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Analysis of forest stands used by wintering woodland caribou in Ontario

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Abstract: Two summers' field surveys at 9 locations in northwestern Ontario showed that woodland caribou (*Rangifer tarandus caribou*) wintering areas supported jack pine and black spruce stands with low tree densities (mean 1552 trees/ha, 39% of a fully stocked stand), low basal areas (mean 14.14 m^2/ha), low volumes (mean 116 m^3/ha, 68% of Normal Yield Tables) and short heights (95% of stands 12 m or less). Ecologically, most sights were classed V30. Significantly more lichen (averaging 39% lichen ground cover) was found on plots used by caribou. Three measured areas showed few shrubs, possibly enhancing escape possibilities and reducing browse attractive to moose. An HIS model predicted known locations of caribou winter habitat from FRI data with 76% accuracy. Landsat imagery theme 3 (open conifer) produced 74% accuracy. Combining these methods permitted prediction of all 50 test sites. The low volumes of timber found in caribou wintering areas suggest that setting aside reserves for caribou winter habitat would not sacrifice as much wood product value as might at first appear.

Key words: *Rangifer tarandus caribou*, landsat, habitat, timber stands, HSI.

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Introduction

During the last 2 decades, forest managers have broadened the scope of their activities to include many uses previously ignored. Providing habitat for woodland caribou constitutes a recent challenge (Cumming, 1992). Unlike white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) which associate primarily with young stands and thus can thrive in a managed forest, caribou frequent even earlier ecological stages (moss, lichen) that paradoxically may not show up until forests are old and sometimes breaking up. Forest management for woodland caribou, therefore, involves some of the problems associated with managing old forests for other species (Cumming, 1994).

To meet these challenges, caribou biologists have often recommended that portions of the forest be reserved from cutting (Johnson *et al.*, 1977; Simpson *et al*, 1985; Ritcey, 1988; Servheen & Scott, 1988; Ministère du Forêts. Ministère du Loisir, de la Chasse et de la Pêche, 1991; Cumming & Beange, 1993; Cumming, 1994). In Ontario, some biologists (Racey *et al.*, 1992) have proposed caribou habitat management by scheduled cutting in large blocks, rather than specific reserve systems, but this scheme also requires delaying wood harvesting of occupied winter habitat until alternate habitat becomes available. The situation is made more urgent by the finding that only about 1800 woodland caribou remain in the commercial forests of Ontario (Cumming, in press).

These considerations raise important questions for those who wish to manage forests to retain caribou winter habitat: what kinds of forest do woodland caribou inhabit in winter? What losses of wood products can be expected if cutting in caribou wintering areas is deferred? Can potential winter habitat be predicted? To answer these questions, we applied standard forest mensuration techniques, augmented by lichen and sighting surveys, to 9 caribou wintering areas known from previous aerial surveys to be frequented by caribou (Cumming & Beange, 1987). We then proposed a habitat suitability index (HSI) for predicting potential caribou habitat in forest planning.

Study areas

The Royal Commission on the Northern Environment (1980) describes the area around Lake

