatum*	4(4)	1(1)	4(4)	1(1)
Grass spp.	93(4)	11(1)	97(3)	12(1)
Round-lobed hepatica *Hepatica americana*	20(20)	3(3)	0(0)	0(0)
Orange-hawkweed *Hieracium aurantiacium*	7(7)	1(1)	20(15)	3(2)
Yellow-hawkweed *Hieracium pratense*	20(15)	3(2)	38(26)	4(3)
Larger blue flag *Iris versicolor*	10(10)	1(1)	0(0)	0(0)
Wild lettuce *Lactura canadensis*	3(3)	0(0)	8(4)	1(1)
Lily *Lilium* spp.	7(7)	1(1)	3(3)	0(0)
Honeysuckle *Lonicera* spp.	10(10)	1(1)	18(12)	2(1)
Ground cedar *Lycopodium* spp.	0(0)	0(0)	8(8)	1(1)
Canada mayflower *Maianthemum canadense*	52(26)	6(3.1)	21(21)	2(2)
Partridgeberry *Mitchella repens*	0(0)	0(0)	13(7)	2(1)
Sweet cicely *Osmorhiza claytoni*	0(0)	0(0)	4(4)	1(1)

Appendix Table 28 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Wood-betony *Pedicularis canadensis*	0(0)	0(0)	3(3)	0(0)
Fringed polygola *Polygola paucifolia*	20(20)	3(3)	17(17)	2(2)
White lettuce *Prenanthes alba*	3(3)	1(1)	4(4)	1(1)
Bracken fern *Pteridium aquilinum*	68(21)	9(3)	100(0)	12(1)
Wintergreen *Pyrola* spp.	7(7)	1(1)	18(9)	2(1)
Rubus spp.	80(15)	9(2)	83(8)	10(1)
Basil *Satureja vulgaris*	4(4)	1(1)	0(0)	0(0)
False Solomon's-seal *Smilacina racemosa*	0(0)	0(0)	3(3)	0(0)
Goldenrod *Solidago* spp.	14(9)	2(1)	19(11)	2(1)
Common dandelion *Taraxacum officinale*	23(15)	3(2)	23(15)	3(2)
Starflower *Trientalis borealis*	14(9)	2(1)	7(7)	1(1)
Large-flowered trillium *Trillium grandiflorum*	12(7)	2(1)	0(0)	0(0)
Low sweet blueberry *Vaccinium angustifolium*	37(19)	4(2)	58(30)	7(4)

Appendix Table 28 (cont.)

Species	Exclosure		Browsed	
	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Violet *Viola* spp.	73(22	9(3)	61(19)	7(2)
Other	13(13)	1(1)	0(0)	0(0)

Appendix Table 29. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 14-year-old bigtooth aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	4(4)	1(1)	0(0)	0(0)
Aster *Aster* spp.	17(4)	4(1)	2(2)	1(1)
Sedge *Carex* spp.	42(4)	9(2)	3(3)	1(1)
Trailing arbutus *Epigaea repens*	5(5)	1(1)	0(0)	0(0)
Daisy *Erigeron* spp.	11(8)	2(2)	4(4)	1(1)
Common strawberry *Fragaria virginiana*	4(4)	1(1)	0(0)	0(0)
Checkberry *Gaultheria procumbens*	50(29)	10(6)	13(13)	3(3)
Grass spp.	67(11)	14(1)	92(4)	24(2)
Yellow-hawkweed *Hieracium pratense*	16(8)	3(2)	23(5)	6(2)
Rattlesnake-weed *Hieracium venosum*	0(0)	0(0)	2(2)	1(1)
Wild lettuce *Lactura canadensis*	0(0)	0(0)	8(8)	2(2)
Honeysuckle *Lonicera* spp.	0(0)	0(0)	10(10)	3(3)

Appendix Table 29 (cont.)

