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# Effects of Progressive Clearcut Logging on Newfoundland Caribou

JAMES A. SCHAEFER,<sup>1</sup> *Biology Department, Trent University, 1600 West Bank Drive, Peterborough, ON K9J 7B8, Canada*

SHANE P. MAHONEY, *Newfoundland and Labrador Department of Environment and Conservation, P.O. Box 8700, St. John's, NF A1B 4J6, Canada*

**ABSTRACT** Logging has often been implicated in the decline of caribou (*Rangifer tarandus*), but its effects are incompletely understood. We used a distance-based approach to assess the effects of progressive clearcut logging on the summer (28 May to 15 Sep) range of caribou in Newfoundland, Canada. We compared distances of random locations and of caribou, from 9 years of radiotelemetry, to landcover types across 3 spatial scales: population range, individual ranges, and radiolocations. We tested for incremental avoidance of cutovers and mature softwood forests, the preferred type for caribou and forest harvesting, while controlling for the confounding effects of each. At the individual range, females selected for hardwood and softwood forests, bogs, and barrens, and they avoided open water. Patterns for males were similar, although they avoided bogs and barrens at both scales. The sexes differed in their response to forest harvesting. Females progressively avoided cutovers, both pre- and postharvest, likely due to their spatial proximity. Females maintained an average of 9.2 km from active cutovers. Cutover avoidance was evident even if we controlled statistically for distances to other habitats, and it accounted for heightened disuse of softwood forests. Compared with females, males occurred in proximity, with no incremental response to clearcutting. These results imply deleterious effects of timber harvesting on female caribou. Long-term investigations will enhance our capacity to evaluate such anthropogenic habitat changes. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):1753–1757; 2007)

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**KEY WORDS** correlated landscape, forestry, habitat selection, logging, *Rangifer tarandus*, spatial scale.

Loss of habitat is the primary agent driving species toward endangerment and extinction (Wilcove et al. 1998). Not surprisingly, therefore, anthropogenic effects on wildlife have frequently been assessed through the prism of habitat selection. For example, the effects of forest harvesting and other range alterations on reindeer and caribou (*Rangifer tarandus*) have been examined as differential use of affected versus nonaffected areas (Dyer et al. 2001, Mahoney and Virgl 2003) or as changes in animal distribution after impact (Smith et al. 2000, Nellemann et al. 2001, Mahoney and Schaefer 2002). The wide-ranging habits of species such as caribou demand long-term studies across vast areas. Such research is still rare (Nellemann et al. 2003, Noel et al. 2004, Cameron et al. 2005), however, and the effects of logging on *Rangifer* are not fully understood (Chubbs et al. 1993, Smith et al. 2000).

A distance-based approach to habitat selection (Connor and Plowman 2001, Connor et al. 2003) offers a way to tease out the effects of anthropogenic landscape change. This framework, still rarely used, is founded on the distances of animals to all habitat categories, in contrast to most conventional analyses, which assign each animal location to only one habitat class. The method entails computing the distance between locations of interest (i.e., representing habitat use and availability at some scale) and the nearest representative of each habitat type. Because proximity of each location to each kind of landscape feature is known, the approach is explicitly multivariate, and distances to each habitat type represent multiple response variables. Therefore, one can control statistically for unwanted variation.

Drawing on this approach, we described the habitat selection and evaluated the effects of clearcut logging on