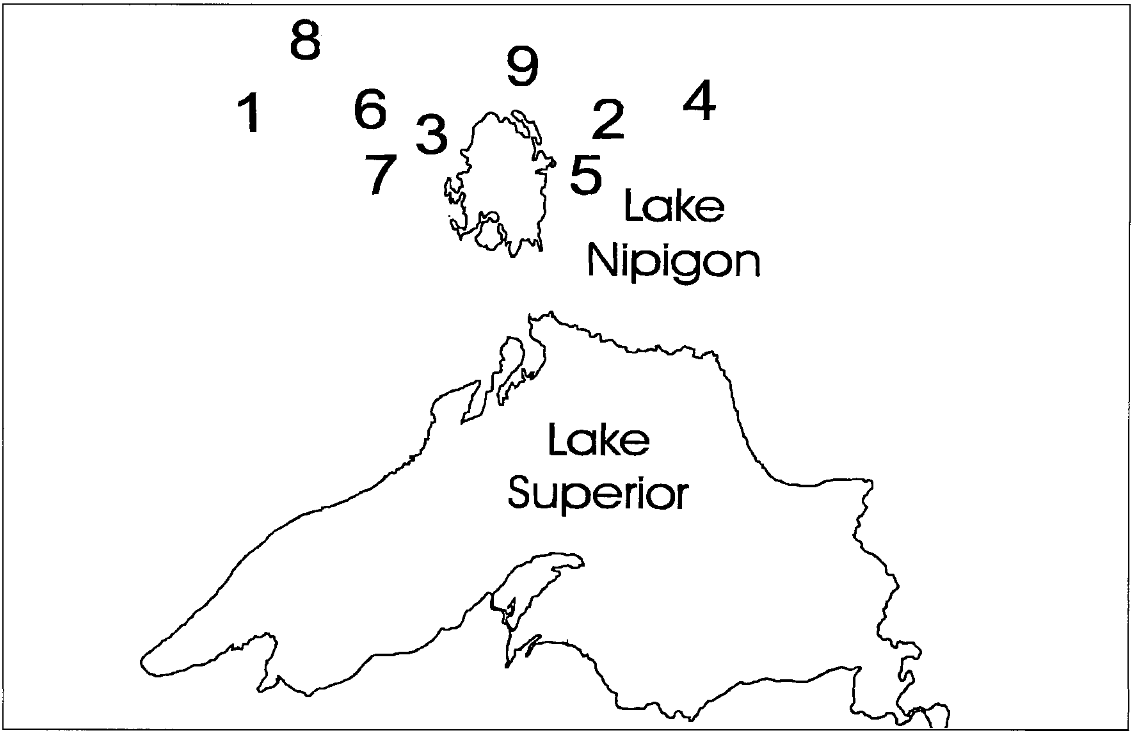

Fig. 1. Locations of study areas relative to Lake Nipigon, in the order they were examined. Location code: 1 Elf Lake, 2 O'Neil Lake, 3 Armstrong Old, 4 Molison Lake, 5 Crocker Point, 6 Armstrong North, 7 Armstrong South, 8 Wabakimi Lake, 9 Lamaune Lake.

Nipigon (from Wabakimi Lake to Molison Lake, Fig. 1) as Canadian Shield made up of granitic rock partially covered by lacustrine sediments and the occasional ground moraine. The mean daily temperature for January is - 19.5 °C. Snow covers the ground for 160 to 200 days of the year. The area receives 160 to 280 cm of snow fall annually. During the years in which surveys determined locations of caribou for this study, maximum snow depths ranged from 35 to 65+ cm (Cumming & Beange, 1987).

Nine study areas were chosen from results of earlier research that documented locations of wintering areas over 4 winters by telemetry and aerial mapping of tracks (Cumming & Beange, 1987) . Four of the chosen areas had been used by caribou all 4 winters; 2, 3 winters; 1, 2 winters; and 2, 1 winter (Fig. 1). The Lamaune Lake study area was clear-cut in 1963, and another area at Springwater Creek that had been selectively logged in part during World War II and in part during 1980 was investigated for lichen regeneration only. All other locations supported virginal stands in the boreal forest zone (Hosie, 1973). The study areas represent the southern limits to the range of woodland caribou in the Lake Nipigon area (Cumming & Beange, 1987).

Methods

To learn what signs of caribou winter use looked like in summer, we marked, during February, 1980, winter feeding craters south of Armstrong and revisited them the following May. We then measured horizontal and vertical distribution of trees in the 9 locations during the summer of 1980. When a wintering area was chosen to be sampled, its boundaries were located on a map and on aerial photographs. The following sample design was used in all areas studied. Three transect lines (400 m long and 100 m apart) were laid out on the photos before the area field work commenced. The starting point was randomly located. Lines were established at right angles to the topography, both to provide for representative sampling and to minimize the need for slope corrections. Each line consisted of 14 sample plots, 10 m long and 20 m apart. This sampling intensity was chosen because it met the guidelines of the Ontario Ministry of Natural Resources

(OMNR) for sampling vertical transects (Ontario Min. Nat. Res., 1980), based on Bickerstaff (1961). Therefore, each study area contained 3 lines with 14 vertical sampling plots and 42 corresponding ground lichen and caribou usage plots. The only exception to this sampling design was at Lamaune Lake where access difficulties reduced sampling to 10 plots located 30 m apart on a single transect across the stand.

Up to 6 collection and analyses strategies were employed at each location. Ontario Forest Resources Inventory (FRI) data were collected (Ontario Min. Nat. Res., 1978) for a detailed description of caribou wintering areas. Vertical distributions of trees were measured using the vertical transect method described by Husch *et al.* (1982). Briefly, this method involves the tally by height class and species of all trees subtended by a vertical angle of 45 degrees. The sampling is carried out on a continuous strip with observations at right angles to the line of travel. Intensity of sampling varied with the size and heterogeneity of the stand. We sampled 100 m/ha, a rate that had been found suitable in the boreal forest (Day, pers. comm.), and agreed with suggestions by Husch *et al.* (1982).

Horizontal profiles of the forest stands were examined in conjunction with the vertical transect sampling, following Avery (1967) and Husch *et al.* (1982). We followed their recommendation in using a small BAF prism (2 m^2) to reduce possible bias. From the horizontal sampling results stand descriptions similar to those used by FRI were developed.

In 1992, we re-assessed these areas using the newly developed Northwestern Ontario Forest Ecology Classification (NWO FEC) for standardization of ecological site characteristics (Sims *et al.*, 1989). Ten plots were located in each of 8 measured locations. V-type plots (NWO FEC) were located at 30 m intervals along the sampling transects. The descriptions of the various vegetation types found in Stocks et al. (1990) were used to confirm the site assessments. Crown closure was estimated from the ground in accordance with the guidelines and charts provided by Sims et al. (1989).

