Woodland caribou calf recruitment in relation to calving/post-calving landscape composition

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Abstract: Since the 1990s, Newfoundland's woodland caribou (*Rangifer tarandus caribou*) population has declined by an estimated 66%. Low calf recruitment has been associated to the decline, possibly triggered by increasing calf predation and/or decreasing resources. To investigate the role of landscape composition in this system, we studied the yearly (2005-2008) calving/post-calving range (CPCR) of 104 satellite-collared females belonging to six herds. We mapped nine disturbance factors (e.g. roads, logging, etc), as well as vegetation cover types (e.g. coniferous, deciduous forests, etc), and determined the total area they occupied within CPCRs yearly for each herd. Using an information theoretic approach, we assessed the model that best explained variation in recruitment using these components. Based on corrected Akaike Information Criterion, the model that best explained variation in calf recruitment included total disturbance and deciduous forest area, both showing the expected negative relationship with calf recruitment. Other landscape variables among the models with $\Delta AIC_c < 2$ were mixed forest, also with a suggested negative relationship, and barrens and wetlands with a significant positive trend. This study highlights the need to minimize total disturbance footprint and account for resulting changes in forest composition within CPCRs during land use planning. Expanding forestry operations and road infrastructure in critical woodland caribou habitat across Canada may additionally contribute to habitat loss via fragmentation. This in turn, may lead to range recession beyond the initial local avoidance footprint. We see the possibility of using calf recruitment models based on landscape parameters, among others, to predict the impact of new industrial developments on calf recruitment.

Key words: avoidance; disturbance; habitat; industrial development; Newfoundland; logging; post-calving range; *Rangifer tarandus caribou*; calf recruitment.

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Introduction

Canada loses an average 50 000 hectares of forest per year due to land development, not including the additional areas temporarily disturbed by forest harvesting or fires (Natural Resources Canada, 2009). If these disturbances occur within the home range of sensitive wildlife populations, the associated habitat loss and fragmentation effects may lead to range recession, associated changes in population dynamics, and eventually population declines (Channell & Lomolino, 2000). The resulting changes in habitat type may also support more generalist predators, who may add additional pressure to the sensitive wildlife species through spill over exploitation (Crête & Desrosiers, 1995). For woodland caribou (*Rangifer tarandus caribou*), who require mature coniferous forests (Rettie & Messier, 2000; Mahoney & Virgl, 2003), the amount of habitat physically lost through disturbance is only exacerbated when

