Annual and monthly range fidelity of female boreal woodland caribou in response to petroleum development

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Abstract: Petroleum-sector development in northern Alberta, Canada has been implicated as one factor influencing the decline of boreal woodland caribou (*Rangifer tarandus caribou*). Previous research showed that caribou are farther from petroleum-sector disturbances within their home range than expected. As petroleum development increases, the distance caribou can selectively place themselves relative to industrial disturbance must decrease, because distances between disturbances decrease. Conceptually, the number of local disturbances becomes so large that caribou either abandon their local avoidance behaviour or leave their traditional home range. We evaluated whether an intense petroleum-development event in northern Alberta was sufficient to result in home range abandonment by female woodland caribou. Using well locations as an index of petroleum development, we found that caribou studied from 1992 to 2000 did not change their annual or monthly range fidelity as a function of development intensity. Caribou remained in peatland complexes containing a large number of petroleum-sector disturbances rather than move to new areas, presumably because the risks of dispersing across upland habitat to reach other suitable habitat are high. Such range fidelity may have fitness consequences for woodland caribou if they suffer greater predation in areas where petroleum development is occurring.

Key words: boreal woodland caribou, home range overlap, industrial activity, peatland, petroleum development, petroleum sector, range fidelity, *Rangifer tarandus caribou*, wellpad.

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Introduction

Fidelity is the tendency of animals to remain in, or return to, a particular spatial location at different times of the year (Switzer, 1993). Fidelity is believed to increase an individual's knowledge of the local environment by increasing their ability to find resources while reducing predation risk (Schaefer *et al*., 2000). As such, fidelity can have a strong effect on an individual's fitness (Lindberg & Sedinger, 1997). Given the potential detrimental effects caused by animals moving away from areas of familiarity, there is a concern that human activities that force animals out of traditionally used areas will have significant effects on wildlife population dynamics (White & Garrott, 1990).

Unlike other caribou ecotypes, boreal woodland caribou (*Rangifer tarandus caribou*) in northern Alberta, Canada, show considerable overlap between their summer and winter ranges, suggesting strong range fidelity to particular locations (Stuart-Smith *et al*., 1997; Dalerum *et al*., 2007). This overlap is believed to occur because the peatland complexes that caribou use provide refuge against predation as well as access to their primary winter forage, lichens. The result is that caribou in Alberta peatlands tend to "stay put" relative to other caribou ecotypes that move more widely in order to gain resources and avoid predation (Stuart-Smith *et al.,* 1997; Dzus, 2001; James *et al.*, 2004). However, disturbance from industrial activity may be changing the value of this sedentary strategy, as populations of boreal woodland caribou in Alberta are in decline (McLoughlin *et al.*, 2003). The mechanisms causing caribou declines are complex, but possible explanations include loss of food caused by habitat alteration, increased predation risk due to numerical changes in predators, indirect competition from increased moose or deer, functional changes in predator behaviour related to the industrial footprint, and/or higher energetic costs associated with avoidance of industrial activity (Edmonds, 1991; Grey, 1999; BCRP, 2000; Dzus, 2001; McLoughlin *et al.*, 2003).

Dyer *et al.* (2001) demonstrated that within their home range, woodland caribou avoid oil and gas wells, roads, and seismic lines, suggesting that at a local scale areas traditionally used by caribou may have changed due to petroleum development. However, other studies have demonstrated that although caribou reduce their use of areas next to large disturbances (such as forestry cut-blocks), the use of areas near smaller disturbances such as seismic lines is variable (Smith *et al.*, 2000; GNWT, 2006; Neufeld, 2006; Antoniuk *et al.*, 2007). This variation may stem from an individual caribou's behaviour, but may also be linked to the configuration and density of development, as the distance an animal can place itself relative to disturbance decreases as the distance between disturbances decreases (Bayne *et al.*, 2005; McCutchen, 2007). Regardless of whether this avoidance behaviour is due to avoidance of industrial activity (Grey, 1999; Dyer *et al.*, 2001; McLoughlin *et al.*, 2003), to reduce contact with other ungulates (Smith *et al.*, 2000; Bayne *et al.*, 2004; Charest, 2005; Wittmer *et al.*, 2005a, b), or to minimize interactions with predators (James & Stuart Smith, 2000; McLoughlin *et al.*, 2005; Neufeld, 2006), the patterns of local habitat selection have led to the ultimate conclusion that petroleum sector activity results in functional habitat loss for caribou (Alberta Woodland Caribou Recovery Team, 2005).

In landscapes where multiple anthropogenic disturbances occur, the accumulation of disturbances leaves caribou with two choices: 1) remain in human-disturbed areas; or 2) abandon traditional areas and relocate to areas where human activities are less intense. Understanding if there is a threshold where the cumulative effects of multiple human disturbances lead female caribou to abandon their traditional home range and disperse is important for defining the habitat needs for this threatened species (COSEWIC 2005). This study was one of several which occurred under the umbrella of the Boreal Caribou Research Program (BCRP; now Alberta Caribou Committee), a collaborative effort between industry, government agencies, and academia. The BCRP research focused on relating caribou ecology to industrial activities, for use in the development of industrial land-use guidelines towards caribou conservation in Alberta.