In addition to the forest stand sampling, ground lichen and caribou usage were also measured as follows: (1) 10 - 1 m^2 plots were located along the line used for vertical stand sampling; (2) plots 1, 5, 10, were "framed" using 4 - 1 m sticks and then occularly assessed for the percentage of ground lichen; (3) evidence of woodland caribou winter use, including pellet groups, browsing, antlers, and bush thrashed trees, were recorded on each plot. Although arboreal lichens may be important to caribou in some places, summer efforts at evaluating use proved too inaccurate for further pursuit, and arboreal lichens were not included in this study.

Visual sighting measures, and lichen regeneration quadrat data were also collected in the summer of 1992. To help assess rhe impacts of these wintering conditions on the caribou themselves, and to obtain a rough measure of shrub availability, visual sighting measures were taken in conjunction with the NWO FEC plots at Crocker Point, O'Neil Lake, and Molison Lake. An 8 1/2" by 11" aluminum clipboard was held at breast height (1.3 m) at the plot centre. This height was chosen because it is the approximate height of a caribou's eye (Godwin, 1990). In each case, we recorded the distance along the transect line at which the clipboard could no longer be seen. If the distance was greater than 30 meters it was recorded as 30+ m. Comparative measures in fully stocked mature black spruce stands were taken near Shebandowan Lake, 100 km west of Thunder Bay, Ontario.

Due to wide interest in times required for lichen to grow again after trees are cut, the Lamaune Lake study area was examined for lichen regeneration 30 years after harvesting. In addition, the cut areas at Springwater Creek were examined on the ground in 1980 and 1992. During the second visit, we ran a transect line through each of the 2 cut-overs (12, 50 years old) at right angles to their common boundary. In each cut area, we established 10 sampling stations spaced 5 m apart, and at each station we measured 2 side by side plots, 1 m^2 in size.

We built our HSI model on FRI data because of their wide availability. Our model was derived from HSI models for moose in the Lake Superior Region (Allen *et al.*, 1987) and for woodland caribou year round habitat in Saskatchewan (Yurach *et al.*, 1991). To test the predictive ability of the FRI stand descriptions against known wintering areas, we obtained stand descriptions for "good habitat" values from the habitat suitability index model and then attempted to locate similar sites in the forest.

Another approach was made possible by Timmermann (pers. comm.) who provided Landsat imagery for Northwestern Ontario that had been developed, analyzed and summarized into 15 possible themes (for forest fuel analysis) for fire management. The Landsat MSS data with a 50 m resolution were corrected to UTM co-ordinates and a supervi-

Table 1. Forest Resources Inventory descriptions, Forest Ecosystem Classifications, and lichen ground cover percentages on 9 locations where caribou repeatedly concentrated during winter.

Survey location[a]	Plots showing use by caribou (%)	FRI Description Working Group	Age (m)	Height closure	Crown Class	Lichen ground cover (%) Site by caribou	Plots used[b] by caribou	Plots not used
1	31	Pj	90	11	40	4	43.1[c]	13.7
2	33	Sb	60	6.5	50	3	27.3	0.6
3	21	Pj	70	18	60	2	50	22.7
4	36	Pj	98	15.1	40	3	30.9	1.9
5	26	Sb	90	12	40	2	24.5	1.9
6	40	Pj	65	13.2	80	3	41.6	31.5
7	40	Pj	65	13.2	80	3	63.1	8.9
8	26	Sb	87	11.4	50	3	24.8	2.1
9	60	Sb	25	4.2	40	3	45.6	29.1
Mean	35		72	11.6	53		38	12
S. D.	11		22	4.2	0.17		12	12

[a] Area code: 1 Elf Lake, 2 O'Neil Lake, 3 Armstrong Old, 4 Molison Lake, 5 Crocker Point, 6 Armstrong North, 7 Armstrong South, 8 Wabakimi Lake, 9 Lamaune Lake.

[b] Signs indicating caribou use of a plot included pellet groups, browsing, antlers, and brush-thrashed trees.

[c] We used original data because square root, logarithmic and arcsin transformations did not substantially improve normality plots.

sed classification was performed to produce 15 forest fuel classes by the OMNR. The dates of the imagery ranged from 1976 to the mid- 1980's. The classified data (data which had already been analyzed into specific classes or themes) were downloaded onto a Sun workstation. The accuracy and reliability of forest fuel mapping by Landsat was checked by contacting the OMNR fire control centres in Thunder Bay and Sault Ste. Marie, Ontario. The only testing available was operational. The mapping system worked very well and met operational requirements (Mr. Turner & Mr. Checkley , OMNR fire control officers, pers. comm).

