The 12th North American Caribou Workshop,
Happy Valley/Goose Bay, Labrador, Canada,
4–6 November, 2008.

Historical changes in caribou distribution and land cover in and around Prince Albert National Park: land management implications

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Abstract: In central Saskatchewan, boreal woodland caribou population declines have been documented in the 1940s and again in the 1980s. Although both declines led to a ban in sport hunting, a recovery was only seen in the 1950s and was attributed to wolf control and hunting closure. Recent studies suggest that this time, the population may not be increasing. In order to contribute to the conservation efforts, historical changes in caribou distribution and land cover types in the Prince Albert Greater Ecosystem (PAGE), Saskatchewan, were documented for the period of 1960s to the present. To examine changes in caribou distribution, survey observations, incidental sightings and telemetry data were collated. To quantify landscape changes, land cover maps were created for 1966 and 2006 using current and historic forest resources inventories, fire, logging, and roads data. Results indicate that woodland caribou are still found throughout the study area although their distribution has changed and their use of the National Park is greatly limited. Results of transition probabilities and landscape composition analyses on the 1966 and 2006 land cover maps revealed an aging landscape for both the National Park and provincial crown land portions of the PAGE. In addition, increased logging and the development of extensive road and trail networks on provincial crown land produced significant landscape fragmentation for woodland caribou and reduced functional attributes of habitat patches. Understanding historical landscape changes will assist with ongoing provincial and federal recovery efforts for boreal caribou, forest management planning activities, and landscape restoration efforts within and beyond the Park boundaries.

Key words: boreal forest; caribou distribution; fire management; landscape change; landscape fragmentation; population history; Prince Albert National Park; *Rangifer tarandus caribou*; woodland caribou.

Rangifer, Special Issue No. 19: 17–31

Introduction

Human land use through settlement, recreation or industrial development may cause habitat fragmentation leading to significant changes in the landscape. Habitat fragmentation is generally defined as "the breaking up of a large habitat into smaller, more isolated, patches" (Andrén, 1994; Fahrig, 1997). Habitat patches are part of the landscape and the use of a patch by wildlife is not only a function of the patch attributes but also of the characteristics of neighboring patches (Andrén, 1994; Fahrig, 1997). In highly fragmented landscapes, the decline of wildlife populations is greater than that expected by habitat loss alone (Andrén, 1994) and ultimately, these changes to the landscape can isolate groups of animals (Bélisle & Desrochers, 2002). Habitat fragmentation is considered one of the greatest threats to biodiversity making it an important conservation issue (Harris, 1984; Forman & Godron, 1986; Saunders *et al.*, 1991).

In the boreal forest, the main factors leading to habitat loss and habitat fragmentation are: changes in natural and anthropogenic disturbance patterns, increased commercial and industrial activities, increased road access to remote areas and recreational activities (Harris, 1984; Forman & Godron, 1986). Fire is a natural disturbance and has long-term ecological benefits (Bergeron, 1991; Klein, 1992; Johnson *et al.*, 2001). In the boreal mixedwood forest of North America, the fire return interval ranges from 30 to 150 years (Johnson, 1992). Changes in fire frequency can be caused by shifts in climate, land use pattern and land management strategies (Clark, 1988; Bergeron, 1991; Johnson & Larsen, 1991; Larsen, 1997). At the time of human settlement, fires were frequent as deliberate burns were set to clear land for agricultural purposes (Williams, 1989; Whitney, 1994; Weir, 1996). After an area is settled, fire frequency tends to decrease as forested areas become fragmented and cannot support the spread of fire (Weir, 1996).

Following settlement of the boreal forest, roads were constructed to provide access for industrial development, primarily forestry (Walker, 1999). Forest harvesting is an important commercial activity across the boreal region and usually targets coniferous stands older than 50 years (Walker, 1999). To be sustainable, logging practices attempt to maintain stands of a variety of ages within a given forest management area (Walker, 1999). In Saskatchewan, fire is suppressed over areas of commercial forest tenures or in proximity to communities; natural forest pattern standards and guidelines for the forest industry aim to produce landscapes and harvest areas that emulate the patterns created by fire (Saskatchewan Environment, 2009). However, occurrence of fire on landscapes where logging activities are prevalent can add a level of complexity and produce a younger stand age structure (Reed & Errico, 1986).