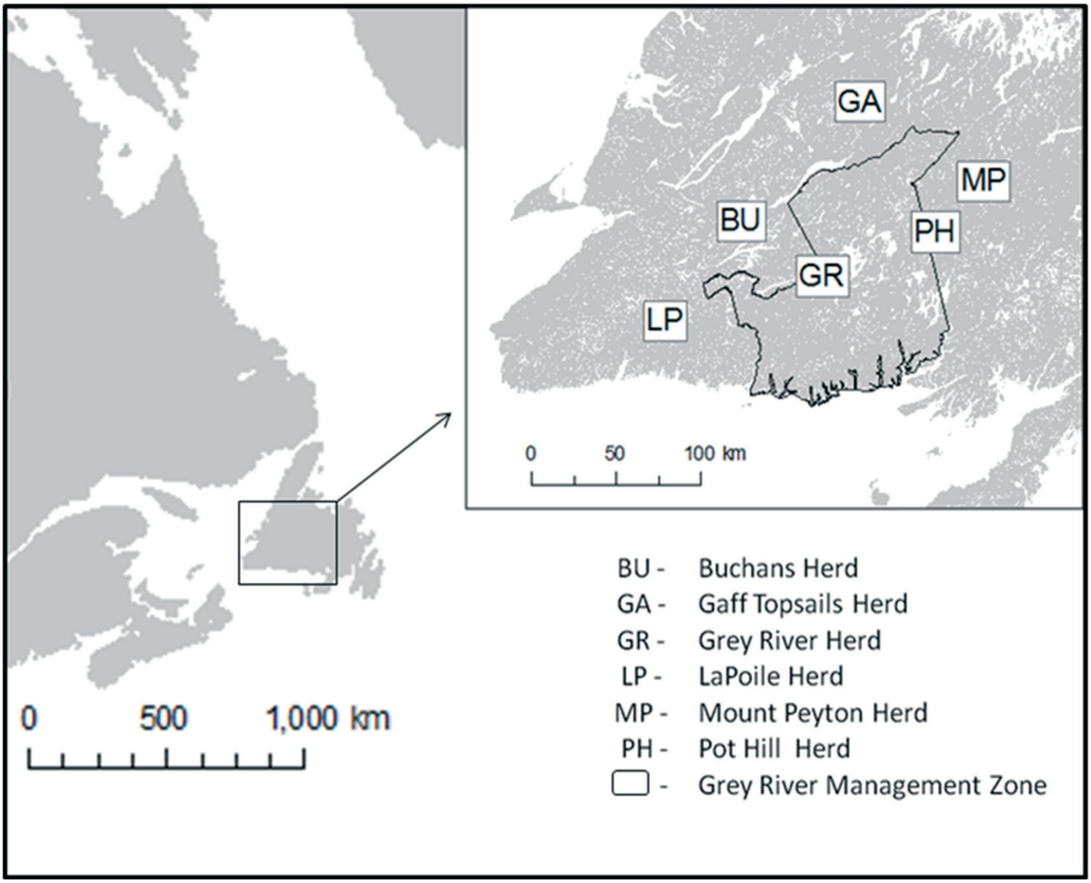

Fig. 1. Study area in central Newfoundland, Canada. Inset shows general location of the female calving/post calving range of six study caribou herds from 2005-2008. Outlined region in the inset represents the Grey River Management Zone, within which caribou hunting is prohibited.

we consider the additional loss via avoidance behaviours (Chubbs *et al.*, 1993; Rettie & Messier, 2000; Courtois *et al.*, 2007; Vors *et al.*, 2007). Indeed, habitat loss limits resource acquisition and predator avoidance, potentially impacting caribou population dynamics.

Research has concentrated on woodland caribou habitat selection, and has typically examined movement patterns and habitat use (e.g., Chubbs *et al.*, 1993; Rettie & Messier, 2000; Gustine & Parker, 2008; Hins *et al.*, 2009). Only a few studies have focused on direct relationships between habitat composition and vital rates (Nellemann *et al.*, 2003; Wittmer *et al.*, 2007; Sorensen *et al.*, 2008). These studies have found that anthropogenic disturbance (e.g. logging), fires, and associated early seral stage forests can be negatively related to both survival and reproduction. Such expansions beyond the common behavioural-type examinations of movement and habitat-use may be increasingly informative from a population-management perspective.

Monitoring has revealed that caribou calf recruitment (calves/100 adult females) is in decline in Newfoundland, and that the population has accordingly declined by 66% since the 1990s (Mahoney *et al.*, 2008). Development has continued to spread across the island during this time; forestry, hydroelectric, mining, recreation, and transportation developments are all additive disturbance factors that have impacts differing across space and time. Combined with natural forest fires, these habitat alterations may hinder calf survival by fostering strong female avoidance behaviours (Dyer *et al.*, 2001, Schaefer & Mahoney, 2007; Weir *et al.*, 2007), which can create higher caribou densities (Nellemann & Cameron, 1996), higher predation rates (James & Stuart-Smith, 2000; Wittmer *et al.*, 2005a), and reduced forage availability (Weladji & Forbes, 2002; Mahoney & Virgl, 2003; Gustine & Parker, 2008).

Our goal was to assess the relationship between calf recruitment and landscape composition for woodland caribou herds in Newfoundland, focusing on the calving/post-calving range (CPCR). Within CPCRs, we quantified landscape composition as the area occupied by total disturbance and vegetation types, and assessed their relationships with the calf recruitment of 6 herds over 4 years. We predicted that total disturbance area would be negatively related to calf recruitment. Among vegetation types, preferred habitats (coniferous forest, barrens, and wetlands) were expected to display a positive trend with calf recruitment (Mahoney & Virgl, 2003; Schaefer & Mahoney, 2007; Hins *et al.*, 2009). Conversely, commonly avoided habitats (deciduous and mixed forests) were predicted to have a negative association with calf recruitment (Mahoney & Virgl, 2003; Wittmer *et al.*, 2007; Hins *et al.*, 2009). Finally, we searched for the model that best explained woodland caribou vital rates in relation to total disturbance and vegetation type areas within CPCRs.

Material and methods

Study area

The study was conducted in the CPCR of six caribou herds across Newfoundland's interior (Fig. 1). The majority of the rugged landscape has been shaped by ice scour and glacial deposits, creating lowlands with many streams, lakes, and ponds and elevations reaching 815 m. The area is extensively covered in forests of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea)* with dense moss (*Hylocomium* spp.) carpeting the forest floor (Daaman, 1983). CPCRs were composed of an average of 31.3% coniferous forest, 15.4% wetlands, 13.7% barren ground, 10.8% shrub land, 10.1% water, and 7.9% other, including deciduous forest, herbs, mixed forest, snow, rock, and shadow. The climate is characterised by cool summers and winters with annual precipitation varying between regions (<1000 mm).