Test sites for these approaches were located in the vicinity of Wabakimi Lake, Ontario, where winter use by woodland caribou was well documented. Fifty locations where winter activity(feeding craters, telemetry locations, track aggregations, and visual sightings) had been observed were chosen from 8 winter surveys of caribou activity from 1978- 1984 and 1989-1991 (no surveys were conducted from 1985-1988, Gollat, pers. comm.) to compare with FRI data and Landsat theme areas.

Results

Three of the 9 surveyed wintering areas were situated on deep sand, the remainder on bedrock. Eight of the 9 were of fire origin. The NWO FEC class V 30 (Jack Pine-Black Spruce/Blueberry/Lichen) described a portion of every study area (half were entirely V30), totaling to 86% of the plots. Class V31 (Black Spruce-Jack Pine/Tall Shrub/ Feathermoss) occurred with V30 on 1 study area (6% of the plots), and V 32 (Jack Pine-Black Spruce/Ericaceous Shrub/Feathermoss) on another (5%). Class V 28 (Jack Pine/Low Shrub) shared an area with V30, V 32 (1%), and V 34 (Black Spruce/Labrador Tea/Feather moss) with V30, V 31 (1%). Non-V30 areas were usually located on water catchments between humps of exposed bedrock, where the slope difference was often sufficient to change the classification on the 10m x 10m sample plots. The mean estimated crown closure (from the ground looking up) was 25% (S.D.=10). Ground cover consisted of 33% (S.D.=18.08) feathermoss (*Pleurozium schreberi* and *Dicranum polysetum*) and 52% (S.D.=20.80) ground lichens (*Cladina* spp.). For further details see Antionak (1993).

Working groups (based on most common species) classed 5 study areas as jack pine, 4 as black spruce. Ground surveys using Ontario's FRI classes indicated that ages of fire-origin stands ranged from 60-98 years (Table 1); the sole harvest-origin stand at Lamaune Lake was 30 years old. Apart from Lamaune Lake (height 4.2 m) heights ranged from

Table 2. Vertical distribution (stems/ha) of all tree species by area and height class compared with Plonski's (1981) Normal Yield tables.

Area	3m	6m	9m	12m	15m	18m	Total	Normal Yield Table[a] Values (stems/ha)
1	619	329	442	127	90	16	1623	3584
2	1302	627	138	28			2095	5140
3	250	56	151	190	283		930	1611
4	1310	645	907	240	2		3106	3673
5	516	552	809	369	3		2249	3099
6	158	83	90	105	237	71	744	3490
7	143	48	190	335	128		844	1815
8	333	492	796	433	16		1981	4020
9	190	119	85				394	9495
MEAN	536	328	401	228	108	44	1552	3992
S.D.	439	241	325	132	106	28	834	2194

[a] Plonski (1981).

6.5-15.1 m. Forest site classes ranged from 2-4, crown closure from 40-80%. Within each study area, plots showing winter use by caribou comprised a mean of 35% (range 21 to 60) .

Vertical distribution of the forest

Descriptions of forests include vertical and horizontal measurements. Measures of vertical distributions showed that all trees were relatively short (Table 2), with no stands reaching the height-over-age ratios required to be included in site class 1 (Plonski, 1981). Overall, 99.9% of the trees were in the 15 m height class or less, and 95% in the 12 m height class or less. Vertical distribution surveys showed no significant difference between rhe used and unused plots (t=1.71, df=8, P>0.1). Therefore all plots within each study area were combined for an overall description of the area (Table 2). Species composition within each study area and between study areas showed no significant differences (t=0.32, df=16, P>0.5; t=.59, df=16, P>0.5). All stands were black spruce and jack pine mixed stands. Other species within the study areas included white birch, trembling aspen (*Populus tremuloides*), larch (*Larix laricina*) and balsam fir (*Abies balsamea*). None of these, nor any combination in total, constituted more than 5% of the stems in any of the study areas. When stems per ha by height class and study area were tested, the ANOVA showed no significant difference between study areas (f=1.411, df=8, 45, P=0.2181) but, as suspected, a highly significant difference among height classes within study areas (f=5.82, df=5.40, P=0.0004).

Vertical distribution of total stems per ha (Table 2) on the plots compared with values from Normal Yield Tables (Plonski, 1981) showed study areas always with fewer stems per ha (t=2.75, d.f. 8, P<0.05) averaging 38.8% of a fully stocked stand. Woodland caribou winter in a range of stem densities which are significantly fewer than fully stocked stands (Table 2).

Horizontal distribution

Differences in horizontal distribution between plots with signs of caribou and those with no evidence of use were not significant (t=1.32, df=8, P>0.2). Therefore the data from these categories were amalgamated (Table 3). Only 1.7% of the total volume was composed of species other than black spruce or

Table 3. Horizontal distribution: volume/ha by species.

