MOOSE BROWSING AND FOREST REGENERATION: A CASE STUDY IN NORTHERN NEW HAMPSHIRE

Daniel H. Bergeron[1], Peter J. Pekins[1], Henry F. Jones[1], and William B. Leak[2]

[1]Wildlife Program, Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH 03824, USA; [2]USDA Forest Service, Northern Research Station, PO Box 640, Durham, NH 03824, USA.

ABSTRACT: The impact of moose (*Alces alces*) browsing on the regeneration of commercial hardwood and softwood tree species was evaluated in 3 regions with different moose population densities (0.26-0.83 moose/km^2) in northern New Hampshire. Regeneration surveys were conducted in 4 age classes of clear-cuts (0-5, 6-10, 11-15, and 16-20 years) in June-August 2009. Stocking rate, tree height, and damage of dominant commercial stems were measured to assess regeneration and browse damage among age classes and regions. We assumed that a stocking rate of 40-60% (stems/plot) dominant commercial tree species without severe damage was an acceptable threshold of browse damage to achieve a fully stocked stand at 80 years. Mean stocking rate of all age classes was above the threshold in all regions (47-85%); the lowest stocking rates (47-52%) occurred in the 0-5 year age class but increased thereafter in all regions. The CT Lakes region (highest moose density) had more damage than both the North and White Mountain regions in the 11-15 year age class (F = 3.05; df; 6; P = 0.0002 and 0.0058, respectively). Tree heights were lower in the CT Lakes region (F = 2.30; df; 6; P = 0.04). Most damage was restricted to a few isolated clear-cuts at higher elevation near moose wintering areas that were possibly shifting to conifer dominance. Regeneration of commercial tree species was not considered a regional problem at any moose density in northern New Hampshire.

ALCES VOL. 47: 39-51 (2011)

Key words: *Alces alces*, browsing, clear-cut, damage, moose, population density, regeneration, stocking, threshold.

Moose (*Alces alces*) are economically and ecologically important in northern New Hampshire with moose viewing a popular attraction and >500 hunting permits issued statewide in 2009 (2009 New Hampshire Wildlife Harvest Summary). Wildlife-associated recreation contributed ~$560 million to New Hampshire's economy in 2006 (USFWS 2006), and moose related activities represent a substantial portion of this figure with ~$375,000 from 2010 permit and license sales alone (K. Rines, New Hampshire Fish and Game [NHFG], personal communication). However, moose browsing can negatively impact the forest industry which is arguably the primary contributor to northern New Hampshire's economy. According to the Governor's New Hampshire Forest Products Industry Task Force Report (2008), the state generates over $2.3 billion annually from forest-based manufacturing and forest-related recreation and tourism.

Adult moose require substantial browse to maintain their characteristically large body size (2.8 kg/moose/day in January in NH; Pruss and Pekins 1992), thus have potential to impact plant communities considerably (Peek 1997, Bowyer et al. 1998), particularly in commercially managed forests that create preferred habitat and forage that attract moose (Westworth et al. 1989, Scarpitti et al. 2005). For example, moose on Isle Royale, Michigan prevented aspen (*Populus spp.*), birch (*Betula spp.*) and balsam fir (*Abies balsamea*) from reaching the overstory, whereas spruce (*Picea spp.*) was little affected (McInnes et al. 1992); sites with previously low moose density and older sites with unreachable foliage escaped damage. Density of 0.3-0.5 moose/km² in Russia retarded growth of preferred forage species such as aspen, causing rapid over-growth by spruce; normal stand development occurred at 0.2-0.3 moose/km² (Abaturov and Smirnov 2002). Moose browsing reduced height of preferred species and released conifers from competition in Finland (Heikkila et al. 2003), winter density of 4.6 moose/km² retarded growth and regeneration of birch in Newfoundland (Bergerud and Manuel 1968), and moose (1.97/km²) reduced browse availability in deer (*Odocoileus virginianus*) wintering areas in northern New Hampshire (Pruss and Pekins 1992). Despite the year-round importance of early-successional browse to moose, and the importance of sustaining commercial forests in northern New Hampshire, little attention has been paid to the impact of moose browsing on forest regeneration (Scarpitti 2006).

In the late 2000s the Connecticut Lakes Timber Company raised concern about the negative impact of moose browsing on regeneration of commercial tree species and its associated impacts on the economic viability of timber resources on their property. Because of the importance of both moose and the timber industry in northern New Hampshire, it is important to balance recreational opportunity with economically viable forests. This research was designed to evaluate the impact of moose browsing on regeneration of commercial tree species in 3 regions of different moose density in northern New Hampshire. Our objectives were to 1) measure the stocking rate of commercial tree species in 4 age classes of clear-cuts, 2) measure the relative quality (damage) of dominant commercial stems in these cuts, and 3) determine if a relationship exists between regional moose density and % damage of commercial tree species.