Newfoundland's woodland caribou are of the sedentary ecotype, and hence undergo smaller seasonal migrations than barren ground caribou (Bergerud, 1996). During the calving/post-calving season, mature coniferous forests are highly preferred for food resources and predator avoidance, especially in disturbed landscapes (Bergerud, 1972; Chubbs *et al.*, 1993; Mahoney & Virgl, 2003). Movement is minimal during this season (Mahoney & Schaefer, 2002); resulting in relatively small CPCR ranges (Mahoney & Virgl, 2003).

Caribou calf predators in this region include coyotes (*Canis latrans*), black bears (*Ursus americanus*), lynx (*Lynx canadensis*), and bald eagles (*Haliaeetus leucocephalus*). Wolves (*Canis lupus*) were once present on the island but were extirpated around 1922 (Allen & Barbour, 1937). In 1985, the canine threat returned with the coyote's range expansion into Newfoundland (Mahoney & Schaefer, 2002). Moose (*Alces americanus*) were introduced to the island in 1904, and have since reached densities as high as four individuals/km^2 (McLaren *et al.*, 2004). Licensed caribou hunting is open from September to December except within the Grey River management zone (Fig.1). Clear-cut forest harvesting has been ongoing since the 1920s in the west, and has spread across the interior.

Table 1. Disturbances found to impact *Rangifer*, associated references, their main finding, and the sources of the files we used to map each factor along with their estimated accuracies (m).

Factor	Reference	Documented Effect	Map Source	Accuracy
Agricultural Land	(Apps & McLellan, 2006)	Negative association with caribou persistence	Dept. of Natural Resources, Forestry Division, Gov. NL.	<20
Recreation Facilities	(Dumont, 1993; Forbes *et al.*, 2001; Nellemann *et al.*, 2001; Anttonen *et al.*, 2011)	Reduced time feeding, Increased densities in non-disturbed areas, Reduced forage availability, Population fragmentation	Dept. of Environment and Conservation, Crown Lands Division, Gov. NL.	<50
Cutovers	(Chubbs *et al.*, 1993; Smith *et al.*, 2000; Schaefer & Mahoney, 2007; Hins *et al.*, 2009)	Used less than expected, Avoided by 1.2km, Avoided by females by 9.2km, Used less than expected.	Dept. of Natural Resources, Forestry Division, Gov. NL.	<20
Exploratory Drilling	(Bradshaw *et al.*, 1997; Bradshaw *et al.*, 1998)	Reduction in body mass, Displacement	Dept. of Natural Resources, Geological Survey of Newfoundland and Labrador, Gov. NL.	<100
Fires > 200ha	(Chubbs *et al.*, 1993; Rettie & Messier, 2000; Dunford *et al.*, 2006; Gustine & Parker, 2008; Sorensen *et al.*, 2008)	Used less than expected, Avoided, Reduced lichen abundance, Avoided, Negative effect on population growth	Canadian Large Fire Database 2009, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.	Unknown
Power Lines	(Vistnes *et al.*, 2001; Nellemann *et al.*, 2003; Apps & McLellan, 2006)	Increase densities in non-disturbed areas, Decrease in density around power lines, Negative association with caribou persistence	Newfoundland and Labrador Hydro	Unknown
Quarries	(Weir *et al.*, 2007; Anttonen *et al.*, 2011)	Displacement up to 4km and reduced group size within 6km	Quarry Management System, Dept. of Natural Resources, Mineral Lands Division. Gov.NL.	<10
Railways	(Nellemann *et al.*, 2001; Simpson & Terry, 2003; Apps & McLellan, 2006)	Population fragmentation, Displacement, Negative association with caribou persistence	Dept. of Environment and Conservation, Parks and Natural Areas Division. Gov. NL.	GPS data <2 CanVex data <100
Roads	(Schindler *et al.*, 2007; Nellemann & Cameron, 1996; James & Stuart-Smith, 2000; Dyer *et al.*, 2001; Vistnes *et al.*, 2001; Nellemann *et al.*, 2001; Cameron *et al.*, 2005; Apps & McLellan, 2006)	Loss of quality habitat within 1km, Decreased use within 4km, Elevated predation, Decreased use within 500m of roads, Increased density in non-disturbed area, Decreased density close to roads, Population fragmentation, Displacement and population split, Decreased caribou persistence	Geobase®, National Road Network. Dept. Environment and Conservation, Forestry Division, Gov. NL.	<10