Area	Black Spruce m^3/ha	Jack Pine m^3/ha	Others m^3/ha
1	71.06	21.18	3.31
2	51.59	4.31	
3	15.22	128.48	
4	169.03	5.79	
5	129.96		8.35
6	19.91	97.27	
7	16.28	92.53	
8	142.4	5.94	2.1
9	37.01	28.38	
Mean	72.5	47.99	4.59
S.D.	56.2	46.71	2.34

Table 4. Horizontal distribution (volume) and basal areas of plots used by caribou in winter compared with those not used and with normal tables by Plonski (1981).

Location	Volume (m^3/ha)			Percentage of normal volume (Plonski, 1981)
	Caribou sign		Total Volume	
	Present	Not present		
1	51	85	94	61
2	75	42	56	72
3	137	150	144	48
4	93	219	175	71
5	99	178	138	56
6	188	109	117	59
7	116	164	109	55
8	100	179	150	97
9	32	54	65	98
Mean	99	131	116	
S. D.	43	58	37	

Location	Basal area (m^2/ha)			Percentage of normal yield (Plonski, 1981)
	Caribou sign		Total Basal Area	
	Present	Not present		
1	11.3	11.7	12.2	51
2	9.7	10.9	10.7	54
3	16	16	9.6	37
4	9.3	26.3	20.7	87
5	12.7	21.7	17.2	50
6	22	12.6	17.6	78
7	13.5	19.2	13.3	59
8	12.7	14.7	18.7	64
9	5.3	21.7	7.2	51
Mean	12.5	17.2	14.1	
S. D.	4.4	5	4.4	

jack pine. An ANOVA showed no significant difference in volume between study areas (f=1.248, df=8, 117, P=0.2774) but a highly significant difference between diameter classes within study areas (f=7.528, df=13, 104, P=0.0001). This is to be expected with the larger volumes occurring in the upper diameter classes. Total volume per ha from all study areas, compared with volumes from Normal Yield Tables (Plonski, 1981), showed that the study areas would yield significantly lower volumes than expected (t=3.91, df=8, P<0.01). On average they supported 68% of the volume listed as Normal Yield Tables (of the same site class) and ranged from 48% to 98% of the table volumes (Table 4).

Basal areas did not differ significantly (t=1.68, df=8, P>0.05) between plots showing usage and those that did not (Table 4). The basal areas for study locations when were significantly lower (t=6.42, df=8, P<0.01) than those from the Normal Yield Tables (Plonski, 1981). The study areas had a mean basal area of 14.14 m2/ha which is less than the mean table value of 24.00 m2/ha. The differences ranged from 37% to 87% below the table values.

Caribou signs revealed a highly significant tendency to occupy plots with a greater coverage of lichen (t=6.54, df=8, P<0.001). The average percent of ground covered in lichen in plots that showed caribou usage was 39% (S.D.=12.4) compared with a covering of 12% (S.D.=11.7) in the unused plots.

Visual sighting measures

Standard forestry measurements do not indicate thickness of understory, therefore, at 3 study areas

Table 5. Lichen regeneration quadrats in 50+ year old and 12 year old cutover stands at Springwater Creek.

Plot no.	Percentage of plot covered with lichens			
	Old Cutover		Recent Cutover	
	Quadrat 1	Quadrat 2	Quadrat 1	Quadrat 2
1	80	70	60	30
2	60	80	0	0
3	10	0	0	0
4	10	40	0	0
5	5	15	0	0
6	40	10	0	0
7	0	0	0	0
8	80	50	0	0
9	30	60	0	0
10	0	0	0	0

special measurements were taken of sighting distances. Mean visual sightings from 10 measurements in each location were 22.4 m (S.D. 8.2), 24.3 m (S.D. 7.0), and 19.2 m (S.D. 5.4). Ten of the 30 determinations showed visibility beyond 30 m. Since no significant differences were found within locations (ANOVA F=1.226, df=2, 27, P=0.309), they were combined to calculate a mean visual distance of 22.0 m (S.D. 7.3), which proved to be significantly (t=4.76, df=38, P<0.001) longer than in the unused spruce forest, mean of 10.8 m (S.D. 1.9), with which it was compared

Regeneration of lichen

Caribou use had been recorded in parts of a stand along Springwater Creek in 1979 that was clear-cut in 1980. Subsequently, neither aerial surveys (Cumming & Beange, 1987) nor ground inspections showed further use by caribou. Our ground surveys in 1992 found that 12 years after the 1980 cutting, lichens grew in only 10% of the plots. In the 50 years following the 1940's selective logging, 80% of the 20 plots had established ground lichens (Table 5).

Assignment of HSI values

In forming an HSI equation we assumed that lichen is the key to winter stand usage (see discussion by Cumming, 1992). The HSI values, then, rate the ability of FRI descriptors to predict the likelihood of ground lichen. The overall HSI value for each stand is determined by multiplying all variable HSI values together, as follows:

HSI (overall) =
((species comp. HSI)(site class HSI)(age HSI)(crown closure HSI))$^{1/4}$

The variables were multiplied because any 1 variable has the potential to decrease the positive attributes of all other variables when indexing stands for potential wintering areas. The product was then taken to the quadratic root to eliminate the effect of 4 multiplicand decimal multiplication. As a result, HSI overall values fall between 0<>1.0. Potential woodland caribou habitat can then be rated on a scale: 0-0.33 poor; 0.34-.066 fair; and 0.67-1.0 good.