Landscape changes, natural and anthropogenic, can have significant impacts on the boreal population of woodland caribou (*Rangifer tarandus caribou*), a threatened species under the Species at Risk Act (2004). Boreal caribou are habitat specialists, dependent on old growth forests to survive (Rettie & Messier, 2000; Smith *et al.*, 2000; Mahoney & Virgl, 2003). They avoid logged areas (Cumming & Beange, 1987; Chubbs *et al.*, 1993; Smith *et al.*, 2000; Johnson & Gilligham, 2002; Lander, 2006), areas near roads and trails (Nellemen & Cameron, 1996; Cameron *et al.*, 2005) and recent burns (Schaefer & Pruitt, 1991; Klein, 1992; Thomas & Gray, 2002; Lander, 2006). Caribou also avoid hardwood stands or stands of younger age classes as these areas often allow for higher densities of other ungulate species (moose, deer and elk) and associated predators. Caribou have persisted in the boreal forest for thousands of years in the presence of fire, provided suitable habitat is available in adjacent areas (Schaefer & Pruitt, 1991; Schaefer, 1996). Logging and road development also often displace caribou (Chubbs *et al.*, 1993; Dyer *et al.*, 2001) and since these activities lead to more permanent landscape changes, they can result in range retraction (Bradshaw *et al.*, 1997; Thomas & Gray, 2002).

The Prince Albert National Park (PANP) and Greater Ecosystem (PAGE) are located in the boreal mixedwood forests of Canada, in the province of Saskatchewan, and part of the Smoothstone-Wapaweka Woodland Caribou Management Unit (SW-WCMU). The fire frequency of this area has decreased following settlement (Johnson, 1992; Weir *et al.*, 2000) and over the past 40 years, significant logging and road development surrounding the Park has occurred. This ecosystem has traditionally been used by a resident population of boreal caribou (Banfield, 1961) but there are concerns over the long-term viability of the population (Arsenault, 2003; Saskatchewan Environment, 2007). In central Saskatchewan, population declines have been documented in the 1940s and again in the 1980s. The first decline led to a ban in sport hunting and an increase in caribou population in the 1950s was attributed to wolf control and hunting closure (Rock, 1988; Rock, 1992). In 1987, another population decline was documented and sport hunting was again banned (Rock, 1988; Rock, 1992). Subsistence harvesting still occurs, although only opportunistically (Trottier, 1988). Work conducted by the University of Saskatchewan (Rettie & Messier, 1998) and more recently through a collaborative effort between Parks Canada, Saskatchewan Environment, the Prince Albert Model Forest, Weyerhaeuser Canada Ltd. and the University of Manitoba (Arsenault & Manseau, 2011) suggests that the population is declining. The Park and surrounding area are managed separately and under different legislations. The management of the National Park centres on the maintenance or restoration of ecological integrity while also providing opportunities for public education and enjoyment (Parks Canada, 1986). Logging has not been permitted within the Park in the past 60 years and fire has been suppressed; however, a prescribed burning program has been put in place to reinstate a natural fire cycle (Prince Albert National Park, 2008). The area outside of the National Park is managed primarily for the forest industry by the Saskatchewan Ministry of Environment (MoE) (Government of Saskatchewan, 2002).

The main objectives of this work were to assess changes in caribou distribution and landscape composition in the PAGE over a period of 40 years, between 1966 and 2006. Since the data sources differed between the crown land and the National Park portion of the PAGE, analyses were done separately for the two areas. Careful attention was given to the production of the historical datasets to allow for a reliable comparison. A better understanding of historical landscape changes should assist with the recovery efforts for woodland caribou and guide current and future forestry management and land-use planning activities.