Material and methods

Study Area

The study area (centered at 56°N, 113°W) included approximately 7000 km^2 of boreal mixedwood and peatland vegetation in the West Side Athabasca River Caribou Range (WSAR) located in northeastern Alberta, Canada (Fig. 1), and was at the southwest corner of the Athabasca oil-sands deposit (Crandall & Prime, 1998). Elevation ranged between 500 m and 700 m above sea level, with higher el-

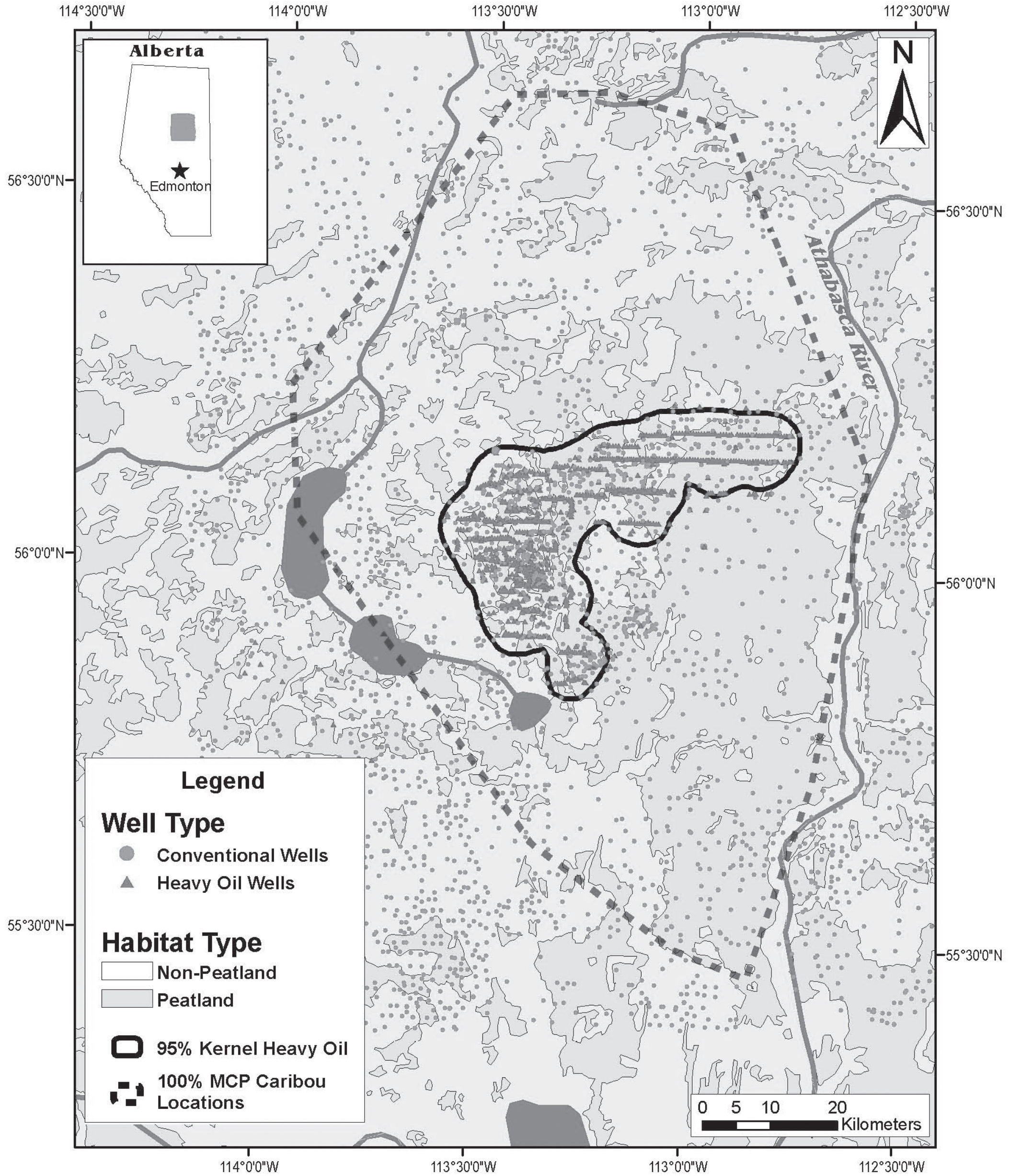

Fig. 1. Map of study area in located northeastern Alberta, with dashed polygon (100% Minimum Convex Polygon) indicating the extent of all woodland caribou locations from the West Side Athabasca River Caribou Range (WSAR). Peatland is shown in dark gray and non-peatland in light gray (Peatland Inventory of Alberta, Vitt *et al.*, 1998). Major rivers are also shown. The locations of all wells in the Alberta Energy and Utilities Board dataset to 2000 are shown. The 95% kernel of most intense petroleum sector development (heavy oil wells) is highlighted. Wells are not shown to scale.

evations dominated by *Populus tremuloides*, *Picea glauca*, and *Pinus banksiana*. Lower elevations were vegetated primarily by *Picea mariana* and *Larix laricina*, which formed large bog and fen complexes (see Bradshaw *et al.*, 1997, 1998; and Dyer *et al.*, 2001 for further description).