Data collection

Between 2005 and 2008, 104 adult female caribou were captured from helicopter using either aerial darting with Carfentanil citrate (3mg/ml Carfentanil at 25 μg/kg reversed with 50 mg/ml Neltrexone at 2500 μg/kg; Canadian Association of Zoo and Wildlife Veterinarians, 2009), or net gunning, and fitted with Argos Satellite collars (Lotek Engineering Systems, Newmarket, Ontario, Canada). Collaring took place during winter months when snow made caribou easier to locate and capture. Health Canada approved the capture and collaring protocol under experimental studies certificates 60021 and 60022. The collars were scheduled to record a location every 4 days. Based on calving dates and calf vulnerability, locations recorded between 1 June and 31 October were chosen to represent the CPCR. To reduce the positional error associated with collar locations, only records with error margins of class 2 (<500 m) or better were used (Lotek Engineering Systems, Newmarket, Ontario, Canada). The resulting 6557 locations (32 ± 7.26 female/herd/year ± SE), belonging to an average of 9 ± 1.30 females per herd/year ± SE, were mapped using ArcGIS 9.3 Geographic Information System (ESRI Inc., Redlands, California, USA). The annual CPCRs of individual collared females were then calculated as the 95% Minimum Convex Polygon (MCP; Mohr, 1947) using the Home Range extension for ArcGIS 9.3 (Rodgers *et al.*, 2007).

A disturbance factor was considered to be any anthropogenic or natural factor affecting the landscape that had been previously associated with caribou avoidance, population decline, or increased predation in the literature. Nine disturbance factors were identified, and yearly maps for each factor were obtained from several sources (Table 1). Disturbance factors were mapped in ArcGIS 9.3 (ESRI Inc., Redlands, California, USA). Human-generated disturbances were given a 250 m avoidance buffer while forest fires were left un-buffered (Sorensen *et al.*, 2008). Woodland caribou have been documented to avoid roads by up to 250 m (Dyer *et al.*, 2001), and cut blocks by 1.2 km and 10.2 km (Smith *et al.*, 2000 and Chubbs *et al.*, 1993 respectively), so a 250 m avoidance buffer was considered a conservative approach. A total disturbance layer was then created by simply merging and dissolving the buffered yearly disturbances to remove any overlap between them. The area of each female's yearly CPCR occupied by this total disturbance layer was extracted in ArcGIS 9.3 (ESRI Inc., Redlands, California, USA) and averaged annually for each herd.

To determine the vegetation types available to each caribou herd, we used raster classified LANDSAT-7 images (25-m pixels) from 2000 (Earth Observation for Sustainable Development of forests; ca. 80% pixel identification accuracy (Wulder *et al.*, 2007)). EOSD data labelled 25×25-m cells as primarily composed of one of 19 vegetation types, which we reduced to 11 by combining the different density classes of the same vegetation types. The total area of each female's yearly CPCR occupied by each vegetation type was extracted in ArcGIS 9.3 (ESRI Inc., Redlands, California, USA) and averaged annually for each herd.

We used calf recruitment rates derived from fall classification surveys to examine the relationship between landscape composition and population declines. Classifications were conducted within areas known to be occupied by each of the six herds during October or November of 2005 to 2008 by helicopter (Eurocopter AS350 Ecureuil or 206 Long Ranger). The classification crew included the pilot and two observers. The surveyed flight path was 1km wide on either side of the helicopter, and included as much open habitat as possible for ease of classification, with the assumption that population structures of caribou found in these open habitats were representative of the entire

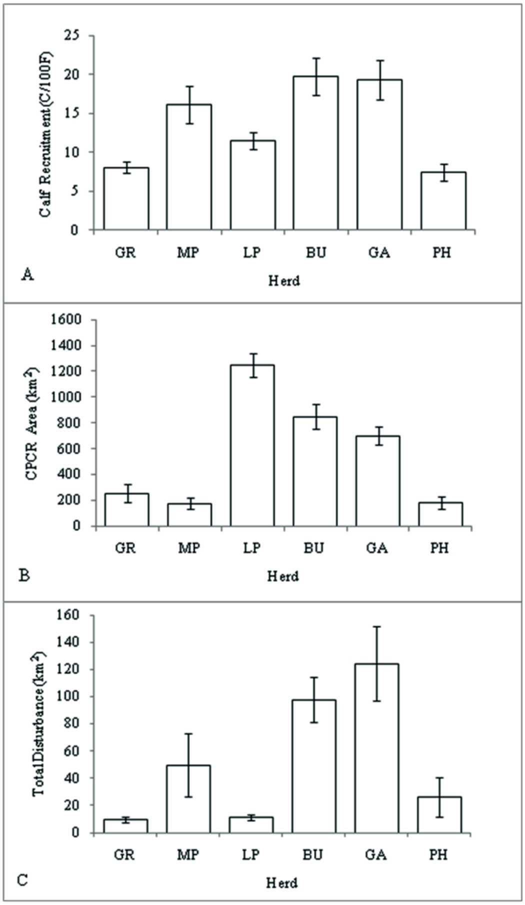

Fig. 2. Difference between caribou herds in respect to average yearly (A) calf recruitment (calves/100 adult females), (B) female's CPCR size (km^2) and, (C) total disturbance area (km^2), from 2005-2008 in Newfoundland, Canada. Error bars are 1 SE of the mean. Abbreviations for herds: gr = Grey River, mp = Mount Peyton, lp= LaPoile, bu = Buchans, ga = Gaff Topsails, and ph = Pot Hill.