Methods

Study area

The Prince Albert Greater Ecosystem (PAGE) is a 13 380 km^2 area located in central Saskatchewan, Canada (Fig. 1). Prince Albert National Park was established in 1927 to represent the southern boreal forest region of Canada. The portion of the Park within the PAGE is 2688 km^2. The remaining part of the PAGE is provincial crown land. This includes the communities of Weyakwin and Waskesiu, the reserve community of Montreal Lake First Nation, Ramsey Bay Subdivision on Weyakwin Lake, and a few private properties. The main commercial activities are forestry, trapping and outfitting and significant in vehicular and off-road traffic for recreation (snow mobiles, all-terrain vehicle use, cross-country skiing, hiking, boating, cottages, etc.).

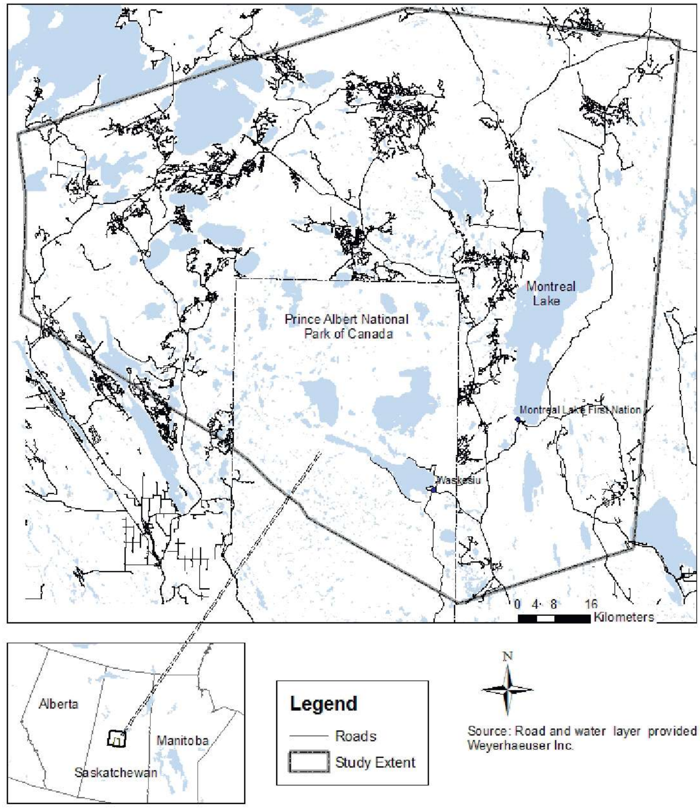

Fig. 1. Prince Albert Greater Ecosystem, Saskatchewan, Canada.

Historically, when fires started in the National Park they were extinguished before much of the landscape burned. In recent years, controlled burns and clearing has been initiated to create a fire barrier along the Park boundaries with the objective of letting non-threatening fires burn in the Park and restoring the natural fire frequency (Prince Albert National Park, 2008). The Saskatchewan Provincial Government manages the area for forestry and produces a 20-year forest management plan which is reviewed every 10 years. The Park produces a park management plan every 5 years. Both planning processes are subject to significant public consultation. The Prince Albert Model Forest was established in 1992, it supports research activities to assist with forest management planning efforts and community sustainability (Prince Albert Model Forest, 2008). Both the Province and the federal government are developing recovery plans for woodland caribou even if the species is not listed in provincial legislation as a species at risk.

Smoothstone-Wapaweka Woodland Caribou Management Unit

Arsenault (2003, 2005) has defined seven Woodland Caribou Management Units (WCMUs) within the Province based on clusters of caribou observations, areas of similar ecological characteristics (Acton *et al.*, 1998) and peatland distribution. The PAGE is part of the Smoothstone-Wapaweka WCMU and fecal-DNA capture-mark-recapture analysis of population size conducted in 2008 based on two capture events estimated the number of caribou at 128 (95% 116, 145) (Hettinga, unpublished results; Hettinga 2010). This corresponds to a population density of 0.009 caribou/km^2 when calculated over the entire PAGE study area, and 0.11 caribou/km^2 when based on MCPs of annual home ranges (Arsenault & Manseau, 2011).

Caribou past and present distribution

In order to examine changes in caribou distribution over time, woodland caribou occurrence data and associated survey efforts were collated for the period of 1950 to present. Data were obtained from Parks Canada and Saskatchewan Ministry of Environment and primarily consisted of survey observations, incidental sightings and telemetry data.