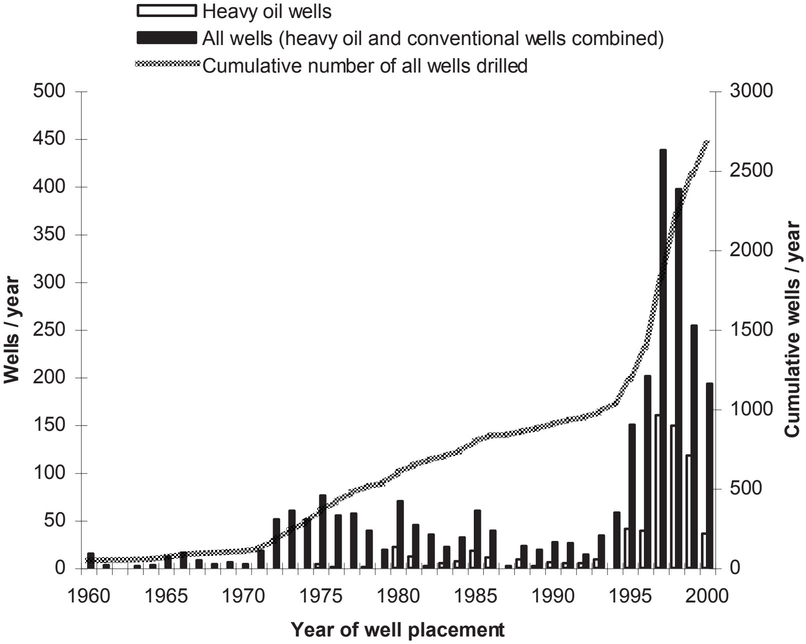

Fig. 2. The number of wells drilled in the WSAR study area from 1960 to 2000. Both the number of heavy oil and the total number of wells (conventional and heavy oil) drilled in each year are shown (bars), as is the cumulative number of wells drilled per year from 1960 to 2000 (smoothed line). Note increase in wells drilled 1995 and onwards.

Caribou Monitoring

Female Boreal woodland caribou in the WSAR were equipped with very high frequency (VHF) radio collars (Lotek Engineering Systems, Newmarket, Ontario) from 1992-2000. Caribou were captured and collared according to procedures described by Stuart-Smith *et al.* (1997) following Animal Care Protocol No. 230001 at the University of Alberta. Caribou were located at least bi-monthly using a fixed-wing aircraft and locations were recorded using a global positioning system.

Petroleum Development in WSAR

Most of the WSAR was subject to some level of petroleum sector activity between 1992 and 2000. Petroleum exploration and extraction occurred mainly in the center of the study area (Fig. 1) and increased dramatically in 1995 and afterwards (Fig. 2). This development created a pulse of activity over a very short period, and was associated with construction of different types of wells (oil and gas), all-weather road access, and a large amount of traffic (600-800 vehicles per day, Dyer *et al.*, 2001). Wells are closely associated with the density of all other types of petroleum disturbances (including seismic lines) and are a reasonable surrogate of total impact by the petroleum sector within the study area (Cumming & Carteledge, 2004). Furthermore, the location, date, and type of every well drilled is known, whereas few of the other disturbances (roads, seismic lines, etc.) can be tracked to a specific time interval. Thus, we did not test for well effects per se, but rather the cumulative effects of petroleum sector activity related to well development (Fig. 2). However, the intensity of petroleum development often depends on the type of well being drilled. The largest disturbance in our area (including: all-weather roads, seismic lines, pipelines, other well sites, tank farms, and field camps) occurred in conjunction with crude-bitumen or "heavy oil" wells, which were present only in the center of the study area. This central area also had the highest density of seismic lines in our study area (1.8 km to 2.4 km of line per km^2).

Analytical Methods

A total of 174 annual home ranges were established for 45 caribou from 1992-2000. Annual home ranges based on 100% minimum convex polygons (MCPs) were calculated using locations from 1 March - 28 February, following Dyer *et al.* (2001). Annual home ranges were calculated using 17-24 locations per animal, with the number of annual MCPs generated per individual caribou ranging from 2 to 8, with a mean of 3.9 (ESRI 1998). In total, 126 comparisons between location of the home range in year *t* and *t+1* existed in our dataset.