METHODS

Study Area

The study area was located in northern New Hampshire and was separated into 3 regions (Fig. 1) based on moose population density (NHFG 2009). The 3 regions from highest to lowest density were CT Lakes (0.83 moose/km²), North (0.61 moose/km²), and White Mountain (0.26 moose/km²), respectively (K. Rines, personal communication). Elevation in the study area ranges from ~120-1900 m, average monthly snow depth ranges from 0-60 cm, and average monthly temperature ranges from -13-19° C (NOAA 2006).

The CT Lakes and North regions were dominated by commercial hardwood species including sugar (*Acer saccharum*) and red maple (*A. rubrum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). Red spruce (*Picea rubens*) and balsam fir tend to be the dominant species at higher elevations (>760 m) and in cold, wet lowland sites (Degraaf et al. 1992). These regions are predominately forested and the majority of the land is privately owned and commercially harvested using various silvicultural techniques (Degraaf et al. 1992);

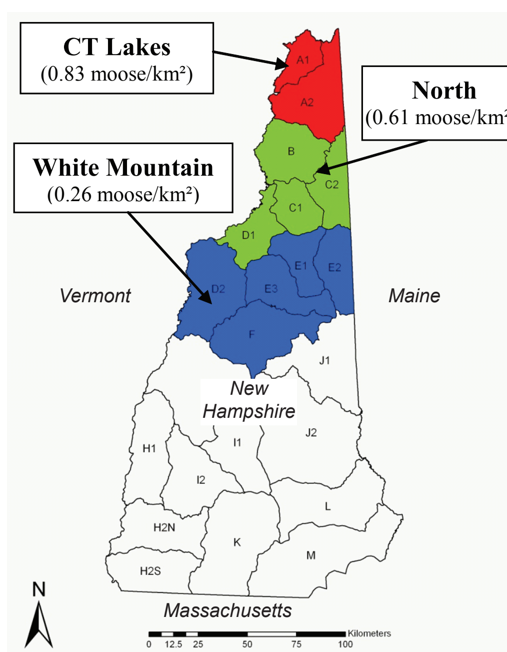

Fig. 1. The location of the 3 study regions in northern New Hampshire used to compare effects of moose browsing on forest regeneration relative to moose density.

they contain ~10% wetlands and open water, and are interspersed with trails and logging roads. The CT Lakes region is hilly with few high mountains, while the North is characterized by high mountainous terrain. The White Mountain region contains the White Mountain National Forest which covers 304,050 hectares and is >95% forested. It had the highest elevations and was dominated by beech, sugar maple, and yellow birch; other common species include white ash (*Fraxinus americana*), red maple, red spruce, and eastern hemlock (*Tsuga canadensis*). Timber harvest in this region is done on a smaller scale than the other regions, with maximum clear-cut size of ~10-12 ha (USFS 2005). White-tailed deer are sympatric with moose throughout the study area.

Field Measurements

Regeneration surveys (Leak 2007) were performed in clear-cuts ≥2.83 ha in June-August 2009 in all regions. Cuts were separated into 4 age classes (0-5, 6-10, 11-15, and 16-20 years old) in each region to measure temporal change across 20 years of growth. This time frame encompassed the age of trees, and 10 years beyond, that moose are most likely to impact architecture and growth through browsing. We surveyed 7-10 stands of each age class spread throughout each of the 3 sample regions. Sample sites were ground-truthed using GPS locations (when available) and cartographic features such as wetlands, streams, and roads.

Small-plot surveys using milacre plots (~ 2.3 m diameter) were used to assess tree density (stems/plot). To avoid repeat measurements, plots were evenly spaced on equidistant transects throughout each clear-cut (Fig. 2). Approximately 75-250 small-plot surveys were conducted in each clear-cut providing approximately 700-1,000 plots/age class per region.

In each plot the dominant stem (tallest tree) was recorded as commercial or non-commercial; commercial species included oak (*Quercus spp*.), sugar and red maple, yellow and white birch (*B. papyrifera*), American beech, aspen, ash, balsam fir, red spruce, and white pine (*Pinus strobus*). Stem damage was assessed qualitatively as fork, broom, or crook on dominant commercial and non-commercial stems (Fig. 3). Height of damage, number of forks and crooks, and severity of crook (based on angle) were also recorded.

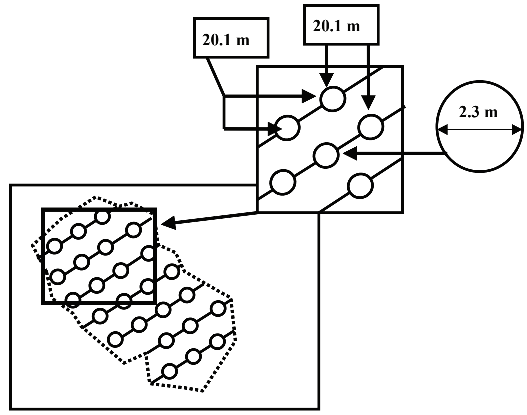

Fig. 2. Example layout of milacre sample plots evenly spaced on equidistant transects in clear-cut study sites.