Landscape reconstruction

Map layers for the National Park and provincial crown land portion of the PAGE were created separately since the type and extent of data available for the two areas differed. Although we tried to create seamless layers for the PAGE area, map resolution issues could not be resolved and prevented us from directly comparing landscape changes between the two areas. For both the Park and the provincial crown land portion of the PAGE, we created map layers for 1966 and 2006 (same resolution) to assess historical landscape changes.

For the National Park area, the map layers consisted of a vegetation layer based on aerial photos taken in the 1960s (Parks Canada, 1986), a road layer and a burn polygon layer produced by Parks Canada, and a time since fire map produced by Weir (1996). Since the time since fire map was based on data collected in the 1990s, 30 years was subtracted from each forest stand to obtain a stand age for the 1966 layer. For the 2006 layer, stand types from the 1966 layer were used (we did not account for forest succession) and 10 years added to the stand ages obtained from Weir (1996) and the time since fire map. To account for natural disturbances that occurred in the past 10 years, after the creation of the time since fire map, the burn polygon layer was used and a burn class was assigned to all forest stands that fell under those polygons.

For the provincial crown land portion of the PAGE, the most recent forest resource inventory (FRI) was used along with a road and a cut block layer developed by Weyerhaeuser Canada Ltd. and a burn layer from the Province. The FRI was based on aerial photos from 2004 and the attributes of each forest stand consisted of cover type (species, height and density), soil type, topography, history of disturbance and stand age. For the current layer, data layers were provided by Weyerhaeuser Canada Ltd. Since a burn class was not available in the FRI, the burn polygon layer was used and a recent burn class assigned to all forest stands that fell under those polygons if the year of origin corresponded to the year of the fire ± 5 years. The cut block layer lacked a harvest year or a stand age for a number of polygons. To determine those stand ages, ring counts on tree cores was done on 10% (142 polygons) of the cut block polygons lacking a harvest year (Cook, 1990). Cut block polygons that were not sampled were assigned an age based on proximity to sampled cut block polygons, on the assumption that stands in a general area were harvested at approximately the same time. For the 1966 layer, 40 years was subtracted from the stand age. Since the FRI was current, stand composition and stand age prior to fire was not available. To obtain this information, older provincial FRI and hard copy maps from the 1960s were used. The maps were scanned and georeferenced and the composition and age of forest stands that burned over the last 40 years were entered manually.

To prepare the map layers for analyses, the vegetation layers were reclassified using a simplified classification scheme (Rettie *et al.*, 1997). Vegetation classes of similar composition were combined to produce 7 habitat classes (Table 1). Each map layer was rasterized at a 100 m grid and filtered using Spatially Explicit Landscape Event Simulator (SELES; Fall & Fall, 2001) to remove patches of less than 2 ha. Patches of this size are smaller than the minimum mapping unit and are often artifacts from the vector to raster conversion.

Validation of the 1966 layer

To validate the created 1996 layer, we used the georeferenced Forest Resource Inventory maps from the 1960s and compared the two layers using 7450 points systematically distributed with the Hawth's tools extension (Beyer, 2004) in ArcGIS 9.2 (Environmental Systems Research Institute, 2006). Stand attributes were derived for each point and compared. The results indicated that more than 70% of the points on the 1966 layer corresponded to the classes extracted from the 1960 hard copy maps. This overall accuracy level is above the accepted standard of 70% (Burnside, 2003). Accuracy levels of 72% were obtained for coniferous mature and 84% for coniferous young and recent burns. Some of the differences may be attributed to different classification schemes, differences in map resolution or differences in the boundaries drawn (limits of the polygons) for each forest stands.

Transition probabilities analyses

Transition probabilities measure the likelihood of one habitat type transitioning into another within a given time period (Burnside, 2003). We calculated the transition probability of each habitat class between 1966 and 2006 by quantifying changes of each pixel in the two layers using SELES (A. Fall, unpublished).