With the equation in place, results of the field research were used to assign values. Maximum HSI values for species age, crown closure, composition, and site class were based on the authors' data and the findings of Racey *et al.* (1992). Zero values were omitted because a single 0 would make the overall HSI value 0, and there is always a chance that a caribou can be anywhere. The major change points were derived from the results of this study and from other values in the literature. Survey results suggested that stand age values should be assigned as follows: from first establishment, when little or no lichen would be present, 0-20=0.01 (mid-range value, Fig. 2). When a stand is first being established there is little or no lichen and therefore a very low value is assigned 0-20=0.01(mid-range value), medium age 20-60=0.5 (mid-range value), mature forest, when lichen availability would be high 60-100=1.0, and older stands that would have a diminishing amount of lichen over time 100-150=(mid-range value) 0.75 (Fig. 2a).

Stands ranging from no crown closure to the development of a canopy would be very young and were rated as 0-10%=0.5 (mid-range value). Maximum lichen growth requires an open canopy, therefore 10%-70%=1.0. As the canopy closes the amount of lichen decreases wirh the corresponding values 70%-100% = (mid-range value) 0.45 (Fig. 2).

Species composition was expressed as total percentage of jack pine and black spruce in the stand. HSI considerations follow. Since no caribou winter activity was found in mixed stands, a low value was assigned to them 0 - 70% = (mid-range value) 0.025. The constrainrs of timber mapping often demand that small pockets of deciduous trees be included in what would otherwise be a pure conifer stand. As the conifer component (suggesting a dry