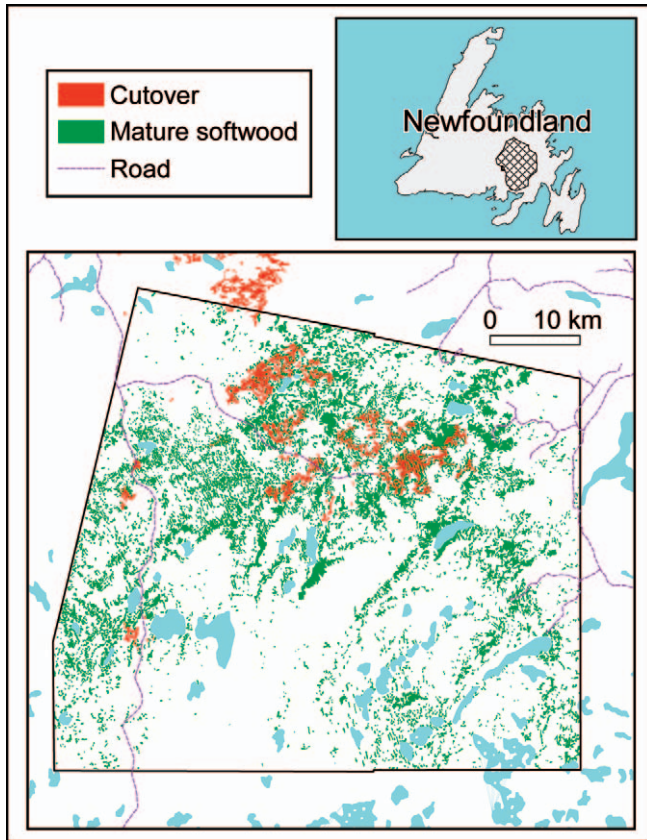
migratory caribou, the Middle Ridge herd of Newfoundland, Canada (Fig. 1). We applied the framework to both males and females, based on 9 years of radiotelemetry, during progressive logging of their summer range. We focused on late May to mid-September when the fate of young is largely determined (Mahoney et al. 1990, Adams et al. 1995). In our study area, mature softwood forests were the preferred habitat type for both loggers and caribou (Chubbs et al. 1993). We predicted, therefore, that negative effects of forest harvesting would be manifest as progressive avoidance by caribou to cutovers, and, only coincidentally, to softwood forests. We used distances to cutovers as covariates in our model to test this second hypothesis. Finally, because of the differing selection pressures between the sexes—minimizing predation risk for females and their young (Fancy and Whitten 1991, Bergerud 1996) and optimizing feeding for males (Chubbs et al. 1993)—we anticipated greater sensitivity by females to cutovers.

## STUDY AREA

The study area, in east central Newfoundland, Canada, encompassed the traditional summer range of the Middle Range caribou herd (Fig. 1; Chubbs et al. 1993). The herd has habitually undertaken a short migration, overwintering on barrens in the southern portion of their range. The summer habitats consisted forests of balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), and white birch (*Betula papyrifera*) as well as bogs containing stunted black spruce and tamarack (*Larix laricina*). Lakes, ponds, heaths, and barrens were common. Human access was limited primarily to the northern segment of the range where roads facilitated forest harvesting and supported most of the hunting activity.

We identified vegetation types from Landsat thematic mapping of 2,700 km<sup>2</sup> from 31 July 1987 (Chubbs et al.

<sup>1</sup> E-mail: jschaefer@trentu.ca



**Figure 1.** Study area of the Middle Ridge caribou herd, Newfoundland, Canada, 1995, highlighting mature softwood forests and cutovers. The herd's annual range is depicted as a hatched area.

1993). We subjected the imagery to a supervised maximum-likelihood classification that delineated 16 classes. Following Chubbs et al. (1993), we combined similar types, encompassing most of the study area, into fewer classes: 1) bogs and barrens, open habitats characterized by *Kalmia* barrens and *Scirpus-Sphagnum* bogs, 2) recent burns, forests burned since 1986, 3) dead and dying softwood, forests dominated by balsam fir and black spruce, killed by severe infestations of spruce budworm (*Choristoneura fumiferana*) or hemlock looper (*Lambdina fiscellaria*), 4) hardwood, stands primarily of white birch and alder shrubs (*Alnus* spp.), 5) softwood, mature forest stands dominated by old black spruce, and 6) water, denoted by numerous ponds and lakes. Clearcutting generally occurred between June and November each year. We updated the classification annually by superimposing new cutovers onto the classified image from forest company maps (Fig. 1).