Landscape composition and configuration

Landscape metrics are commonly used when assessing fragmentation (e.g. Hargis *et al.*, 1998; Southworth *et al.*, 2002; Burnside *et al.*, 2003; Jackson *et al.*, 2005). Total area, patch number, area-weighted mean patch size, mean nearest neighbor, mean shape index

Table 1. Habitat classes used in the mapping and analyses of the provincial crown land and National Park portion of the PAGE.

Provincial Crown Land	National Park	Habitat Class	Age (years)
Jack Pine Mature	Jack Pine Mature	Mature Coniferous	≥40
Jack Pine/Black Spruce Mature	Jack Pine/Black Spruce Mature	Mature Coniferous	≥40
Black Spruce Mature	Black Spruce Mature	Mature Coniferous	≥40
White Spruce Mature	White Spruce Mature	Mature Coniferous	≥40
Coniferous Mixedwood Mature	Coniferous Mixedwood Mature	Mature Coniferous	≥40
Brushland	Brushland	Treed Muskeg	na
Closed Treed Muskeg	na	Treed Muskeg	na
Black Spruce/Larch	Black Spruce/Larch	Treed Muskeg	All ages
Open Treed Muskeg	na	Treed Muskeg	Na
Open Muskeg	na	Treed Muskeg	Na
Fen, marsh, bog	Meadow, marsh, bog	Treed Muskeg	Na
Hardwood Mixedwood	Hardwood Mixedwood, Aspen Mixedwood	Hardwood Mixedwood	All Ages
Hardwood	Hardwood	Hardwood Mixedwood	All Ages
Coniferous Young	Coniferous Young	Coniferous Young/Recent Burn	<40
Recent Burn	Recent Burn	Coniferous Young/Recent Burn	<40
Recent Logged	na	Recent Logged	<40
Road	Road	Road	na
Water	Water	Water	na

and amount of linear features were computed for each habitat type on the 1966 and 2006 map layers for the National Park and provincial crown land portions of the PAGE using Fragstats (McGarigal & Marks, 1995). Differences in landscape metrics between 1966 and 2006 were tested for statistical significance using t-tests in SAS 9.1 (SAS Institute Inc., 2003).

To further assess changes in landscape configuration, we used results from resource selection function analyses presented in Dyke (2008) which shown a greater selection of mature coniferous and treed muskegs away from avoided habitat types such as hardwood mixedwood. ArcGIS 9.2 was used to measure distances from a source patch, either coniferous mature or treed muskeg, to the nearest hardwood mixedwood patch. Resulting distances were compared using *t*-tests (SAS Institute Inc., 2003).

Results

Caribou past and present distribution

Although the survey efforts varied greatly between decades (particularly on provincial crown land), our results indicate that the extent of caribou use of the National Park portion of the PAGE has changed over the last 50 years, with very limited use detected since the 1980s (Fig. 2). Despite multiple surveys conducted throughout the Park in recent years and large radio-collaring programs, only one observation was made over the last 14 years, in 2007. Caribou are still present over most of the provincial crown land portion of the PAGE despite their low density and clustered distribution. A comparison of home range sizes using location data of radio-collared adult females from 1992-1995 (Rettie & Messier, 2001) and 2004-2008 (Arsenault & Manseau, 2011)