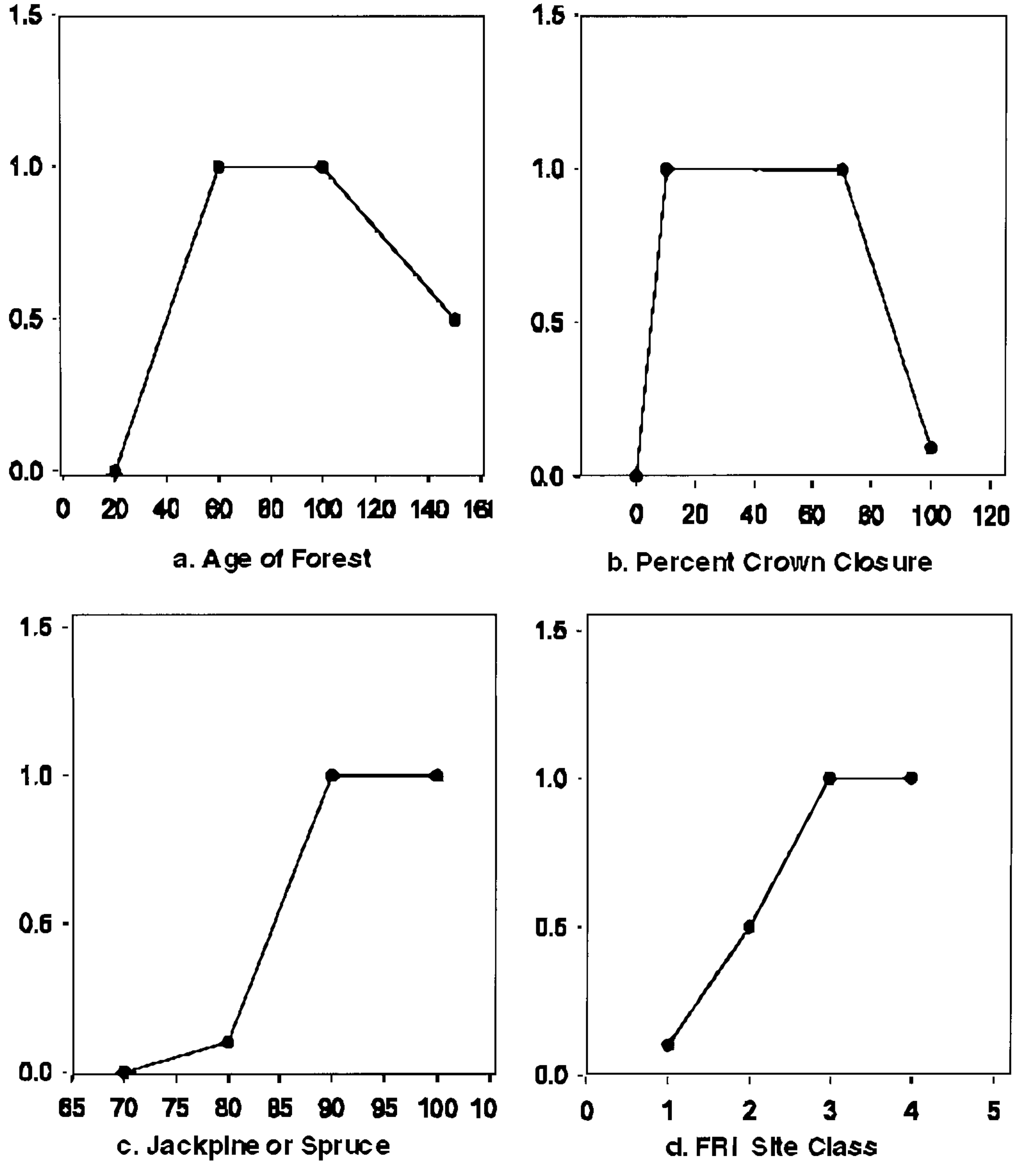

Fig. 2. HSI relationships for places where woodland caribou winter in Ontario. HIS scales are on the verticle axes.

site) increases there is an increase in the likelihood of lichen presence (Sims et al 1989) and the following values were assigned: 70%-80%=0.05 (mid-range value), and 80%-90%=0.45 (mid-range value). Pure conifer stands were currently being used, thus they were given the highest rating 90%-100%=1.0 (Fig. 2c)

Site classes based on the relationship of tree height over age (Plonski, 1981) are affected by the moisture and nutrients available on a site. The lower the site class the drier or poorer the site which makes it more suitable for lichen. Since no caribou were found in site class X or 1 they were assigned the lowest values: X and 1= 0.1. Since 2 of the 9 study areas were site class 2 they were assigned a medium value 2= 0.5. The remaining site classes, 3 and 4, made up 78% of the study areas and were given the highest values 3=14=1.0 (Fig. 2d)

Tests of FRI Data and Landsat Imagery

Use of the HSI model with FRI data predicted 38 of the 50 known caribou winter areas. In a total area of

516 000 ha for which Landsat imagery was available, 107 000 ha (21%) was water, 346 000 ha forested land. In the latter, 22% was classified as theme 3, which predicted 37 of the 50 locations correctly. However, these were not all the same locations as predicted with FRI. When both approaches were combined, the known caribou-use stands were predicted 50 times out of 50.

Discussion

Answers to our questions were obtained from our results. Caribou chose mainly V30 type forests for winter habitat (a finding that supports Morash & Racey, 1990), and our FRI data confirmed this conclusion. Horizontal distribution analysis showed low basal areas and volumes, modest densities, and relatively short heights (95% are 12 m or less), all characteristics that tend to make the stands of little interest economically. Maximum recovery of wood products would be no more than 2-3 m-sawlogs per tree from the tallest trees in the stands. Even so, the quality would be low. Poorly stocked stands produce trees that are heavily limbed with tapering trunks (Stoddard, 1978), factors that reduce their value as sawlogs. Near Armstrong, the forest might be economical to harvest because of existing road access and the flat sandy country which allows for low harvest costs. But even here low wood volumes might make individual stands unmerchantable.

The distribution of trees across a number of height classes suggested that these uneven aged stands (overstory of shade intolerant jack pine, understory of black spruce), once cut, might be difficult to replace. To insure the return of a similar forest, the slash would have to be spread across the site to distribute the serotinous and semi-serotinous cones so that heat near the ground would open them (Burns, 1983). This action would simulate regeneration after fire better than planting and would leave lichen on site. Sims *et al.* (1990) suggest a rotation age of 70 to 80 years on low growth jack pine and black spruce stands, but this would entail harvesting during the peak period of caribou benefits. For caribou, the rotation age should be extended to over 100 years.

The HSI model might have a number of uses. It could be combined with a GIS digitized FRI map to locate potential woodland caribou wintering areas and to predict how changes in forest stand composition would affect woodland caribou winter habitat. The latter might be expanded to model changing forest conditions on computer GIS programs as the forest is "grown" and "harvested", permitting managers to see compare presenr inventory with predicted consequences management action. Since high HSI value stands indicate correspondingly low economic worth, concentrations of high HSI stands might suggest a candidate places for non-timber management objectives, such as park land or wildlife areas. However, this was a first attempt at such a model and the HSI values assigned to the variables may require modification for different areas. Other variables such as predation and snowfall could be added to further define the winter habitat of woodland caribou.

The value of the described stands to the caribou remains speculative, but we suggest some possibilities. The finding of significantly more lichen on plots used by caribou supports the suggestion that lichen presence may represent a benefit. Lichen growth is limited by the amount of sunlight that reaches the ground. Hale (1961) estimated that lichens contain between 10% and 25% the chlorophyll of regular plants, and thus require large amounts of sunlight for growth. Apparently the amount of sunlight in the study area stands was sufficient for fruticose lichens. The mean density of 1552 trees per ha allowed a 39% lichen ground cover; the maximum value obtained of 3106 trees per ha still showed 31% lichen cover. Yet Moore and Vesrspoor (1973) found that tree densities between 3080 and 4840 per ha constituted a transition range between lichen and moss as ground cover, and suggested that a mid-point of 3960 per ha might be the limiting density for lichen growth. Furthermore, Rencz & Auclair (1978) in northern Quebec found that a mean black spruce density of 556 trees per ha resulted in a 97% ground cover of lichen. Thus, the densities of trees in our study areas may be near the maximum that lichen can tolerate.