The 95% kernel estimate for all crude bitumen wells drilled in the study area was 1,036 km^2 in size at the end of 2000 (Fig. 1). Before the major development event (1992-1994), the number of crude-bitumen wells drilled in the entire study area was 87. From 1995-2000, 802 crude bitumen wells were drilled in the kernel while only 25 crude bitumen wells were drilled outside the kernel. The timing of development (before 1995 *vs.* after 1995) was included in all models as a categorical variable (TIME). Overall, 71% of our monitored home ranges partially overlapped the 95% heavy oil kernel. On average, caribou had 31 ± 29% (SE) of their home range area in the kernel with 16% of home ranges overlapping the kernel by 50% or more. We did not directly compare whether the proportion overlap between each caribou's home range and the well kernel changed over time because the areas where caribou capture occurred in the WSAR changed considerably over the duration of the study.

To assess whether caribou abandoned their annual and monthly home ranges in response to petroleum development, we calculated annual and monthly range fidelity. For all VHF locations within a caribou year we calculated the harmonic mean location of all points (n = 17 to 24 per caribou per year). We then measured the distance from the centroids of each animal's locations between year *t* and year *t+1* (ADISTANCE). We also examined changes in home range location by calculating the area of shared home range between two consecutive MCPs and dividing it by the smaller of the two home ranges (AOVERLAP). This measure was expressed as a proportion overlap. Monthly range fidelity was calculated by finding the harmonic mean location per month of individual caribou (n = 2 to 8 locations per caribou per month). We then measured the distance between the centroid of each monthly home range between year *t* and *t+1* *(*MDISTANCE). We did not estimate proportion overlap of monthly MCPs because there were insufficient points per month to create MCPs.

To assess the level of petroleum sector activity to which each caribou was exposed, we calculated four measures. First, we calculated the total number of wells in the annual home range (AHR-WELL). The number of wells encountered is partly a function of the size of the home range so we included home range size (SIZE) in year *t* as a covariate in all analyses. Many of the wells and other human disturbances in the home range of a caribou may not be encountered by the animal, so we also calculated the total number of wells that individual caribou were known to have interacted with. Bradshaw *et al.* (1997) demonstrated that caribou in northern Alberta react to industrial noise at distances of ~500 m; thus a circular buffer of 500 m radius was placed on each caribou location. Within each buffer we counted the number of wells that caribou were expected to encounter based on VHF locations (hereafter A500-WELL). The total number of wells that were within 500 m of each caribou location was then used as an index of human activity level. Wells that are abandoned or have started producing often have less activity at them than those that are being drilled. Therefore, we also counted the number of wells drilled between year t and year t+1 at both spatial scales (hereafter AHR-DRILL at the level of the home range & A500-DRILL within the 500 m buffers).

To assess how the density of wells influenced monthly range fidelity, we calculated the total number of wells that caribou encountered by calculating the total number of wells within 500 m of each VHF location. To calculate the total number of wells (MHR-WELL) and wells being actively drilled (MHR-DRILL) that were encountered per monthly home range we could not count the number of wells in a monthly MCPs as there were insufficient points. Instead, we used an arbitrary buffer size around the mean monthly location of VHF-collared animals to count the total number of wells encountered within a theoretical monthly home range. The mean monthly home range of six GPS-collared caribou in this area was 50.1 ± 68.8 km^2 using a 95% kernel estimator (Dyer *et al.*, 2001). The size of the theoretical monthly home range was a 4 km radius buffer around the harmonic mean centroid of VHF points for that month. M500-WELL and M500-DRILL were computed using the buffers for each month.

The mean distance moved between years was analyzed using mixed-effects regression models with Akaike's Information Criteria corrected for small sample size (AIC_c) used to compare model fits (Burnham & Anderson, 2002). Mixed models are a form of generalized linear model that account for the lack of independence among observations caused by monitoring the same caribou in more than two time intervals. The identity of each individual caribou was treated as a random effect in the analysis. Mixed models are particularly useful in repeated-measures designs when there are continuous covariates in the model and when replication is not equal among categorical variables (McDonald *et al.*, 2000; Rabe-Hesketh & Everitt, 2004). In an effort to meet the assumption of normality required by the mixed model we square-root transformed ADISTANCE, ln-transformed MDISTANCE, ln-transformed SIZE, ln-transformed AHR-WELL, ln-transformed AHR-DRILL, and arc-sine square-root transformed OVERLAP. No transformation could be identified that normalized A500-WELL, A500-DRILL, M500-DRILL, or M500-WELL so they were entered into the model in their original units.