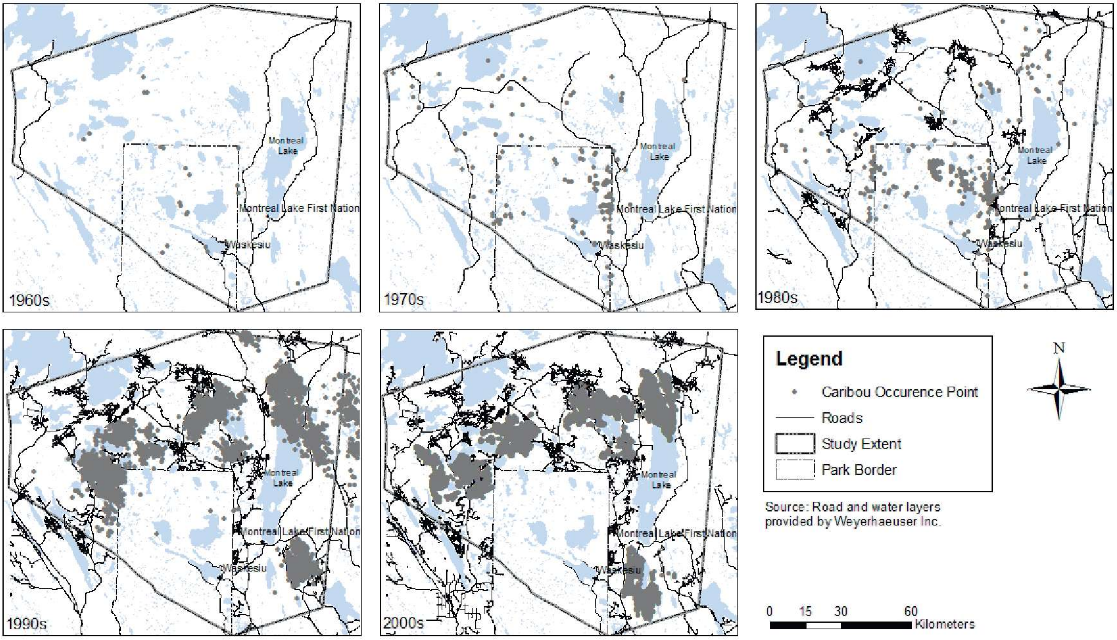

Fig. 2. Compilation of boreal caribou occurrences in the Prince Albert National Park for the period of 1960 to the present.

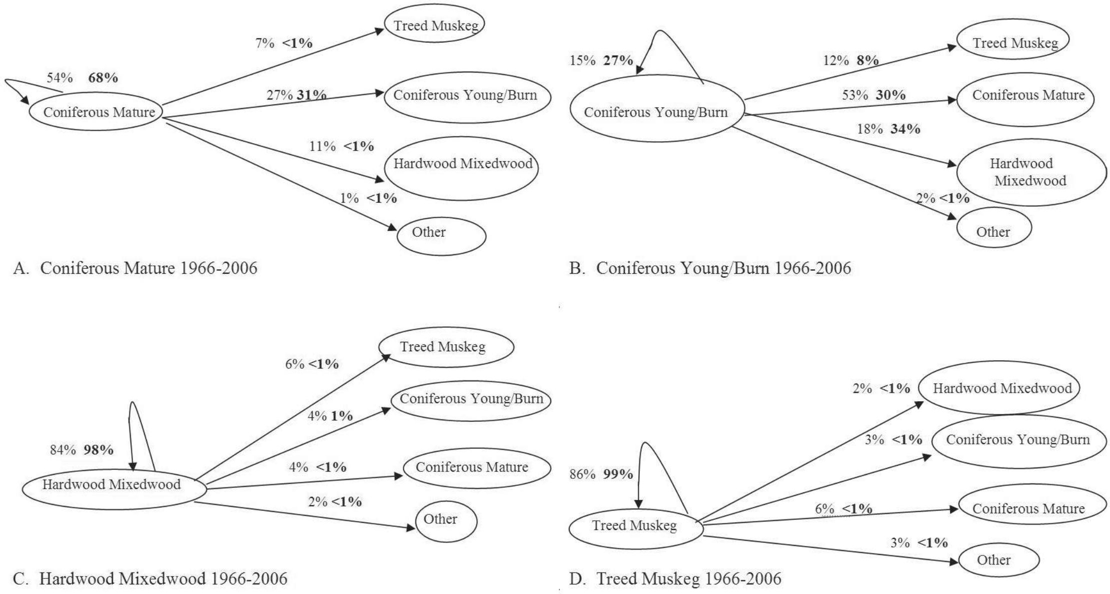

Fig. 3. Habitat transition probabilities between 1966 and 2006 for the Provincial crown land (normal font) and National Park portions (bold font) of the Prince Albert Greater Ecosystem. The main habitat types consisted of coniferous mature (A), coniferous young and burn (B), hardwood mixedwood (C) and treed muskeg (D).