Data Analysis

Browse defects that classified a tree as severely damaged included broomed stems and multiple forks above breast height (~1.4 m). Damage considered not severe enough to affect tree quality included single forks and crooks. Studies indicate trees with such damage usually recover during subsequent growth and are harvested in normal rotation time (Switzenberg et al. 1955, Carvell 1967, Trimble 1968, Jacobs 1969). The milacre plot size equals the area required by the dominant stem when the stand reaches 10.16-15.24 cm (4-6 in) (mean stand diameter/average basal area) in northern hardwood and mixed wood stocking guides (Leak et al. 1987, Fig. 4). Based on these stocking guides, a minimum of 40-60% of sample plots in each age class should contain a dominant commercial stem without severe damage to achieve a fully

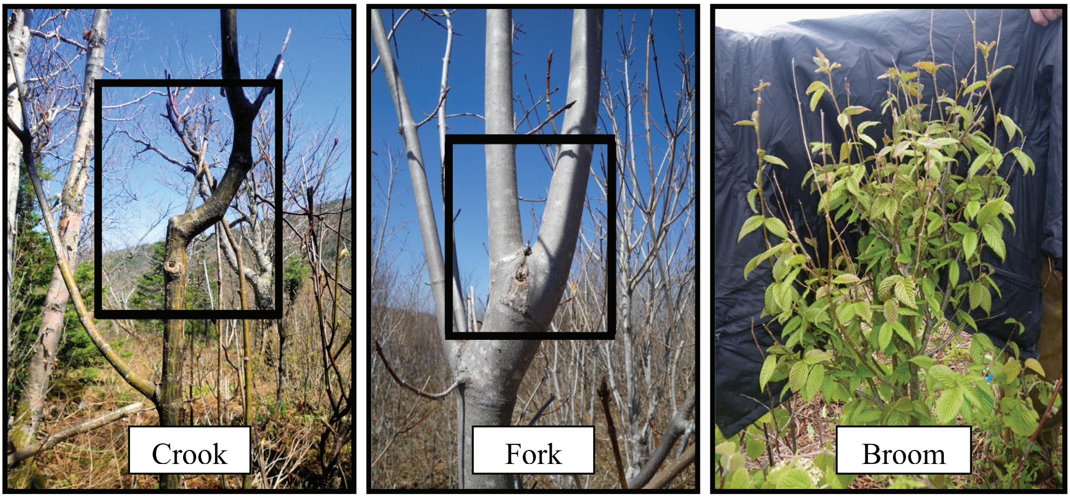

Fig. 3. Illustration of the 3 qualitative browse categories used to describe browsing damage of dominant commercial stems (photos by D. Bergeron).

stocked stand at 80 years (Leak et al. 1987, Fig. 4).

The relative height of the dominant stem was estimated in the 3 older age classes to further assess browsing impact. The proportion of plots containing a dominant commercial stem ≥3.0 m without severe damage was used to compare relative height between age classes. Vegetation ≥3.0 m was presumed to be above the height of typical moose browsing (Bergstrom and Danell 1986).