Much of our data showed a high level of heterogeneity across the range of our predictor variables. One explanation for heterogeneous variance is that the mean is not a good descriptor of the data because there are not one, but many rates of change (Cade & Noon, 2003). Increasingly ecologists have also started looking at whether the extremes between variables show differential patterns from the mean (Scharf *et al.* 1998). The rationale for looking at upper and lower limits of response is that the response of an organism can not change by more than the upper limit set by the measured predictor variables, but may change less on average than they do at the maximum. This is believed to occur when other unmeasured factors limit the organism's behavior, and thus the mean does not fully describe the pattern of response. To test whether the distance moved by caribou in response to energy sector development showed different patterns using the mean versus the minimum and maximal response we used quantile regression. Details of the method can be found in Cade & Noon (2003) and Scharf *et al.* (1998). We chose to model the 20 & 80% quantiles. These quantile values were selected to ensure we had sufficient information to accurately estimate standard errors based on rules of thumb described in Scharf *et al.* (1998). Model selection was done using a variant of AIC_c described in Cade *et al.* (2005), and data were analyzed in

Table 1. Akaike weights for the ten models based on mean response for each of the fidelity measures used to assess if boreal woodland caribou (*Rangifer tarandus caribou*) abandoned monthly and annual home ranges in response to industrial activity in the West Side Athabasca River Caribou Range (WSAR). The higher the value in the model set the better the fit of the model to the data relative to other models in that set. Note: in text, prefixes "A" and "M" were added to measures (e.g. "*A*HR-WELL" is the total number of wells in an *annual* home range).

Model	Annual home ranges		Monthly home ranges
	Distance between years[1]	Proportion overlap[2]	Distance between years[1]
BASE	0.62	0.04	0.62
TIME	0.15	0.20	0.08
HR-WELL	0.09	0.14	0.12
HR-DRILL	0.03	0.16	0.06
500-WELL	0.03	0.07	0.03
500-DRILL	0.03	0.05	0.06
TIME + HR-WELL	0.03	0.04	0.01
TIME + HR-DRILL	0.01	0.11	0.01
TIME + 500-WELL	0.01	0.11	0.00
TIME + 500-DRILL	0.01	0.08	0.01

[1] Distance is defined as the distance in kilometers between the harmonic mean location of all points in an annual or monthly home range between year *t* and year *t+1*.

[2] Proportion overlap is the area shared between home ranges in year *t* and *t + 1* as determined by 100% MCPs divided by the area of the smaller home range.

their original units as assumptions of normality are not required for quantile regression. Quantile regression analyses did not account for the lack of independence caused by using multiple individuals. Inclusion of random effects in quantile regression is an area of active statistical research and no agreed upon method has been established (Koenker, 2004). Analyses were done in Stata 10 (Stata, 2007) using the xtmixed and qreg commands.

For each dependent variable used to describe annual range fidelity we tested which of 10 models best described our data. Our base model hypothesized that caribou range fidelity was a function of individual variation (random effect in mixed model) and SIZE. Quantile regression models did not include random effects to account for individual variation. For monthly range fidelity we also included month as a categorical variable. The remaining models examined combinations of TIME and the various human impacts (see Table 1).

Results

The average distance (± 1 SD hereafter) between centroids of consecutive annual home ranges was 5.45 ± 4.31 km, and ranged from 0.1 km to 19.1 km. The most parsimonious explanation for the data given the models considered was the null model. Within the null model, individual variation ($\chi2 = 7.3$, P=0.004) and ln-home range size in year t ($\chi2 = 3.7$, $P < 0.001$) explained the differences in mean distance (square-root transformed) between centroids of sequential home ranges. Individuals with larger home ranges were less likely to be in the same central location in year t+1. Adding any combination of human disturbance variables or TIME did not improve model fit suggesting that the average location of caribou MCPs did not change in response to industrial activity (i.e. Fig. 3A). There was little support for the hypothesis that petroleum sector development influenced the overlap of a caribou's