The Middle caribou herd grew after 1960 to an estimated 20,958 animals in 1995, followed by decline to 14,981 animals in 2003 (S. P. Mahoney, Newfoundland and Labrador Department of Environment and Conservation, unpublished files). Licensed hunting commenced in the early 1970s, and, by the late 1990s, approximately 1,100 caribou were harvested each year. Potential natural predators included black bear (*Ursus americanus*) and lynx (*Lynx canadensis*). Wolves (*Canis lupus*) were extirpated from Newfoundland circa 1922, but coyotes (*Canis latrans*) arrived on the island in 1985 and preyed on both adult

and young caribou. Moose (*Alces alces*), an introduced species, were common in forests.

## METHODS

### Data Collection and Preparation

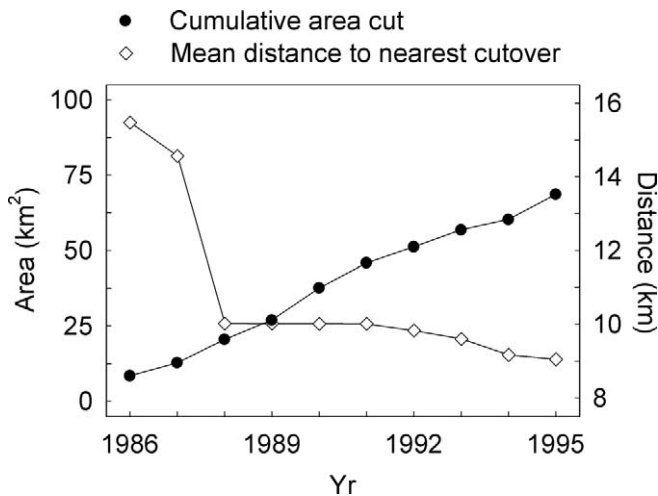
We conducted radiotelemetry tracking of yearling and adult caribou from 1987 to 1995. We chemically immobilized animals and fitted them with mortality-sensing very high frequency radiotransmitters (Lotek Engineering, Newmarket, ON, Canada) having a battery life expectancy of 48 months. We carried out radiotelemetry reconnaissance approximately fortnightly by airplane, although more frequently during summer. Radiolocations had an accuracy of  $\leq 500$  m based upon repeated blind-test positioning of dummy (haphazardly placed test) transmitters.

Our analysis included radiolocations between 28 May and 15 September within the limits of the Landsat imagery (Fig. 1). During this time of year, 91% of all telemetry locations occurred within these bounds. For most tests, because of the staggered entry and variable duration of observations of each animal, we treated the animal-year as the sampling unit. We included any animal-year with  $\geq 6$  radiolocations. This furnished 176 animal-years (from 46 F) and 61 animal-years (from 24 M), with an average of 14.4 radiolocations per animal-year (range = 6–23). The number of radiotracked animals per year varied from 7 to 28 (F) and from 3 to 13 (M).

We framed habitat selection as differences between resource use and availability across 3 nested spatial scales: 1) the population range, the minimum convex polygon (MCP) around radiolocations within the study area, 2) individual ranges, the MCPs around radiolocations for each animal-year within the population range, and 3) radiolocations within each individual range. We represented availability by the adjacent scale, one rank up in this spatial hierarchy (Schaefer and Messier 1995). We analyzed males and females separately.

We applied the distance-based approach (Connor and Plowman 2001, Connor et al. 2003). The technique involves measuring the distance from each animal location as well as from random locations, to the nearest representative of each habitat class. We assigned points within a habitat polygon a distance of zero. In the case of higher scale entities (i.e., individual and population ranges), we generated many random points—sufficient to stabilize the average distance to habitats—from a uniform random distribution. For clearcuts, we computed distances to the ultimate edge of each cutover (i.e., at the end of the yr), even when forest harvesting was ongoing and the impacted area was increasing in size. Clearcuts were typically small ( $< 300$  m in breadth); we expected any bias from within-year variation to be negligible.