population. Caribou were identified as adult/yearling/calf based on a combination of the relative body size, face length and antler presence/size, while adult females were differentiated from adult males based on the presence of a vulva patch or penis sheath (Bergerud, 1963). Calf recruitment was expressed as the number of calves per 100 adult females (Mahoney & Schaefer, 2002; Mahoney & Virgl, 2003; Schaefer & Mahoney, 2007). No classification data was available for the Grey River herd in 2005, the Mount Peyton herd in 2005, or the LaPoile herd in 2006, leaving a sample size of 21 herd/year combinations.

Statistical analysis

We first used general linear models (Proc GLM in SAS 9.1; SAS Institute Inc. Cary, NC, USA) to assess how calf recruitment, CPCR size, and total disturbance area varied between herds and years. Linear mixed models (Proc MIXED in SAS 9.1; SAS Institute Inc. Cary, NC, USA) were used to examine the relationship between calf recruitment and total disturbance or vegetation type area, between total disturbance area and CPCR size, as well as between the number of radio-relocations and CPCR size. Possible herd effect was controlled for by including herd as a categorical fixed variable in the mixed models. Because our data were from several herds being measured within the same year, we included "year" as a random term in our models to avoid pseudo-replication. Finally, we searched for the best model to explain change in calf recruitment in terms of landscape composition using an information-theoretic approach (Akaike, 1973; Burnham & Anderson, 2002; Stephens *at al.*, 2005). This was done using linear mixed model analyses (Proc MIXED in SAS 9.1; SAS Institute Inc. Cary, NC, USA) and possible model parameters included herd, total disturbance area, and 1-2 of the five vegetation type variables expected to impact calf recruitment based on findings from habitat selection literature (barrens, wetlands, and coniferous, mixed, and deciduous forest). We restricted ourselves to models with five or fewer terms to avoid over-parameterization of the models (Quinn & Keough, 2002), and vegetation types were checked for multicollinearity. Models were evaluated based on their corrected Akaike's Information Criterion (AIC_c) weight values and we report only those models with AIC_c weights > 0. For the sake of pluralism and because we were also interested in effect size, direction, and parameter precision, we report parameter estimates and their accompanying *P* values (Stephens *et al.*, 2005) for models not distinguishable from the best model (i.e. ΔAICc < 2). A *P* value < 0.05 was used to denote statistical significance.

Results

Average calf recruitment differed significantly between the herds ($F_{5,15}$ = 7.92, P < 0.001; Fig. 2A), but not between years ($F_{3,17}$ = 0.81, P = 0.51). Yearly calf recruitment ranged from 5.70 calves per 100 adult females in the Pot Hill herd up to 26.58 calves per 100 adult females in the Buchans herd.

Average CPCR area differed significantly between the herds ($F_{5,15}$ = 8.86, P < 0.001; Fig. 2B), but did not differ between years ($F_{3,17}$ = 0.59, P = 0.63). Females belonging to the Gaff Topsails and Buchans herds had CPCRs approximately 3.80 times larger than those from the Mount Peyton, Grey River, or Pot Hill herds; while females from the LaPoile herd had CPCRs 5.30 times larger. CPCR size was not significantly dependent upon the number of radio relocations ($F_{3,11}$ = 0.12, P = 0.74).

The total disturbance layer covered an average of 11.0% of CPCRs, and was composed of 40.9% roads, 37.3% logged areas, 10.3% fires, 5.4% power lines, and 6.2% other (agriculture, cabins, railway, drilling holes and quarries). Average total disturbance area within CPCRs differed significantly between herds ($F_{5,15}$ = 6.99, P = 0.002; Fig. 2C) ranging from 0.6% of the total CPCR area for the LaPoile herd to 36.9% of the total CPCR area for the Mt. Peyton herd. Total disturbance area did not vary between years ($F_{3,17}$ = 0.06, P = 0.98).