Analysis of variance (ANOVA) was used

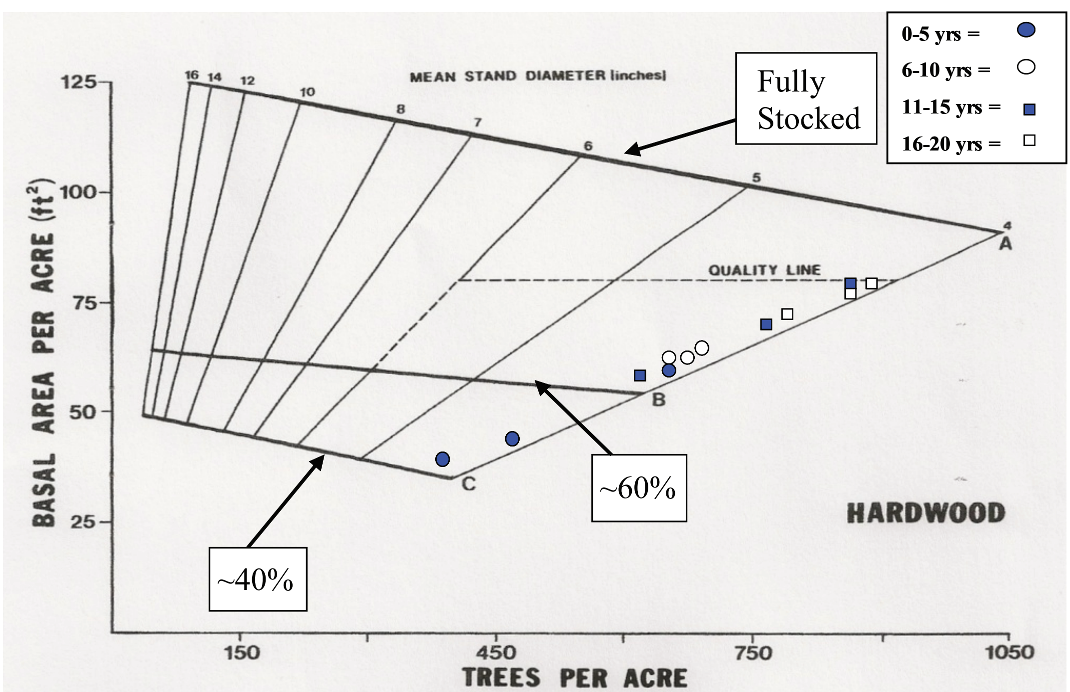

Fig. 4. Stocking guide for main crown canopy of even-aged hardwood stands. The A-line is fully stocked, the B-line is suggested residual stocking (~60%), and the C-line is minimum stocking (~40%) (Leak et al. 1987). The proportion (%) of commercial trees without severe damage are plotted by age class.

to examine for differences in mean stocking rate of commercial trees, browse damage, and height of vegetation. A Shapiro-Wilk test was used to test if the data were normally distributed and a Bartletts' test was used to check for homogeneity of variance (Zar 1999). Pairwise comparisons were made with Tukey's test. Linear regression was used to test for relationships between browse damage and moose density. Analyses were performed with Systat v. 13. Significance for all tests was assigned *a priori* at $\alpha = 0.05$.

RESULTS

Stocking rate of commercial trees ranged from 49-85% in all age classes in each region, and increased with age class (Table 1). Stocking rate was 71-77% in each region by the 6-10 year age class, and ≥85% by the 16-20 year age class. The proportion of commercial trees with severe damage was low (<10%) in all regions and age classes except in the 11-15 year age class in the CT Lakes region (16%, Table 1). Severe damage in this age class was higher in the CT Lakes than the North and White Mountain regions ($F = 3.05$; df = 6; $P = 0.00016$ and 0.00581, respectively).

The proportion of plots containing a commercial tree without severe damage was above the threshold stocking level of 40-60% in all age classes and regions, and generally increased with age class (Table 1, Fig. 4). The proportion of undamaged trees ≥3.0 m increased with age class in each region; for the most part, this proportion was inversely related to regional moose density (Table 1). Height in the 11-15 year age class was lower in the CT Lakes region than in the North (F= 2.30; df = 6; $P = 0.005$) and White Mountain regions ($F = 2.30$; df = 6; $P = 0.016$), and in

Table 1. Summary of stocking rates in relation to damage by moose in 4 age classes of clear-cuts in 3 regions with different moose density in northern New Hampshire.

Sample region and age class	Stocking rate of dominant commercial trees (%)	Stocking rate of dominant commercial trees w/o severe damage (%)	Stocking rate of dominant commercial trees w/ severe damage (%)	Proportion of dominant commercial trees w/o severe damage and ≥3.0 m tall (%)
CT Lakes*				
0-5	49	47	2	N/A
6-10	77	69	8	22 (a)
11-15	78	61	16 (a)*	43
16-20	87	78	9	63
North				
0-5	67	64	3	N/A
6-10	71	67	4	39 (ab)
11-15	86	85	1 (b)	69
16-20	87	85	2	70
White Mountain				
0-5	53	52	1	N/A
6-10	73	67	7	48 (b)
11-15	79	75	4 (b)	67
16-20	85	84	0	80

NA = not applicable

* Rows with unlike letters are statistically different (P<0.05).

the 6-10 year age class ($F = 2.30$; df = 6; $P = 0.008$) in the White Mountain region.

Severe damage and population density were correlated ($P = 0.0089$), although damage was considered low (1-16%) overall in each region. Only 3 of the 116 clear-cuts (2.6%) were considered severely damaged. Two of these were in the 11-15 year age class in the CT Lakes region and 1 was in the 6-10 year age class in the White Mountain region. Stocking of commercial trees in these clear-cuts was ≤75% and >50% of these stems were severely damaged; damage to hardwoods was nearly 100% whereas damage to conifers was minimal (Table 2).

At least 3 commercial species accounted for ≥50% of the species composition in each age class in each of the 3 sample regions (Tables 3-5). The majority of these species were classified as light to no damage. The proportion of non-commercial species declined as age class increased in all sample regions (Tables 3-5).