Few lichens were recorded 12 years after logging but some lichen was present after 30 years and heavy lichen regeneration was present on sites selectively cut 50 years ago. Although the sample is small results agree with Carrol & Bliss (1982) in northern Saskatchewan who found successful lichen regeneration 45 years after fires. Rencz & Auclair (1978) in northern Quebec reported 47 years. In northwestern Ontario, Webb (pers. comm.) and Harris (1996) observed that lichen regeneration may be sooner after logging than by fire, because the lichen is already on the site and does not have to re-invade the site. Racey *et al.* (1996) found caribou using stands 40 years after logging, in the same area.

If these stands are near their maximum, why do caribou not move to more open areas? Perhaps there is a difference between lichens on the ground and lichens available to caribou. Conifer forest canopy reduces the hardness and thickness of snow cover (Schaefer & Pruit, 1991) when compared with open sites. Caribou move into these stands in the winter because of the more favourable snow conditions (Darby & Pruit, 1984). Therefore these low density conifer areas produce lichens which are easier to access for food in winter. The range of height distributions within our study locations may alter snow conditions during different times of winter and in different years, and such a range may provide optimal feeding throughout the winter and over a series of different winters. Choosing a specific canopy density may not provide the best winter habitat for all snow conditions. An overhead canopy which is open enough to allow lichen growth in the summer yet closed enough to reduce ground snow depths is may be the optimum.

Another possible benefit from these forest stands might relate to the observed lack of shrubs and good visibility. The 3 measured areas showed almost total lack of shrub understory to block ground vision, a condition that might have several benefits: the ground is not shaded allowing good lichen growth; caribou should be able to detect predators (wolves) more easily; and, caribou escape will not be hindered by understory. The lack of shrubs in these areas also suggested a reduction of amounts of browse available for moose. Allen *et al.* (1987), modeling moose habitat, calculated that a moose would require 3 kg of browse per day in concentrated patches to survive. Although browse volumes were not measured in this study, it seems doubtful that our study locations would grow such browse densities; these areas would probably not support many moose in the winter (Harry, 1957; Dodds, 1960; Telfer, 1974; Crete & Bedard, 1975; Miquelle & van Ballenberghe, 1989).

Implications for management

The low volumes of timber found in this study suggest that setting aside reserves for winter caribou habitat would not sacrifice as much wood product value as might at first appear. Cumming & Beange (1987) found that caribou wintering areas totaled 5-9% of whole forests. These stands on average supported only 68% of normal yield. Therefore, the loss in wood product value from reserving these stands might be in the neighbourhood of 3-6% of total volume. Loss of dollar values from these volumes should be further reduced since the timber values of stands being used as wintering areas by woodland caribou are not high. Seventy-eight percent of the stands studied were either site class 4 (protection forest, which is already set aside from harvesting) or site class 3 which is the most fragile and least productive of the merchantable stands. The stands are slow growing, low density, and on dry, fragile sites (sand and bedrock) that would be hard or impossible to regenerate to fully stocked stands. Considering the low product value, the cost of harvesting trees of low densities would make these stands economically marginal at best. Managing such stands for caribou management purposes might require that the areas being removed from production because optimizing regeneration and growth would not be in the best interests of caribou winter habitat production.

Managing forests for caribou may require optimizing lichen production while retaining a suitable canopy to reduce snow depths and hardness. At the same time, it appears that the stands should have an open canopy and understory to allow for predator detection and escape, and to reduce browse supplies that might attract alternate prey for wolves. Harvesting of natural stands should not occur during the peak lichen period between age 60 to 100 years. Yet later harvesting might be better than no harvesting. It may return the areas to winter habitat for caribou in a shorter time than natural fires, and may accelerate lichen regeneration, but further studies are needed to ascertain if adequate crown closure can be developed to coincide with peak lichen development. The wintering areas would require a range of canopies to provide adequate micro- winter habitat to allow for changing snow conditions.

Forest harvesting in known wintering areas should occur only in locations where caribou have alternate habitat away from the disturbance. Erikson (1975) recommends winter harvesting to reduce lichen disturbance and provide arboreal lichens for food, but these factors may be outweighed by the negative aspects of winter disturbance. In our view, harvesting should be carried out in late summer to reduce poaching and road kills, to eliminate plowed winter roads providing easy access for poachers and wolves, and to minimize impacts on other birds and mammals that might result from harvesting during the spring reproductive period (Telfer, pers. comm.).

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