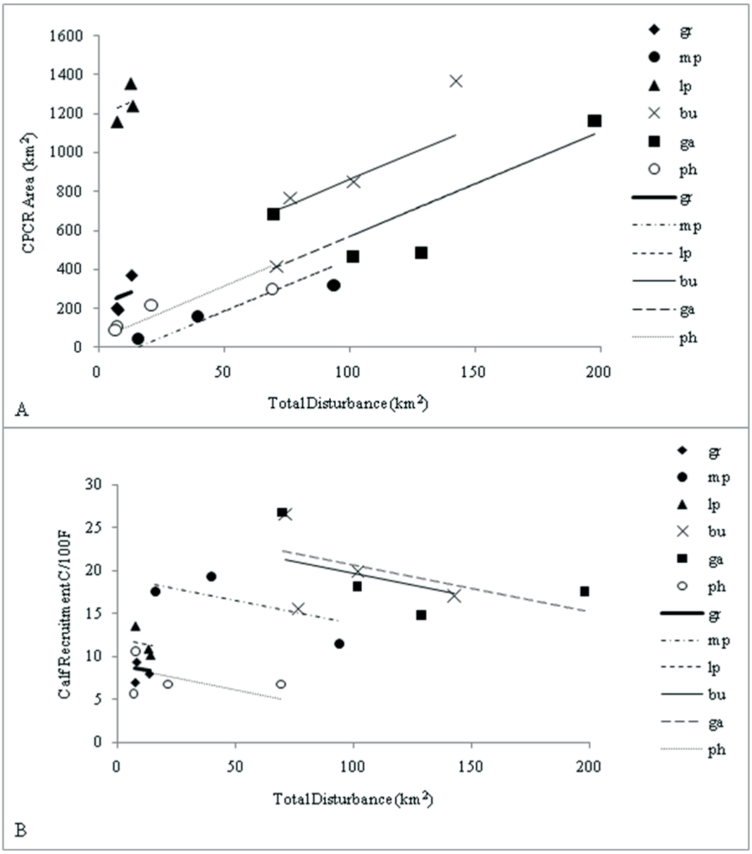

Fig. 3. Relationship between total disturbance area (km²) and (A) the average female CPCR size (km²) and (B) calf recruitment (calves/100 adult females) from 2005-2008 in Newfoundland, Canada. Abbreviations for herds: gr = Grey River, mp = Mount Peyton, lp= LaPoile, bu = Buchans, ga = Gaff Topsails, and ph = Pot Hill.

CPCR size was significantly ($F_{3,11}$ = 24.14, P < 0.001) related to disturbance level, such that CPCR size increased by an average 5.40 km² (SE = 1.18) for every additional km² of disturbed area within CPCRs (Fig. 3A). CPCRs of collared females had an average overlap of 32.05 ± 25.35% within herds.

A significant negative relationship ($F_{3,11}$ =

Table 2. AIC_c, delta AIC_c, and AIC_c weights of top selected linear mixed models among all possible models using three or less of the following landscape parameters; Abbreviations: Dist = Total Disturbance, Barr = Barrens, Coni = Coniferous Forest, Decid = Deciduous Forest, Mixed = Mixed Forest, and Wet = Wetlands. All other model combinations had more terms and/or a AICc and are therefore not included

Model	AIC_c	ΔAIC_c	$AIC_c\omega$
Dist + Decid	93.80	0.00	0.15
Dist + Mixed	94.00	0.20	0.14
Dist + Decid + Mixed	94.00	0.20	0.14
Dist + Mixed + Wet	94.60	0.80	0.10
Dist + Decid + Barr	94.70	0.90	0.10
Dist + Mixed + Barr	94.90	1.10	0.09
Dist + Barr	95.50	1.70	0.07
Dist + Coni	96.10	2.30	0.05
Dist + Decid + Wet	96.50	2.70	0.04
Dist + Wet	96.90	3.10	0.03
Dist + Coni + Decid	97.20	3.40	0.03
Dist + Coni + Mixed	97.50	3.70	0.02

7.21, P = 0.02) occurred between total disturbance area within CPCRs (km²) and calf recruitment (b = - 0.05, SE = 0.02; Fig. 3B). Of the eleven natural landcover types, mixed forest area within CPCRs (km²) was the only one that was significantly related to calf recruitment, the relationship being negative (b = - 0.35, SE = 0.14, $F_{3,11}$ = 6.08, P = 0.03).

When linear mixed models were used to examine the relationship between calf recruitment and landscape composition (while including herd as a categorical fixed variable and year as a random term in the models), AIC_c weights revealed a confidence set of 12 candidate models, i.e. models with AICc weight > 0 (Table 2). The top model included a negative effect of total disturbance area (b = - 0.05, SE = 0.02) and a negative effect of deciduous forest (b = - 0.13, SE = 0.26), and was 1.11 times more likely than the second ranked model. Plotting observed calf recruitment vs. calf recruitment as predicted by the top model gave an R^2 value of 0.81 (Fig. 4). The most prominent vegetation type variables among the models with $\Delta AIC_c < 2$ were deciduous and mixed forest, with the latter showing the expected negative, but non-significant trend with calf recruitment (b = - 0.14, SE = 0.21). Barrens and wetlands were also within $\Delta AIC_c < 2$, displaying the expected positive trend with calf recruitment (b = 0.05, SE = 0.02 and b = 0.07, SE =0.03 respectively).