DISCUSSION

Moose browsing has not substantially impacted regeneration of commercial tree species in northern New Hampshire on a regional basis. Stocking rate of commercial tree species without severe damage was above the minimum threshold of 40-60% in all regions and age classes, and severe damage from browsing was low in all regions and age classes (Table 1). Stocking rates in the 0-5 year age classes were lowest (49-67%) and due to high stocking of early successional, non-commercial species such as blackberry (*Rubus allegheniensis*), raspberry (*Rubus idaeus*), and pin cherry (*Prunus pennsylvanica*), not browsing. Severe browse damage in these age classes was only 1-3%, and stocking rate jumped to >70% by the 6-10 year age class (Table 1).

Relative height of trees increased with age class and was negatively correlated with moose density. Bergerud and Manuel (1968) noted that if browsing pressure is removed, "hedged" stems may escape and recover for harvest within a normal rotation time. One leader becomes apically dominant in forked stems (Jacobs 1969), and crooked stems straighten with added radial growth (Switzenberg et al. 1967, Trimble 1968). The increased height in regions with lower moose density is suggestive of a relationship between damage and moose density. However, because stocking rate was above the threshold level in all regions, and

Table 2. Summary of stocking rates and browsing damage by moose in 3 severely damaged clear-cuts identified in this study in northern New Hampshire.

Sample region and age class	Stocking rate of dominant commercial trees (%)	Proportion of commercial trees w/ severe damage (%)	Proportion of dominant commercial trees w/o severe damage and ≥3.0 m tall (%)	Stocking rate of dominant commercial hardwoods (%)	Stocking rate of dominant commercial softwoods (%)
CT Lakes					
11-15	69	63	16	72 (98)*	28 (2)
11-15	75	52	22	75 (100)	25 (0)
Average	78	22	43	NA	NA
White Mountain					
6-10	69	52	16	99 (97)	1 (3)
Average	73	10	48	NA	NA

NA = not applicable

*Numbers in parenthesis indicate severe browse damage (%).

Table 3. Browse damage of dominant stems in different aged clear-cuts in the CT Lakes sample region in northern New Hampshire. Row totals do not always add up due to rounding of numbers.

Age class	Species	Severe damage (%)	Moderate damage (%)	Light damage (%)	No damage (%)	Total (%)
6-10						
	American beech	0	0	0	0	1
	Aspen spp.	1	1	3	1	5
	Balsam fir	0	1	4	16	22
	Red maple	1	2	3	1	6
	Red spruce	0	0	0	4	5
	Sugar maple	2	3	8	2	15
	White birch	3	1	4	2	9
	Yellow Birch	1	1	5	4	11
	Non commercial	NA	NA	NA	NA	27
11-15						
	American beech	0	0	1	1	2
	Aspen spp.	0	0	0	0	1
	Balsam fir	0	0	2	15	17
	Red maple	5	5	5	2	17
	Red spruce	0	0	0	4	4
	Sugar maple	0	2	2	1	6
	White birch	8	1	5	4	18
	Yellow Birch	4	2	5	3	14
	Non commercial	NA	NA	NA	NA	21
16-20						
	American beech	0	0	0	1	1
	Aspen spp.	0	0	1	0	1
	Balsam fir	1	1	1	23	26
	Red maple	1	2	7	3	12
	Red spruce	0	0	0	11	12
	Sugar maple	1	2	4	2	10
	White birch	4	2	6	3	15
	Yellow Birch	2	1	4	1	8
	Non commercial	NA	NA	NA	NA	14

severe damage levels >10% occurred in only 1 age class in the CT Lakes, this relationship has negligible impact on regional forest productivity.

Several studies have examined the impacts of moose density on tree species. In central Newfoundland winter densities of >4.6 moose/km² caused severe damage to balsam fir and white birch (Bergerud and Manuel 1968); lower density of 2.32 moose/km² reduced serious damage of these species (Bergerud et al. 1968). Angelstam et al. (2000) examined the effects of moose density across 3 geographic regions (Sweden, Finland, and Russian Karelia) with density ranging from 0.2-1.7 moose/km², and found the proportion of severely damaged and dead stems increased 36-fold in the highest density region; regions with densities of ≤0.3-0.4 moose/km² had less damage. In Sweden, clipping studies showed that densities of 0.8-1.5 moose/km² do not impact winter browse availability, but densities of ≥2.0 moose/km² will (Persson et al. 2005). Faison et al. (2010) measured browse damage in southern New England at densities of 0.5-1.1 moose/km² and found only 3% of study sites were browsed intensively. Moose density in our study area in the previous 20

Table 4. Browse damage of dominant stems in different aged clear-cuts in the North sample region in northern New Hampshire. Row totals do not always add up due to rounding of numbers.