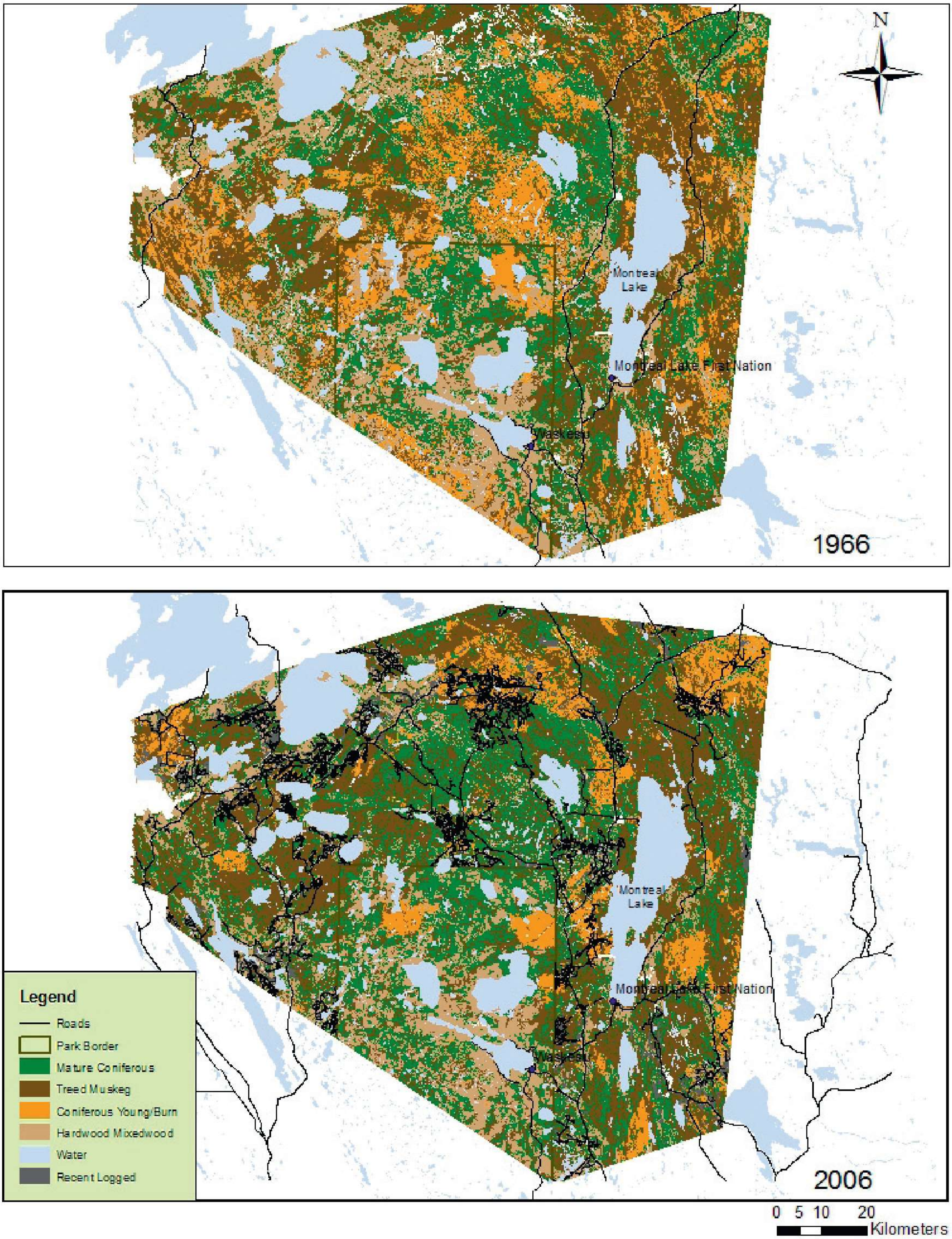

Fig. 4. Landcover, natural and anthropogenic disturbances in the Prince Albert Greater Ecosystem in 1966 and 2006.