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Ground cedar *Lycopodium* spp.	0(0)	0(0)	5(5)	1(1)
Canada mayflower *Maianthemum canadense*	9(5)	2(1)	0(0)	0(0)
Cow wheat *Melampyrum lineare*	13(7)	3(2)	11(8)	3(2)
Pinesap *Monotropa hypopithys*	2(2)	1(1)	0(0)	0(0)
Bracken fern *Pteridium aquilinum*	96(4)	20(2)	100(0)	27(3)
Sheep sorrel *Rumex acetosella*	0(0)	0(0)	13(13)	3(3)
Rubus spp.	17(8)	3(2)	3(3)	1(1)
False Solomon's-seal *Smilacina racemosa*	4(4)	1(1)	0(0)	0(0)
Twisted-stalk *Streptopus amplexifolius*	2(2)	1(1)	0(0)	0(0)
Common dandelion *Taraxacum officinale*	4(4)	1(1)	3(3)	1(1)
Low sweet blueberry *Vaccinium angustifolium*	91(5)	19(1)	93(7)	24(1)
Highbush blueberry *Vaccinium corymbosum*	27(14)	6(3)	10(10)	3(3)
Other	2(2)	1(1)	0(0)	0(0)

Appendix Table 30. Mean absolute (AF) and relative frequency (RF) and standard errors (SE) of herbaceous species in exclosures and areas open to browsing on 14-year-old quaking aspen clear-cuts in Pigeon River Country State Forest, Michigan (1994).

	Exclosure		Browsed	
Species	AF (SE)	RF (SE)	AF (SE)	RF (SE)
Yarrow *Achillea millefolium*	0(0)	0(0)	7(7)	1(1)
Plantain-leaved pussytoes *Antennaria plantaginifolia*	0(0)	0(0)	3(3)	1(1)
Wild sarsaparilla *Aralia nudicaulis*	11(1)	1(0)	7(7)	1(1)
Aster *Aster* spp.	100(0)	11(1)	100(0)	10(1)
Ox-eyed daisy *Chrysanthemum leucanthemum*	0(0)	0(0)	3(3)	1(1)
Field bindweed *Convolvulus arvensis*	0(0)	0(0)	4(4)	1(1)
Bunchberry *Cornus canadensis*	41(21)	5(2)	32(21)	3(2)
Sweet-fern *Comptonia pergrina*	0(0)	0(0)	10(10)	1(1)
Upright bindweed *Convolvulus spithamaeus*	0(0)	0(0)	23(23)	3(3)
Wood fern *Dryopteris* spp.	0(0)	0(0)	3(3)	0(0)
Trailing arbutus *Epigaea repens*	0(0)	0(0)	4(4)	1(1)
Daisy *Erigeron* spp.	4(4)	1(1)	0(0)	0(0)

Appendix Table 30 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Daisy fleebane *Erigeron strigosus*	0(0)	0(0)	3(3)	1(1)
Horsetail *Equisetum* spp.	0(0)	0(0)	7(7)	1(1)
Common strawberry *Fragaria virginiana*	56(10)	6(1)	81(11)	8(1)
Bedstraw *Galium* spp.	23(23)	2(2)	34(28)	3(2)
Checkberry *Gaultheria procumbens*	33(33)	4(4)	37(32)	4(4)
Yellow avens *Geum aleppieum*	0(0)	0(0)	3(3)	0(0)
Grass spp.	100(0)	11(1)	100(0)	10(1)
Round-lobed hepatica *Hepatica americana*	13(13)	2(2)	8(4)	1(0)
Orange-hawkweed *Hieracium aurantiacium*	0(0)	0(0)	37(19)	4(2)
Yellow-hawkweed *Hieracium pratense*	41(17)	5(2)	34(18)	4(2)
Wild lettuce *Lactura canadensis*	3(3)	0(0)	8(8)	1(1)
Lily *Lilium* spp.	14(3)	2(0)	0(0)	0(0)
Honeysuckle *Lonicera* spp.	32(5)	4(0)	0(0)	0(0)