We generated 5,000 random points within our study area. The mean distance to habitats at this scale seemed to stabilize at 2,000 points. Of this total, 3,267 points fell within the population range of males; 3,970 points fell within the population range of females; and, on average, 269 points fell



**Figure 2.** Expansion of clearcutting on the Middle Ridge caribou range, Newfoundland, Canada, 1987–1995, expressed as changes in area and average distance of random points in the study area to nearest cutover.

within each individual range. At the levels of population and individual ranges, we determined mean distances to each habitat from the random points within the appropriate MCP.

### Statistical Analyses

To test for habitat selection, we applied *t*-tests (rather than ratios; Connor et al. 2003) to the differences between use and availability for each habitat category. At the larger scale (random points within the population range vs. random points within individual ranges), we treated the mean distance for the population range as a parameter, and we used 1-sample *t*-tests. At smaller scale of analysis (random points within the individual ranges vs. radiolocations), availability was unique to each case. Here, *t*-tests were paired.

To test for effects of clearcutting, we used analysis of variance (Quinn and Keough 2002), where year of radio-tracking was the class variable and distances from radiolocations to habitat types and clearcuts of each year (regardless of whether they had yet occurred) were the response variables. Because we predicted progressive movement away from softwood forests and clearcuts, we analyzed differences between years as planned, linear contrasts. First, we tested for incremental avoidance of cutovers using all age classes simultaneously (with multivariate analysis of variance [MANOVA]) and each age class individually (with analysis of variance [ANOVA]). Second, to account for the potential

confounding effect of habitat, we repeated the MANOVA by entering distances to habitat types as covariates. Third, we tested for progressive avoidance of softwood forests (with ANOVA). Finally, to control for the effects of cutovers, we repeated this ANOVA by entering distances to cutovers as covariates. We analyzed each sex separately.

We set  $\alpha = 0.05$  to balance the risks of type 1 versus type 2 errors, even for multiple comparisons. Type 2 errors are a concern in studies of habitat selection (Marcum and Loftsgarden 1980) and conservation biology (Caughley and Gunn 1996). We conducted analyses using MapInfo 5.0 (MapInfo Corp., Chicago, IL) and Statistica '99 (StatSoft Inc., Tulsa, OK).

## RESULTS

Forest harvesting on the summer range of Middle Ridge caribou, expressed as area, occurred at a relatively consistent rate (Fig. 2). Total clearcutting averaged 6.7 km<sup>2</sup> per year (range = 3.4–10.6 km<sup>2</sup>). In contrast, the mean distance to cutovers changed dramatically. A sharp decline took place in 1988, coincident with the expansion of forestry into previously untouched parts of the study area. By 1995, random points occurred, on average, 9.1 km away from the nearest clearcut, a decrease from 15.5 km in 1986.

Landscape features, both natural and anthropogenic, were spatially correlated. Based on distances from random points within the study area, cutovers of different age classes, 1987–1995, were strongly and positively associated ( $0.413 < r < 0.986$ ). Distances of random points to softwood forests were also positively correlated to distances to cutovers originating in these same years ( $0.079 < r < 0.319$ ).

Caribou demonstrated the most intense selection for habitats at the scale of the individual range (Table 1). Some patterns were consistent between the sexes: selection for mature softwood, dead and dying softwood, and avoidance of water. The strongest divergence between males and females occurred in the case of open habitats. Females selected for bogs and barrens at the scale of the individual range, whereas males exhibited consistent avoidance of this open habitat. Females selected for hardwoods; males did not. Within the individual range, patterns were less pronounced. At this finer scale, only selection for recent burns and avoidance of bogs and barrens by males was evident (Table 1).