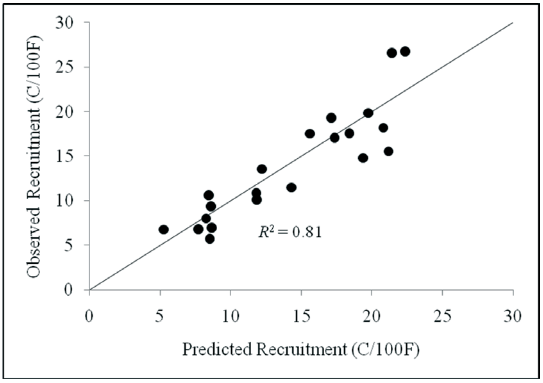

Fig. 4. Observed calf recruitment (calves/100 females) from 2005-2008 in Newfoundland, Canada, versus calf recruitment (calves/100 females) as predicted by top AIC_c ranked linear mixed model (accounting for herd) with year as a random term; recruitment = herd + total disturbance + deciduous forest. The line represents where the points would lie if the model fit the observed calf recruitment perfectly.

Discussion

In general, caribou populations with greater than 15% young in the total population (at 6 -10 months after calving) are expected to be in growth phase (under low hunting pressures) (Bergerud, 1992). Converting our calf recruitment results to percent young by including adult males and yearlings in the ratio gives an average of 12% young in the total population, which supports speculations that declines in woodland caribou populations may be related to poor calf recruitment (Rettie & Messier, 1998). Although calf recruitment was low, percent disturbances for Newfoundland herds (average 11%) were comparatively smaller than those found in Northern Alberta (average 54% industrial and 22% fire disturbance within herd's ranges, with 2/6 herds not in decline (Sorensen *et al.*, 2008)). Increased avoidance zones associated with differences in fragmentation patterns may be an important additional factor contributing to Newfoundland caribou population declines (Dyer *et al.*, 2001; Joly *et al.* 2006; Hins *et al.*, 2009), where disturbances may be highly dispersed in Central Newfoundland and more clumped in Northern Alberta.

The CPCR sizes were statistically different between herds, with the Lapoile herd, found in the south east, covering the largest area. Acquisition of high quality habitats may be driving this difference, since Lapoile's CPCRs had approximately 14% less coniferous forest than the other herd's CPCRs.

CPCR size also varied according to disturbance levels. With every additional km^2 of total disturbance within female's CPCRs, we saw an expansion of 5.40 km^2. Courtois *et al.* (2007) also found caribou range size to increase from 224 to 1198 km^2 as disturbance climbed from 0 to 40%, but size declined again at disturbance levels greater than 40%. Disturbance levels in our study were always below 40%, even with the possibly underestimated avoidance zone of 250 m, which agrees with Courtois *et al.*'s findings. This relationship between disturbance and CPCR size may also be linked to fragmentation effects, which can create many small habitat patches. When avoidance zones are large, these habitat patches may no longer be functional, leaving caribou to abandon an even larger area through these avoidance behaviours (Joly *et al.*, 2006). Schaefer (2003) documented widespread range recession for woodland caribou throughout Ontario with increased human activity and associated resource extraction practices. Fortunately, the disturbance and associated fragmentation levels in Newfoundland do not appear to have reached the upper limit in which ranges become compressed. However, assuming similar movement paths, increasing range size could lead to more travel time and hence higher energy expenditure (Bradshaw *et al.*, 1997). Increased movement has also been suggested to increase calf predation risk for woodland caribou, as movement can decrease the effectiveness of the 'space-out' antipredator strategy (Harrington, 2001; Gustine *et al.*, 2006).

The relationship between the extent of total disturbance within CPCRs and calf recruitment shows promise as a useful conservation management tool for Newfoundland populations. This comes as no surprise, given the extensive literature documenting the negative associations between human activity and *Rangifer* behaviour/persistence (e.g. Schaefer, 2003; Vistnes & Nellemann, 2008). Contrary to Sorensen *et al.* (2008)'s findings that caribou populations should be in a growth phase if year-round home ranges contain less than 61% industrial footprint or 66% burnt areas, our populations contained a maximum of 37% disturbed areas during the more sensitive calving/post-calving season, but were in decline. In Quebec, Courtois *et al.* (2007) found no difference between calf recruitment in undisturbed and disturbed landscapes (areas within 500 m of recent cuts, burns, regeneration sites, lichen-less heath, hardwood or mixed forest stands). From this study, herd calf recruitment was expected to decrease by 1 with every additional 20 km^2 of total disturbance within female's CPCRs. Caution must be exercised when extrapolating such correlative study results for management of local populations, as the mechanisms behind such relationships are not often known or understood, and can vary between herds and regions. There are also multiple other factors that must be considered, including historical population dynamics, sex and age ratios, and body condition.