Appendix Table 30 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Evening lychnis *Lychnis alba*	0(0)	0(0)	3(3)	0(0)
Ground cedar *Lycopodium* spp.	0(0)	0(0)	13(13)	1(1)
Canada mayflower *Maianthemum canadense*	69(9)	8(2)	28(18)	3(2)
Naked miterwort *Mitella nuda*	0(0)	0(0)	10(10)	1(1)
Partridgeberry *Mitchella repens*	7(7)	1(1)	8(8)	1(1)
Pinesap *Monotropa hypopithys*	4(4)	0(0)	0(0)	0(0)
Sensitive fern *Onoclea sensilibis*	0(0)	0(0)	10(10)	1(1)
Sweet cicely *Osmorhiza claytoni*	17(17)	2(2)	10(10)	1(1)
Wood-betony *Pedicularis canadensis*	4(4)	1(1)	4(4)	1(1)
Fringed polygola *Polygola paucifolia*	23(19)	3(2)	10(10)	1(1)
Bracken fern *Pteridium aquilinum*	93(4)	10(1)	97(3)	10(2)
Wintergreen *Pyrola* spp.	0(0)	0(0)	8(8)	1(1)
False Solomon's-seal *Smilacina racemosa*	0(0)	0(0)	3(3)	1(1)

Appendix Table 30 (cont.)

Species	Exclosure AF (SE)	Exclosure RF (SE)	Browsed AF (SE)	Browsed RF (SE)
Goldenrod *Solidago* spp.	7(3)	1(0)	17(9)	2(1)
Twisted-stalk *Streptopus amplexifolius*	3(3)	0(0)	0(0)	0(0)
Lesser switchwort *Stellaria graminea*	0(0)	0(0)	13(13)	1(1)
Common dandelion *Taraxacum officinale*	20(12)	2(1)	20(15)	2(1)
Starflower *Trientalis borealis*	20(10)	2(1)	20(15)	2(2)
Large-flowered trillium *Trillium grandiflorum*	8(8)	1(1)	0(0)	0(0)
Red clover *Trifolium pratense*	0(0)	0(0)	3(3)	0(0)
Buffalo clover *Trifolium stoloniferum*	0(0)	0(0)	3(3)	1(1)
Low sweet blueberry *Vaccinium angustifolium*	0(0)	0(0)	3(3)	0(0)
Viburnum spp.	0(0)	0(0)	11(1)	1.(0)
Violet *Viola* spp.	59(21)	6(2)	67(17)	7(1)
Other	3(3)	0(0)	10(10)	1(1)

LITERATURE CITED

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Aldous, S. E., and C. F. Smith. 1938. Food habits of Minnesota deer as determined by stomach analysis. Trans. N. Am. Wildl. Conf. 3:756-767.

_____. 1952. Deer browse clipping study in the Lake States region. J. Wildl. Manage. 16:401-409.

Alverson, W. S., D. M. Wallier, and S. L. Solheim. 1988. Forests too deer: edge effects in northern Wisconsin. Conserv. Biol. 2:348-358.

Back, G. N. 1982. Impacts of management for ruffed grouse and pulpwood on nongame birds. Ph.D. Dissertation. Univ. of Minnesota, Minneapolis. 96pp.

Bartos, D. L., and W. F. Mueggler. 1982. Early succession following clearcutting of aspen communities in northern Utah. J. Range Manage. 35:764-768.

Bender, L. C. 1992. The Michigan elk herd: ecology of a heavily exploited population. Ph.D. Dissertation. Michigan State Univ., East Lansing. 199pp.

Beyer, D. E., Jr. 1987. Population and habitat management of elk in Michigan. Ph.D. Dissertation. Michigan State Univ., East Lansing. 148pp.

Boyce, M. S. 1989. The Jackson elk herd: intensive wildlife management in North America. Cambridge Univ. Press, New York, N.Y. 306pp.