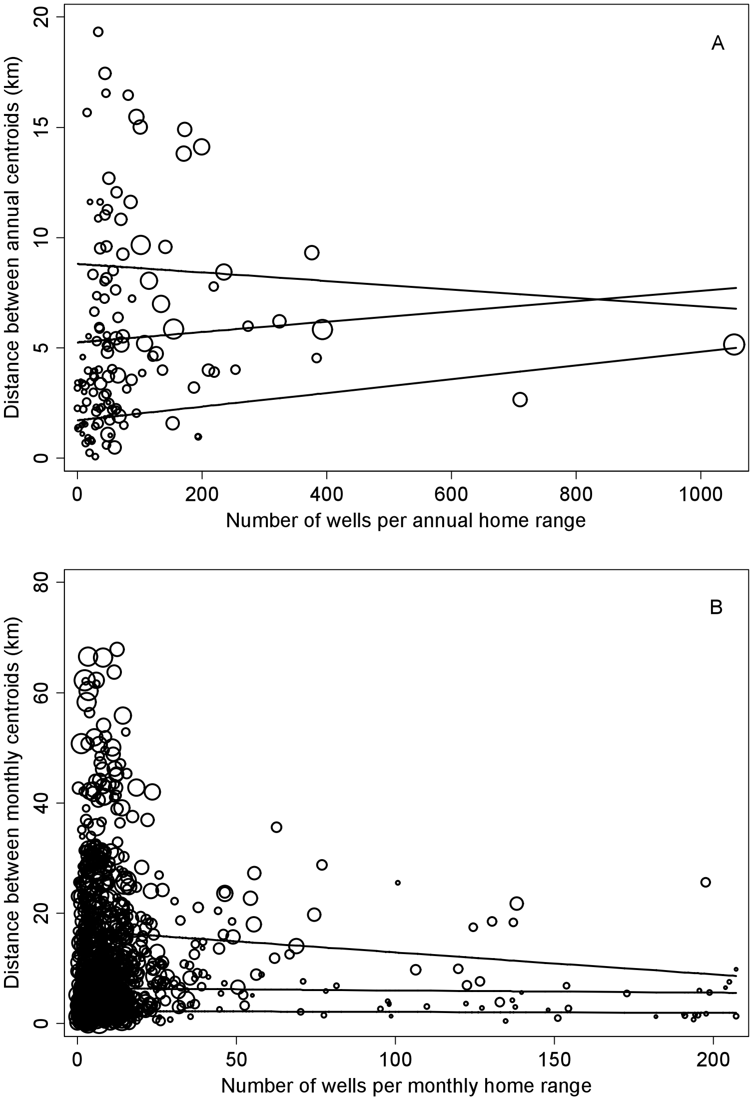

Fig. 3. Scatterplots showing: A) Distance (km) between centroids of annual home ranges in consecutive years versus the total number of wells within the annual home range of caribou in year *t* (AHR-WELL); B) Distance (km) between centroids of monthly home ranges in consecutive years versus the total number of wells within the monthly home range in year *t* (MHR-WELL). Lines of best fit indicate maximum (80% quantile), mean, and minimum response (20% quantile). Monthly home range was a circular buffer 4 km in radius. The size of the circles is proportionate to the overall size of the animal's annual home range.

home range from year t to t+1. Mean OVERLAP was 0.76 ± 0.19 and was not significantly correlated with any of the wellpad variables. There was very weak evidence that TIME explained some of the variation in OVERLAP. Before intense development, OVERLAP was 0.69 ± 0.22, and after development it was 0.77 ± 0.19.

Based on quantile regression (Fig. 3A), the minimum distance moved between years (20% quantile) was best predicted by the null model, with AREA being a significant predictor (slope = 0.0031: 95% CI = 0.0014 to 0.0047). For maximum distance moved there was support for the model ADISTANCE ~ SIZE + AHR-WELLS for the 80% quantile. Relative to the null model the ΔAICc was 7.5. This model suggested the maximum distance moved between years decreased as caribou experienced more wells. However, two caribou tracked in 1997 and 1998 drove this relationship as they had extremely high numbers of wells in their annual home ranges and showed strong fidelity between years. Dropping these two individuals resulted in the maximal response to AHR-WELLS no longer being deemed important. Quantile regression results using OVERLAP were strongly influenced by these two outliers. No human disturbance variables were identified as important when they were removed.

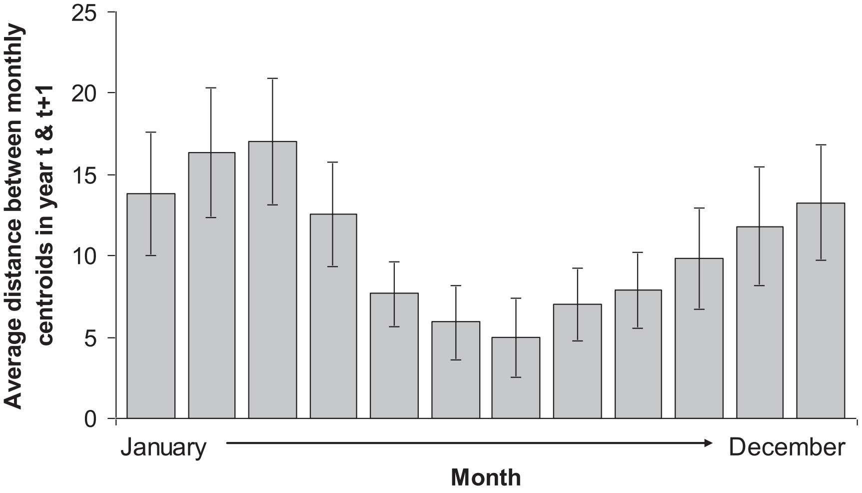

Fig. 4. Monthly range fidelity as assessed by measuring the average distance (km) between monthly centroids of caribou observed in year *t* and year *t+1*. The centroid of each monthly location was calculated by taking the harmonic mean of 2 to 8 observations per month per caribou. Between 1992 and 2000, we recorded 1359 months where the same caribou (n=45) was located between consecutive years. Error bars represent 95% confidence intervals.