The extent of deciduous and mixed forests areas within CPCRs were both highly selected for among the most likely AIC_c-based models and had a negative relationship with recruitment. Wittmer *et al.* (2007) found survival of adult female mountain caribou to decrease with increasing mid-seral forest stands in British Columbia. Regenerating forest stands have also been found to be preferentially selected by coyotes in Eastern Quebec (Boisjoly *et al.*, 2010), who are major calf predators in Newfoundland. Barrens and wetlands' positive trends with recruitment is supported by Mahoney & Virgl (2003), Schaefer & Mahoney (2007), and Hins *et al.* (2009), who found these vegetation types to be preferred by woodland caribou. In general, females tend to use a variety of habitats during summer with an emphasis on coniferous forests (Chubbs *et al.*, 1993). Although coniferous forest was not among the variables found in the top AIC models, it was a preferred landcover type in Newfoundland (Schaefer & Mahoney, 2007), was related to adult female survival in BC (Wittmer *et al.*, 2007), and was found to be important for calf predator refuge (Bergerud, 1972).

Although the mechanisms through which disturbed areas are related to calf recruitment are not clearly understood, there are several plausible and connected theories in the literature. Caribou disturbance avoidance can create functional habitat loss and limited forage availability, leading to slower female growth and fat accumulation (Nellemann *et al.*, 2000; Vistnes *et al.*, 2001), lower pregnancy rates (Thomas, 1982), lighter calf birth weights, slower calf growth rates, and poor calf recruitment (Weladji & Forbes, 2002; Cameron *et al.*, 2005). Disturbance avoidance can also lead to density increases (Nellemann & Cameron, 1996), which can break down the woodland caribou antipredator tactic of dispersing or 'spacing out' during calving (Bergerud *et al.*, 1990). Disturbances tend to create pockets of early successional forests (Carleton & MacLennan, 1994; Hins *et al.*, 2009), which are not suitable for caribou (Rettie & Messier, 2000; James *et al.*, 2004), but are favoured by other prey and predator species, (Laliberte & Ripple, 2004; Boisjoly *et al.*, 2010). Predators (wolves) have been found to spill over into caribou habitat to make use of this alternative prey in Alberta, BC, and Ontario (Seip, 1992; Cumming *et al.*, 1996; James *et al.*, 2004). In Newfoundland, there are no wolves, but existing caribou predators are known to prey upon moose calves (Mahoney & Virgl, 2003) and could be benefitting from habitat disturbances. Additionally, linear features such as power lines or roads can provide lower resistance travel routes for these predator populations (Edmonds & Bloomfield, 1984), leading to higher predator success rates (James & Stuart-Smith, 2000).

Total disturbance area has been highlighted as an important measure and management tool to relate calf survival to human industry. Protection of habitat within CPCRs may encourage woodland caribou population persistence in Newfoundland, and thus disturbance sources within such zones should be limited. Establishment of protected areas would be ideal, but when disturbances are inevitable, they could be amalgamated to reduce the combined footprint and maintain large connected blocks of habitat to allow for adequate space-use strategies (Courtois *et al.*, 2007). A typical example would be coordinated land use planning, such that new transmission lines, pipe lines, or roads are constructed together (Culling *et al.,* 2004). Caribou CPCRs may also be improved by reclamation of previously disturbed sites and controlling traffic levels, which were found to be effective in restoring historical reindeer ranges in Norway (Nellemann *et al.*, 2010).

Our vegetation results suggest that not only is the amount of disturbance important, but so are the changes in forest structure that follow. An increase in deciduous and mixed forest area during disturbance recovery may lead to increased predation risk for calves, therefore directly affecting calf recruitment. We recommend conservation of coniferous forests within and around CPCRs, and that when disturbances must occur, that they are planned and implemented in such a way that coniferous seedling and caribou habitat regeneration is favoured. Possibilities include using forest harvesting techniques that are less invasive than clear-cutting, which has been thought to increase moose, black bear, and coyote habitat (Stone *et al.*, 2008). These techniques, such as cutting with protection of advance regeneration and soils, or diameter-limit cutting, can leave behind a functional forest ecosystem that not only prevents disturbance-related changes, but also saves costs of site reclamation/replanting (Timoney & Peterson, 1996).

In coming years, with additional data and an improved model, we may be able to identify a disturbance threshold at which recruitment rates fall below sustainable levels. In the meantime, these findings should inform managers of possible methods of evaluating the consequences of further industrial development on habitat availability, predation risk, and calf recruitment for this region.

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