Byelich, J. D., J. L. Cook, and R. I. Blouch. 1972. Management for deer. Pages 120-125 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

Cade, B. S. 1985. Habitat suitability index models: American woodcock (wintering). US Dept. Inter., Fish and Wildl. Serv. Biol. Rep. 82(10.105). 23pp.

Canfield, R. H. 1941. Application of the line intercept method in sampling range vegetation. J. For. 39:388-394.

Campa, H., III. 1989. Effects of deer and elk browsing on aspen regeneration and nutritional qualities. Ph.D. Dissertation. Michigan State Univ., East Lansing. 122pp.

_____, J. B. Haufler, and D. E. Beyer, Jr. 1992. Effects of simulated ungulate browsing on aspen characteristics and nutritional qualities. J. Wildl. Manage. 56:158-164.

_____, _____, and S. R Winterstein. 1993. Effects of white-tailed deer and elk browsing on regenerating aspen: a ten year evaluation. Pages 304-311 in I. D. Thompson, ed. Proc. of the Int. Union of Game Biol. XXI Congress. Vol. 2. Halifax, Nova Scotia, Canada.

_____, S. R. Winterstein, J. B. Haufler, L. B. Bender, and D. E. Beyer. 1995. Survival and cause-specific mortality of Michigan elk, 1981-1994. Abstract only. 57th Midwest fish and wildlife conference, Detroit, Michigan.

DeByle, N. V. 1979. Potential effects of stable versus fluctuating elk populations in the aspen ecosystem. Pages 13-19 in M. S. Boyce and L. D. Hayden-Wing, eds. North American elk: ecology, behavior and management. Univ. of Wyoming Press, Laramie.

_____. 1985. Animal impacts. Pages 115-123 in N. V. DeByle and R. P. Winodur, eds. Aspen: ecology and management in the western United States. USDA For. Serv. Gen. Tech. Rep. RM-119.

DeGraff, R. M., G. M. Whitman, J. W. Lanier, B. J. Hill, and J. M. Keniston. 1980. Forest habitat for birds of the northeast. U.S. For. Serv., Northeast. For. Exp. Stn., Broomall, Pa. 598pp.

_____, _____, and D. Rudis. 1981. Forest habitat for mammals in the northeast. U.S. For. Serv., Northeast. For. Exp. Stn., Broomall, Pa. 182pp.

_____, and D. Rudis. 1981. Forest habitat for reptiles and amphibians of the northeast. U.S. For. Serv., Northeast. For. Exp. Stn., Broomall, Pa. 239pp.

Eaton, L. E. 1986. Response of songbirds and small mammals to whole tree harvesting of aspen. M.S. Thesis, Michigan State Univ., East Lansing. 90pp.

Fralish, J. S. 1972. Youth, maturity, and old age. Pages 52-58 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

Freese, F. 1978. Elementary forest sampling. USDA For. Serv. Handb. 232. 91pp.

Gaffney, W. S. 1941. The effects of winter elk browsing, south fork of the Flathead river, Montana. J. Wildl. Manage. 5:427-453.

Gill, J. L. 1978. Design and analysis of experiments in the animal and medical sciences. Vol. 1. Iowa State Univ. Press, Ames, Ia. 411pp.

Graham, S. A., R. P. Harrison, and C. E. Westell, Jr. 1963. Aspens: phoenix trees of the Great Lakes region. The Univ. of Michigan Press, Ann Arbor. 272pp.

Grover, K. E., and M. J. Thompson. 1986. Factors influencing spring feeding site selection by elk in the Elkhorn Mountains, Montana. J. Wildl. Manage. 50:466-470.

Gullion, G. W. 1985. Aspen management - an opportunity for maximum integration of wood fiber and wildlife benefits. Trans. N. Amer. Wildl. and Resour. Conf. 50:249-261.

Gysel, L. W., and L. J. Lyon. 1980. Habitat analysis and evaluation. Pages 305-327 in S.D. Schemnitz, ed. Wildlife management techniques manual. Fourth ed. The Wildlife Society, Washington D.C.