Age class	Species	Severe damage (%)	Moderate damage (%)	Light damage (%)	No damage (%)	Total (%)
6-10						
	American beech	0	1	4	3	7
	Aspen spp.	0	1	8	1	10
	Ash spp.	0	1	2	3	5
	Balsam fir	0	0	1	4	5
	Red maple	2	3	6	2	13
	Red spruce	0	0	0	0	1
	Sugar maple	1	2	7	1	11
	White birch	0	0	2	1	4
	Yellow birch	0	2	7	4	14
	Non commercial	NA	NA	NA	NA	30
11-15						
	American beech	0	0	0	0	0
	Aspen spp.	0	0	5	4	9
	Ash spp.	0	0	0	0	1
	Balsam fir	0	0	2	34	36
	Red maple	0	2	7	2	11
	Red spruce	0	0	0	5	5
	Sugar maple	0	1	3	0	4
	White birch	0	1	7	3	11
	White pine	0	0	0	0	0
	Yellow birch	0	0	4	3	8
	Non commercial	NA	NA	NA	NA	14
16-20						
	American beech	0	1	2	2	4
	Aspen spp.	0	0	4	2	6
	Ash spp.	0	0	0	0	0
	Balsam fir	0	1	3	33	36
	Red maple	1	2	9	1	13
	Red spruce	0	0	1	9	10
	Sugar maple	0	1	4	1	7
	White birch	0	1	5	1	8
	Yellow birch	0	1	2	1	4
	Non commercial	NA	NA	NA	NA	12

Table 5. Browse damage of dominant stems in different aged clear-cuts in the White Mountain sample region in northern New Hampshire. Row totals do not always add up due to rounding of numbers.

Age class	Species	Severe damage (%)	Moderate damage (%)	Light damage (%)	No damage (%)	Total (%)
6-10						
	American beech	3	6	20	7	37
	Aspen spp.	0	0	2	1	3
	Ash spp.	0	1	4	3	8
	Balsam fir	0	0	0	0	0
	Oak spp.	0	0	0	0	1
	Red maple	0	1	4	1	5
	Red spruce	0	0	0	1	1
	Sugar maple	0	0	1	0	1
	White birch	0	2	7	3	12
	White pine	0	0	0	1	1
	Yellow birch	2	1	4	2	8
	Non commercial	NA	NA	NA	NA	23
11-15						
	American beech	1	4	18	5	29
	Aspen spp.	0	0	2	1	3
	Ash spp.	1	1	6	2	9
	Balsam fir	0	0	1	2	3
	Red maple	1	1	7	1	11
	Red spruce	0	0	0	2	2
	Sugar maple	0	0	2	0	3
	White birch	0	0	7	3	10
	Yellow birch	1	1	5	2	10
	Non commercial	NA	NA	NA	NA	19
16-20						
	American beech	0	2	12	4	18
	Aspen spp.	0	0	7	3	10
	Ash spp.	0	0	3	1	4
	Balsam fir	0	0	0	1	1
	Oak spp.	0	0	1	0	1
	Red maple	0	1	8	1	10
	Red spruce	0	0	0	1	1
	Sugar maple	0	0	2	0	3
	White birch	0	1	13	7	20
	White pine	0	0	0	0	0
	Yellow birch	0	1	9	5	16
	Non commercial	NA	NA	NA	NA	15

years was nearly double (~1.5-2.0 moose/km²) that of current moose density (<1.0 moose/km² in all regions; K. Rines, personal communication).

Browse damage was greatest in the 11-15 year age class in the CT Lakes region and higher than in the North and White Mountains regions (Fig. 5); however, the overall stocking level was above the threshold value. Two clear-cuts accounted for this difference, one adjacent to and the other within 1 km of a moose wintering area. Moose often use traditional wintering areas to reduce movement and often concentrate in above average numbers (Renecker and Schwartz 1997). Heavy damage associated with high winter densities of moose was measured in Finland (Heikkila et al. 2003) and Newfoundland (Bergerud and Manuel 1968). The only clear-cut severely damaged in the 6-10 year age class in the White Mountains region was also within 1 km of moose winter habitat. No statistical difference in damage between region or age class (Fig. 5) occurred after we removed these 3 cuts from our study design, indicating the importance of measuring and identifying both local and regional impacts.