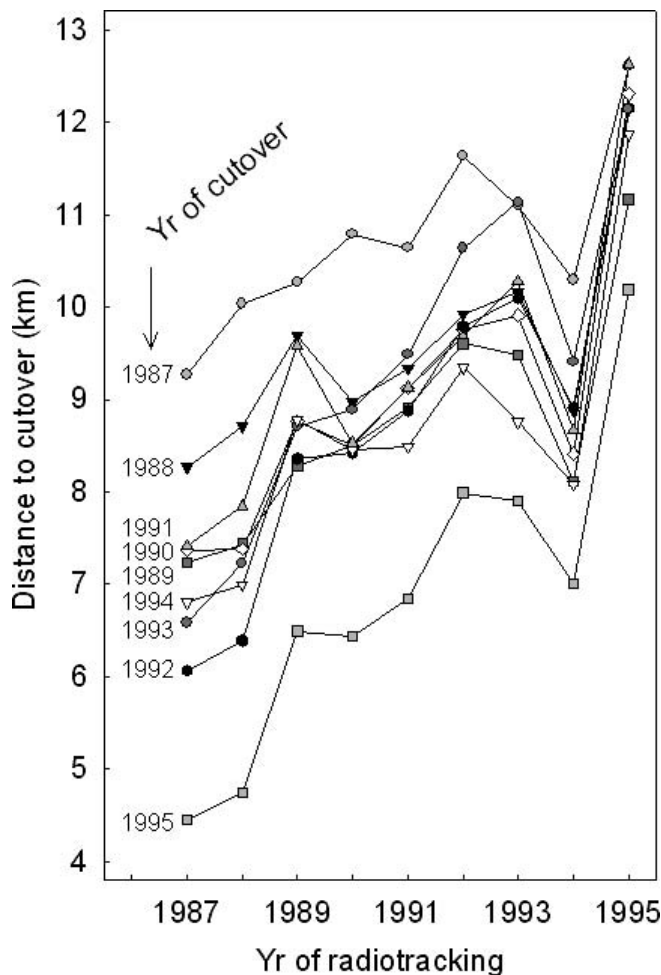
Females exhibited progressive avoidance of cutovers even prior to harvesting (Fig. 3; Wilk's  $\lambda = 0.864$ ,  $df = 9,159$ ,  $P < 0.005$ ), and this trend persisted when we entered distances

**Table 1.** Average distance (m) to landcover classes across spatial scales by male and female Middle Ridge caribou, Newfoundland, Canada, 1987–1995.

Sex	Scale	Bogs and barrens	Recent burns	Dead and dying softwood	Hardwood	Mature softwood	Water
F	Population range <sup>a</sup>	218*	2,016	2,188*	2,144*	402*	967*
	Individual ranges <sup>a</sup>	199*	2,082	1,342*	1,569*	262*	1,102*
	Radiolocations	203	2,008	1,351	1,508	264	1,065
M	Population range <sup>a</sup>	218*	2,128	1,806*	1,917	347*	967*
	Individual ranges <sup>a</sup>	251*	2,023*	1,567*	1,843	210*	1,221*
	Radiolocations	275*	1,685*	1,531	1,797	202	1,247

<sup>a</sup> We determined values for population and individual ranges from random points.

\* Adjacent scales are significantly different ( $P < 0.05$ ).



**Figure 3.** Mean distance of female Middle Ridge caribou to nearest cutover of each age class, Newfoundland, Canada, 1987–1995.

to other habitats as covariates (Wilk's  $\lambda = 0.844$ ,  $df = 9,153$ ,  $P < 0.002$ ). This avoidance was significant for each cutover age class ( $F_{1,167} > 3.93$ ,  $P < 0.05$ ; all tests) with the exceptions of 1989 ( $F_{1,167} = 3.70$ ,  $P = 0.056$ ) and 1994 ( $F_{1,167} = 3.32$ ,  $P = 0.070$ ), which were marginally significant. There was remarkable consistency among years in the distance to active cutovers with an average ( $\pm$ SE) of  $9.23 \pm 0.33$  km ( $n = 9$ ; Fig. 3). Females also exhibited apparent, progressive disuse of mature softwood habitat during the study ( $F_{1,167} = 3.81$ ,  $P = 0.053$ ), but this trend disappeared once we entered distances to cutovers as covariates ( $F_{1,158} = 0.112$ ,  $P = 0.739$ ).