Hammill, J. and R. Moran. 1986. A habitat model for ruffed grouse in Michigan. Pages 15-18 in J. Vernor, ed. Wildlife 2000. Univ. of Wisconsin Press, Madison.

Haufler, J. B., H. Campa, III., and D. Beyer. 1984. Elk responses to management activities in Michigan. Annual report on file. Mich. Dept. Nat. Resour., Lansing. 27pp.

_____, _____, and _____. 1985. Elk responses to management activities in Michigan. Annual report on file. Mich. Dept. Nat. Resour., Lansing. 34pp.

Hobbs, N. T., D. L. Baker, J. E. Ellis, and D. M. Swift. 1979. Composition of elk diets during winter and summer: a preliminary analysis. Pages 47-53 in M. S. Boyce and L. D. Hayden-Wing, eds. North American elk: ecology, behavior and management. Univ. of Wyoming Press, Laramie.

Jones, J. R. 1976. Aspen harvesting and reproduction. Pages 30-34 in Utilization and marketing as tools for aspen management in the Rocky Mountains. USDA For. Serv. Gen. Tech. Rep. RM-29.

Knight, J. E. 1975. Use of openings by elk in northern Michigan. M.S. Thesis. Michigan State Univ., East Lansing. 38pp.

Laidly, P. R. 1990. *Populus grandidentata* Michx.: bigtooth aspen. Pages 544-550 in R. M. Burns and B. H. Honkala, eds. Silvics of North America. Vol. 2, Hardwoods. USDA Handb. 654. 877pp.

Leatherberry, E. C., and J. S. Spencer, Jr. 1996. Michigan forest statistics, 1993. USDA For. Serv. Res. Bull. NC-170. 144pp.

Lyon, L. J., and C. E. Jensen. 1980. Management implications of elk and deer use of clear-cuts in Montana. J. Wildl. Manage. 44:352-362.

_____, and A. L. Ward. 1982. Elk and land management. Pages 443-477 in J. W. Thomas and D. E. Toweill, eds. Elk of North America: ecology and management. Stackpole Books, Harrisburg, Pa.

Maini, J. S. 1972. Silvics and ecology in Canada. Pages 67-73 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

Marquis, D. A., and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep. NE-65. 7pp.

McCaffery, K. R., J. Tranetzki, and J. Piechura. 1974. Summer foods of deer in northern Wisconsin. J. Wildl. Manage. 38:215-219.

McGuire, J. R. 1972. Some problems and issues in managing the aspen resources. Pages 1-3 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

Michigan Department of Natural Resources. 1984. Elk Management Plan. 1984. Mimeo on file. Lansing. 46pp.

Michigan State Forest Operations Inventory System. 1982. Compartment and stand evaluation. For. Manage. Div. Mich. Dep. Nat. Resour., Lansing. Typewritten manuscript. 50pp.

Moran, R. J. 1973. The Rocky Mountain elk in Michigan. Res. and Dev. Rep. 267. Mich. Dep. of Nat. Resour., Lansing. 93pp.

Mueggler, W. F., and D. L. Bartos. 1977. Grindstone Flat and Big Flat exclosures - a 41-year record of changes in clearcut aspen communities. USDA For. Serv. Res. Pap. INT-195. 13pp.

National Oceanic and Atmospheric Administration. 1994. Climatological data: Michigan annual summary. Natl. Climatic Cent., Asheville, N.C.