Although damage was low in all regions and age classes, site-specific severe browsing may shift local species composition. The 2 severely damaged cuts in CT Lakes were stocked predominately with deciduous species that had much higher damage relative to coniferous species (Table 2), suggesting that coniferous species may eventually dominate these stands. Intense browsing of preferred deciduous species allowed spruce biomass to increase on Isle Royale, Michigan (McInnes et al. 1992), and high browsing of preferred forage allowed rapid over-growth by spruce in Russia (Abaturov and Smirnov 2002). Severe browsing by moose does not appear to be shifting regional species composition. At least 3 commercial hardwood species and/or balsam fir accounted for ≥50% of the species composition in each age class in the CT Lakes and North regions (Tables 3 and 4), and the majority was classified as light to no damage. As softwoods are less common in the White Mountain region, one concern could be a shift toward beech dominance due to severe browsing of more preferred species; however, other

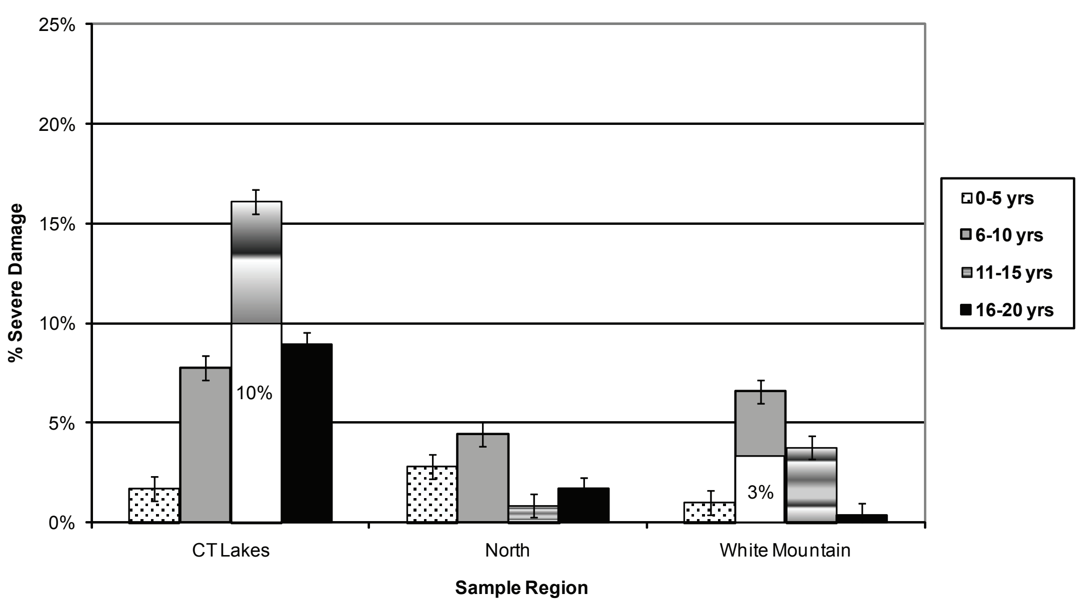

Fig.5. Proportion (%) of plots with severe damage in 4 age classes of clear-cuts in 3 regions with different moose density in northern New Hampshire. The solid white bars represent proportions after 3 severely damaged cuts were removed from the data set (2 in CT Lakes and 1 in White Mountain region).

commercial species accounted for 36-66% of the species composition and increased with age class (Table 5). Further, the proportion of non-commercial species declined in each older age class in all regions.

Our results indicate that stocking rates of commercial tree species were above the accepted threshold stocking level in all 3 regions. Moose density and browse damage appeared to be correlated, however, damage was low in each region at all moose densities. Severe browsing was site-specific and likely influenced by proximity to winter habitat; however, forest composition may shift to coniferous species in such situations. Measurements taken in the 0-5 year age class are most likely poor indicators of regeneration potential as the forest tends to compensate with additional growth. Presumably, evident heavy browsing in this young age class created the perception that regeneration and stocking would be impacted long term. This study indicates that measuring regeneration and stocking in a series of age classes provides a more accurate assessment of the temporal and permanent impact of moose browsing on forest productivity.

ACKNOWLEDGEMENTS

Funding for this research was provided by the NHFG. This study was possible due to the cooperation of numerous commercial and private landowners who granted access to their property including, but not limited to, Wagner Forest Management, Ltd., the Connecticut Lakes Timber Company, and the Dartmouth College Land Grant. We are grateful to the biologists of the NHFG, the USDA Forest Service, and the many students from the University of New Hampshire who were critical to the project's success, especially Wes Smith. In particular we would like to thank Kristine Rines, NHFG moose biologist.

REFERENCES

Abaturov, B. D., and K. A. Smirnov. 2002. Effects of moose population density on development of forest stands in central European Russia. Alces Supplement 2: 1-5.

Angelstam, P., P. E. Wikberg, P. Danilov, W. E. Faber, and K. Nygren. 2000. Effects of moose density on timber quality and biodiversity restoration in Sweden, Finland, and Russian Karelia. Alces 36: 133-145.

Bergerud, A. T., and F. Manuel. 1968. Moose damage to balsam fir-white birch forests in central Newfoundland. Journal of Wildlife Management 32: 729-746.

_____, _____, and H. Whalen. 1968. The harvest reduction of a moose population in Newfoundland. Journal of Wildlife Management 32: 722-728.