Males differed sharply from females in their response to clearcutting. Over the course of the study, males showed no propensity for change in the proximity to cutovers (Wilk's  $\lambda = 0.764$ ,  $df = 9,44$ ,  $P = 0.173$ ), nor was there any significant variation in use of mature softwood forests ( $F_{1,52} = 0.324$ ,  $P = 0.571$ ). Compared with females, the mean distance of males to active clearcuts ( $7.78 \pm 1.06$  km;  $n = 9$ ) was substantially lower and more variable across years.

## DISCUSSION

Our study adds to the mounting evidence of deleterious effects of timber harvesting on caribou (Chubbs et al. 1993,

Cumming and Hyer 1998, Smith et al. 2000, Fisher and Wilkinson 2005). Females of the Middle Ridge herd avoided cutovers, even several years before clearcutting (Fig. 3). These displacement patterns may have stemmed from the spatial associations among cutovers, from road construction and block layout before cutting, and lagged effects after habitat alteration (Schaefer and Pruitt 1991). Shifts in calving distribution in *Rangifer* also may be driven by numerical increases and depletion of high-quality forage (Bergerud 1996). Although we cannot entirely discount such density dependence, the pattern of progressive cutover avoidance by females was persistent, even when we controlled statistically for all other habitat types.

Caribou are associated with mature coniferous forests (Klein 1982, Schaefer and Pruitt 1991, Terry et al. 2000, Joly et al. 2003). The importance of these habitats to Middle Ridge caribou was underscored by selection at the broader scale of the individual range (Table 1; Rettie and Messier 2000). Both sexes selected for old softwood forests, although females tended to be associated with bogs and barrens, whereas males avoided them. This may represent differing selection pressures between the sexes, that is, for females and their young, the minimization of predation risk (Fancy and Whitten 1991, Bergerud 1996, Rettie and Messier 2000, Mahoney and Virgl 2003), and, for males, enhanced foraging and reduction in insect harassment (Chubbs et al. 1993). In our study area, Graham (1992) reported that tabanid fly abundance tended to be lowest in cutovers and on forest access roads.

Like our study, most other assessments of anthropogenic effects on reindeer and caribou range have focused on changes in occupancy across space (Nellemann et al. 2000, Dyer et al. 2001, Mahoney and Virgl 2003, Johnson et al. 2005) or time (Smith et al. 2000, Nellemann et al. 2001, Mahoney and Schaefer 2002, Noel et al. 2004). These reactions are presumed to translate into demographic effects. Less often have impairments to the survival or reproduction of *Rangifer* been demonstrated (Nellemann et al. 2003, Wittmer 2004, Cameron et al. 2005) due to the difficulties of inferring effects on such a long-lived, mobile animal.

The avoidance response by female caribou is consistent with the effects of other human landscape changes on *Rangifer*, where diminished occupancy within 1–5 km is common (Dyer et al. 2001; Nellemann et al. 2001, 2003; Mahoney and Schaefer 2002; Cameron et al. 2005), although not universal (Noel et al. 2004). Such avoidance can be even higher, up to 10 km, for females (Nellemann et al. 2000). Smith et al. (2000) surmised an avoidance zone for both sexes of as much as 11 km from cut blocks. Chubbs et al. (1993) reported that Middle Ridge females, displaced away from cutovers, showed heightened selection for softwood forests. In contrast, over the course of our study, we found a tendency toward declining use of these forests, an apparent consequence of cutover avoidance. Unlike other studies of caribou–forestry interactions conducted during winter (Cumming and Hyer 1998, Smith et al. 2000), our focus was late spring and summer when calf survivorship is in the balance (Mahoney et

al. 1990, Adams et al. 1995) and the sensitivity to disturbance may be at its peak (Johnson et al. 2005).

## MANAGEMENT IMPLICATIONS

The continuing appropriation of woodlands implies a narrowing scope for caribou to avoid impacted areas. Nevertheless, for a given level of habitat alteration, aggregating disturbances rather than scattering them across the landscape is likely to help mitigate the effects on forest-dwelling caribou. This strategy would represent a considerable challenge in Newfoundland, where merchantable stands of timber are often dispersed. Reconciliation of forest exploitation with the conservation of forest-dwelling caribou will be a major challenge for the 21st century (Schaefer 2003).

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