Monthly range fidelity of VHF collared animals was best predicted by the BASE model. Mean distance between monthly centroids was strongly influenced by individual variation ($\chi 2 = 47.6$, $P < 0.001$), MONTH ($\chi 2 = 352.6$, $P < 0.001$), and SIZE ($\chi 2 = 6.2$, $P < 0.001$). Based on VHF data, caribou showed monthly range fidelity with the mean location between consecutive years being farther apart in the winter months than during the summer. For example, the average distance between July home range in consecutive years was 4.98 ± 7.79 km between years. In January it was 13.81 ± 11.32 km (Fig. 4). Again, the larger the home range the further away the central monthly location was between year t and t+1. Adding human disturbance variables or TIME did not improve model fit for mean distance moved (Figure 3B). There was very weak support for the model MDISTANCE ~ SIZE + MONTH + M500-WELL (ΔAICc relative to BASE = 2.9). The model predicted that as the number of wells encountered increased, the distance an animal was year to year during a specific month decreased.

Annual home range size of caribou was 382 km^2 and ranged from 14 km^2 to 1525 km^2. On average, the number of wells per annual home range was 95 and ranged from 1 to 1056. Controlling for home range size, well density averaged 26 per 100 km^2, and ranged from 1.3 to 220.2. Average well density increased over 4 times from 1992 to 2000 (11.5 to 47.9 wells per 100 km^2). All of the models described were also run using the arithmetic mean and median of VHF locations to calculate the centroid location of monthly and annual home ranges. We also calculated overlap using the larger of the two annual home ranges as well as using SIZE in year t+1 in all models. While the absolute values differed between these different measures, no differences in statistical significance or model support were observed for the human disturbance variables or TIME so these analyses are not reported.

Discussion

Previous research on boreal woodland caribou in the WSAR shows that they avoid petroleum development sites at local scales within their home range (Dyer *et al.*, 2001). However, our results suggest that the cumulative impact of disturbance does not seem to have reached a point whereby caribou abandon their annual or monthly home ranges. Caribou in the

WSAR showed similar home range location and overlap in areas with differing degrees of petroleum sector development, despite the dramatic increase in petroleum activity in 1995 and onwards. Our results are similar to Dalerum *et al.* (2007) who found that boreal caribou in Alberta did not alter their home range size or location after fire, even though some home ranges had up to 76% of their area burned. In these caribou home ranges, minimum proportion overlap between years was about 0.7 using a 95% kernel estimator to estimate the home range. This is similar to the minimum proportion overlap between home ranges we observed (0.76). In Saskatchewan where there was no petroleum development at the time of their study, Rettie & Messier (2001) found minimum proportion overlap in consecutive years was 0.52 for boreal woodland caribou based on MCPs. Of the 51 comparisons of annual range location done by Rettie & Messier (2001), only two animals shifted their ranges completely between successive years. Of the 126 pairs of annual ranges we examined, none resulted in complete abandonment of home ranges, although minimum overlap was 4%.

We propose four hypotheses to explain why boreal caribou do not abandon their home ranges when exposed to petroleum sector development. First, the magnitude of disturbance created by the petroleum sector may not have been sufficient to force individual boreal caribou to move their home ranges to areas of lower activity within the study area or to abandon the study area entirely. The disturbances created by the petroleum sector may be sufficiently spaced apart such that caribou can still utilize a local avoidance strategy, though given that the average well density increased over 4 times from 1992 to 2000, and seismic line densities in the center of the study area ranged from 1.8 to 2.4 km/km^2, locations sufficiently away from activities may be lacking. Boreal caribou subject to major changes in habitat suitability by fire (Dalerum *et al.*, 2007) did not move their home ranges either, suggesting that something else is limiting dispersal.

A second alternative hypothesis is that selection for peatland may be so strong that animals are not willing to disperse across other habitats to reach new peatlands. The home ranges of many of our study animals incorporated a high proportion of the peatland habitat in the WSAR area (Tracz, 2005). Resource selection function analysis utilizing a smaller GPS dataset indicated that caribou continued to use "preferred" peatland habitat regardless of the level of industrial activity, and did not select for "lesser" quality upland habitats (Tracz, 2005). McLoughlin *et al.* (2005) showed the majority of adult caribou mortality occurred when caribou were close to peatland/upland interfaces. The perceived risk of crossing upland habitat or unfamiliar habitat to reach new peatland areas may simply be too great for caribou to consider such a dispersal event even when human or natural disturbance in their home range is high (Dalerum *et al.*, 2007). Boreal woodland caribou in Alberta, on average, have larger home ranges than other woodland caribou in Canada (Bradshaw *et al.*, 1995; Stuart–Smith *et al.*, 1997), with perhaps the exception of the Northwest Territories (Nagy *et al.*, 2004). For caribou, maintenance of a large home range may provide sufficient peatland habitat for forage while also providing predator avoidance at a broad scale, thus lessening a need to move a home range into a novel and unfamiliar area.