Bergstrom, R., and K. Danell. 1986. Moose winter feeding in relation to morphology and chemistry of six tree species. Alces 22: 91-112.

Bowyer, R. T., V. V. Ballenberghe, and J. G. Kie. 1998. Timing and synchrony of parturition in Alaskan moose: long-term versus proximal effects of climate. Journal of Mammalogy 79: 1332-1344.

Carvell, K. L. 1967. The response of understory oak seedlings to release after partial cutting. Bulletin 553. West Virginia University Agricultural Experiment Station, Morgantown, West Virginia, USA.

Degraaf, R. M., M. Yamisaki, W. B. Leak, and J. W. Lanier. 1992. New England Wildlife: Management of Forested Habitats. General Technical Report NE-144. USDA Forest Service, Northeast Experiment Station, Radnor, Pennsylvania, USA.

Faison, E. K., G. Motzkin, D. R. Foster, and J. E. McDonald. 2010. Moose foraging in the temperate forests of southern New England. Northeastern Naturalist 17: 1-18.

Governor's New Hampshire Forest Products Industry Task Force Report. 2008. <http://www.nhdfl.org/library/pdf/For-

estIndustryTaskForceReportAug.pdf> (accessed September 2009).

Heikkila, R., P. Hokkanen, M. Kooiman, N. Ayguney, and C. Bassoulet. 2003. The impact of moose browsing on tree species composition in Finland. Alces 39: 203-213.

Jacobs, R. D. 1969. Growth and development of deer-browsed sugar maple seedlings. Journal of Forestry 67: 870-874.

Leak, W. B. 2007. Accuracy of regeneration surveys in New England northern hardwoods. Northern Journal of Applied Forestry 24: 227-229.

_____, D. S. Solomon, and P. S. DeBald. 1987. Silvicultural guide for northern hardwood types in the Northeast (revised). Research Paper NE-603. USDA Forest Service, Northeastern Forest Experiment Station, Broomall, Pennsylvania, USA.

McInnes, P. F., R. J. Naiman, J. Pastor, and Y. Cohen. 1992. Effects of moose browsing on vegetation and litter of the boreal forest, Isle Royale, Michigan, USA. Ecology 73: 2059-2075.

National Oceanic and Atmospheric Administration (NOAA). 2006. National Weather Service Forecast Office Gray/Portland. <http://www.weather.gov/climate/xmacis.php> (accessed December 2010).

New Hampshire Fish and Game Department (NHFG). 2009. Wildlife Harvest Summary. New Hampshire Fish and Game Department, Concord, New Hampshire, USA.

Peek, J. M. 1997. Habitat Relationships. Pages 351-375 *in* A. W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North American Moose. Smithsonian Institution Press, Washington, D. C., USA.

Persson, I. L., K. Danell, and R. Bergstrom. 2005. Different moose densities and accompanied changes in tree morphology and browse production. Ecological Applications 15: 1296-1305.

Pruss, M. A., and P. J. Pekins. 1992. Effects of moose foraging on browse availability in New Hampshire deer yards. Alces 28: 123-136.

Renecker, L. A., and C. C. Schwartz. 1997. Food habits and feeding behavior. Pages 403-439 *in* A. W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North American Moose. Smithsonian Institution Press, Washington, D. C., USA.

Scarpitti, D., C. Habeck, A. R. Musante, and P. J. Pekins. 2005. Integrating habitat use and population dynamics of moose in northern New Hampshire. Alces 41: 25-35.

_____. 2006. Seasonal home range, habitat use, and neonatal habitat characteristics of cow moose in northern New Hampshire. M.S. Thesis. University of New Hampshire, Durham, USA.

Switzenberg, D. F., T. C. Nelson, and B. C. Jenkins. 1955. Effect of deer browsing on quality of hardwood timber in northern Michigan. Forest Science 1: 61-67.

Trimble, G. R. Jr. 1968. Form recovery by understory sugar maple under uneven-aged management. U.S. Forest Service Research Note NE- 89, Newtown Square, Pennsylvania, USA.

U.S. Department of the Interior, Fish and Wildlife Service (USFWS), and U.S. Department of Commerce, U.S.Census Bureau. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Washington, D. C., USA.

U.S. Department of Agriculture Forest Service (USFS). 2005. Land and Resource Management Plan: White Mountain National Forest. White Mountain National Forest, Laconia, New Hampshire, USA.

Westworth, D., L. Brusnyk, J. Roberts, and H. Veldhuzien. 1989. Winter habitat use by moose in the vicinity of an open pit copper mine in north-central British

Columbia. Alces 25: 156-166.

Zar, J.H. 1999. Biostatistical Analysis, 4th Edition. Prentice Hall, Inc. Englewood Cliffs, New Jersey, USA.