_____. 1995a. Climatological data: Michigan, January. Natl. Climatic Cent., Asheville, N.C.

_____. 1995b. Climatological data: Michigan, February. Natl. Climatic Cent., Asheville, N.C.

_____. 1995c. Climatological data: Michigan, March. Natl. Climatic Cent., Asheville, N.C.

_____. 1995d. Climatological data: Michigan, April. Natl. Climatic Cent., Asheville, N.C.

_____. 1995e. Climatological data: Michigan, May. Natl. Climatic Cent., Asheville, N.C.

_____. 1995f. Climatological data: Michigan, June. Natl. Climatic Cent., Asheville, N.C.

_____. 1995g. Climatological data: Michigan, July. Natl. Climatic Cent., Asheville, N.C.

Nelson, J. R., and T. A. Leege. 1982. Nutritional requirements and food habits. Pages 323-367 in J. W. Thomas and D. E. Toweill, eds. Elk of North America: ecology and management. Stackpole Books, Harrisburg, Pa.

Packard, F. M. 1942. Wildlife and aspen in Rocky Mountain National Park, Colorado. Ecology 23:478-482.

Perala, D. A. 1972. Regeneration: biotic and silvicultural factors. Pages 97-101 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

_____. 1990. *Populus tremuloides* Michx.: quaking aspen. Pages 555-569 in R. M. Burns and B. H. Honkala, eds. Silvics of North America. Vol. 2, Hardwoods. USDA Handb. 654. 877pp.

Roberts, M. R., and C. J. Richardson. 1985. Forty-one years of population change and community succession in aspen forests on four soil types, northern lower Michigan, U.S.A. Can. J. of Bot. 63:1641-1651.

Rogers, L. L., J. J. Mooty, and D. Dawson. 1981. Foods of white-tailed deer in the upper Great Lakes region - a review. USDA For. Serv. Tech. Rep. NC-65. 24pp.

Sakai, A. K., M. R. Roberts, and C. L. Jolls. 1985. Successional changes in a mature aspen forest in northern lower Michigan: 1974-1981. Am. Midl. Nat. 113:271-282.

Sampson, A. W. 1919. Effect of grazing upon aspen reproduction. USDA Bull. 741. 29pp.

Schier, G. A., and A. D. Smith. 1979. Sucker regeneration in a Utah aspen clone after clearcutting, partial cutting, scarification, and girdling. USDA For. Serv. Res. Note INT-253. 6pp.

Siegel, S. 1988. Non-parametric statistics for the behavioral sciences. Second ed. McGraw-Hill Book Company, New York, N.Y. 312pp.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. Third ed. W. H. Freeman and Co., New York, N.Y. 887pp.

Spiegel, L. E., C. E. Huntly, and G. R. Gerber. 1963. A study of the effects of elk browsing on woody plant succession in northern Michigan. Jack Pine Warbler 41:68-72.

Steel, R. G., and J. H. Torrie. 1980. Principles and procedures of statistics: a biometric approach. Second ed. McGraw-Hill Book Company, New York, N.Y. 632pp.

Stoeckeler, J. H., and J. W. Macon. 1956. Regeneration of aspen cutover areas in northern Wisconsin. J. For. 54:13-16.

Tardy, S. W. 1991. Soil survey of Cheboygan County, Michigan. USDA Soil Conserv. Serv. 256pp.

Tierson, W. C., E. F. Patric, and D. F. Behrend. 1966. Influence of white-tailed deer on the logged northern hardwood forest. J. For. 64:801-805.

Tilghman, N. G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. J. Wildl. Manage. 53:525-532.

Veatch, J. O. 1953. Soils and land of Michigan. Mich. State College Press, East Lansing. 241pp.

Westell, C. E., Jr. 1954. Available browse following aspen logging in lower Michigan. J. Wildl. Manage. 18:266-271.

_____. 1956. Ecological relationships between deer and forests in lower Michigan. Soc. Am. For. Proc. 1955:130-132.

Yahner, R. H. 1995. Eastern deciduous forest: ecology and wildlife conservation. Univ. of Minnesota Press, Minneapolis. 220pp.

Zazada, Z. A. 1972. Mechanized harvesting systems can aid management. Pages 131-136 in Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1.

Zehngraff, P. J. 1949. Aspen as a forest crop in the Lake States. J. For. 47:555-565.