A third hypothesis is that caribou do not show changes in home range location or size because the extent of human disturbance in Northeastern Alberta has occurred to such an extent that caribou have limited, or no further viable locales to access and/or exploit. The inability of caribou to move away from areas of disturbance may be further compounded by potential increases in predator numbers, predator efficiency, and increased alternative prey that seem to be occurring in upland areas around caribou ranges in western Canada (Rettie & Messier, 1998; James & Stuart Smith, 2000; Bayne *et al.*, 2004; Charest, 2005; Neufeld, 2006). Regardless of the mechanism, boreal caribou in Northeastern Alberta seem to exist as a series of isolated sub-populations with limited movement of individuals between different herds (Dzus, 2001). This scenario suggests that caribou may be "stuck" in the available habitat in their defined herd range having no alternative places to move to, either within their range or between ranges, and by default remain subject to increasing industrial expansion and associated cumulative effects.

A fourth hypothesis is that caribou may have become habituated to anthropogenic disturbance in the WSAR. Two caribou that were exposed to the most human activity showed relatively high levels of annual fidelity, and an increase in home range overlap after 1995 further suggests a possibility. In other areas caribou have displayed habituation to industrial features and the activities associated with them, suggesting a degree of resilience to habitat loss and disturbance (see Wolfe *et al.*, 2000 for review). However, as woodland caribou in the WSAR displayed avoidance of industrial features and associated activities at locations within their seasonal home ranges (Dyer e*t al.*, 2001), we are hesitant to use the term "habituated".

Although there were limited numbers of locations to generate monthly centroids, our data show strong evidence of between-year range fidelity on a monthly basis by woodland caribou. The greatest level of fidelity occurred during July and August, although this was not significantly different than the May / June calving season. Given that most mortality of adults caribou and calves occurs post-calving (Stuart Smith *et al.*, 1997; Rettie & Messier, 1998; Wittmer *et al.*, 2005*a*), it seems reasonable to conclude that seasonal fidelity during this time occurs to minimize predation risk. However, parturition may represent only the initiation of fidelity, as caribou showed strong fidelity in our study area throughout the summer months when calves are more mobile. By limiting movements during the spring and summer, caribou may simply be attempting to maintain their avoidance strategy within the remaining "safe" peatland habitat.

The population of boreal woodland caribou we studied in the WSAR was believed to have a population growth rate close to 1 during the period of our study (McLoughlin *et al.*, 2003). Since then, this herd has been in decline (Boreal Caribou Research Program unpublished data, 2005). Whether this declining population growth rate at the herd level is driven by low survival of calves in the area of most intense petroleum development, or if adult female mortality is also a factor is unknown. If low numbers of calves, or if calf and/or adult survival are related to areas of highest industrial activity, there is potential that an "ecological trap" has been created. In an ecological trap caribou perceive that sufficient resources such as food are available and thus choose to stay in an area despite the increased predation risk. Declines in caribou within the WSAR will require immigration from more productive "source" herds in order to be rescued from extirpation based on current demographic rates. However, given that limited exchange that seems to occur between herds (Dzus, 2001) the possibility of such a rescue effect seems unlikely. Perhaps most relevant is the fact that most of Alberta's woodland caribou herds are in decline suggesting that source herds may be rare or even non-existent.

Concern over the impact of anthropogenic disturbances is not unique to Alberta, but rather a circum-arctic issue with many populations of *Rangifer* (e.g. barren-ground and reindeer) subject to increasing levels of disturbance (Reimers & Colman, 2003). In Alaska, industrial activities led to reduced access to preferred feeding habitats and a concentration in caribou distribution, leading to use of areas with lower forage biomass and likely reproductive consequences (Cameron *et al.*, 2005, Nellemann & Cameron, 1998). Wild reindeer in Norway may be confined in areas away from human disturbance, potentially leading to increased grazing pressure and selection of areas with lower quality forage (Vistnes & Nelleman, 2007, Vistnes *et al.*, 2008), though topography, snow cover, and migratory behaviour may potentially counteract aversion effects (Reimers *et al.*, 2006). By limiting habitat and movement opportunities, stressed populations of *Rangifer* may have a further decrease in their resilience (Vistnes & Nelleman, 2007), a growing concern if climate events also negatively impact behaviour (Stein *et al.*, 2009).

Given that boreal woodland caribou in the WSAR do not abandon their home ranges and movement between herds is minimal, management decisions that mitigate impacts within each herd are important. The tenure system allowing petroleum exploration and extraction in Alberta makes it possible for development to occur to some degree in all caribou ranges in Alberta. Thus, while practices may be improving - the total footprint continues to increase (Schneider, 2002). Further investigation is required of whether caribou conservation can be achieved by managing industrial activity in each herd range, versus a zoning approach whereby a few herds are given extreme protection. Even though the Alberta Government has adopted the Alberta Woodland Caribou Recovery Plan (Alberta Woodland Caribou Recovery Team, 2005), a recommendation relating to a "moratorium on further mineral and timber allocations" for herds deemed "in immediate risk of extirpation" has not been adopted. Regardless of which management actions demonstrate the best chance of conserving caribou in the long-term, the political resolve to actually implement the recommendations is paramount to success (Gerrand, 1997; Schneider, 2002).

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