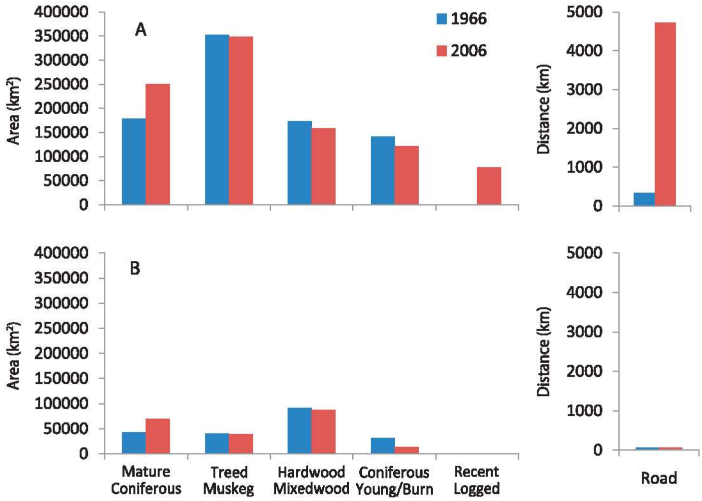

Fig. 5. Area covered by the main habitat types and linear features in 1966 and 2006 on the Provincial Crown Land (A) and National Park (B) portions of the Prince Albert Greater Ecosystem.

Table 2. Changes in habitat patch metrics ($\bar{x}$ ± s.e.) between 1966 and 2006 for the National Park portion of Prince Albert Greater Ecosystem.

Landscape metrics and habitat types	1966	2006	*P*
Area-weighted mean patch size (ha)			
Coniferous Mature	7186 ± 1000	8317 ± 1128	<0.0001
Treed Muskeg	647 ± 159	624 ± 155	0.0014
Hardwood	4895 ± 980	4905 ± 958	0.887
Coniferous Young/Burn	2010 ± 464	4771 ± 1413	<0.0001
Mean nearest neighbour (m)			
Coniferous Mature	225 ± 388	166 ± 192	0.0007
Treed Muskeg	183 ± 232	188 ± 241	0.6451
Hardwood	182 ± 176	193 ± 211	0.4499
Coniferous Young/Burn	258 ± 455	1323 ± 2292	0.0208
Mean shape index			
Coniferous Mature	1.98 ± 1.64	1.98 ± 1.70	0.898
Treed Muskeg	1.91 ± 1.03	1.91 ± 1.02	0.9535
Hardwood	1.97 ± 1.44	1.95 ± 1.40	0.9217
Coniferous Young/Burn	1.96 ± 1.10	2.11 ± 1.16	0.2536
Number of patches			
Coniferous Mature	436	544	
Treed Muskeg	954	945	
Hardwood	443	447	
Coniferous Young/Burn	279	28	

showed a significant reduction in areas used from an average minimum convex polygon (MCP) of 441 km^2 (s.d. = 393, n = 31) in 1992-1995 to 221 km^2 (s.d. = 145, n = 23) in 2004-2008.

Transition probabilities

Transition probabilities showed similar trends in the National Park and provincial crown land portion of the PAGE. The most notable changes were with forest stands in the coniferous mature and coniferous young/burn classes (Fig. 3A,B). Less than 27% of the coniferous young/burn class remained in that class. A large portion of these stands aged to coniferous mature or to hardwood mixedwood; the transition to a hardwood mixedwood class being higher for the National Park area. Fifty four percent of National Park land and 68% of provincial crown land remained in the coniferous mature class. A substantial portion of land within the PAGE as a whole also transitioned to coniferous young/recent burn class. Of all habitat types, hardwood mixedwood and treed muskeg had the highest probability of remaining the same habitat type (Fig. 3C,D). For hardwood mixedwood, 84% on provincial crown land and 98% on National Park land remained in the same class between 1966 and 2006. Similarly, 86% of treed muskegs on provincial crown land and 99% in the Park area remained treed muskegs.

Landscape changes

The predominant change to older stand ages suggests an ageing forest over the PAGE landscape as a whole. The transitioning of large tracts of crown land in the PAGE to coniferous young/burn stands corresponds to an increase in the number of cut blocks and the development of road and trails network (Figs. 4, 5). The first mill was built in 1966 and the amount of area logged increased from 0 ha logged in 1966 to 58211 ha logged in 2006. The road network remained the same in the National Park but increased 14-fold on the provincial crown land portion of the PAGE, from 342 km to 4730 km over the same 40-year period (0.03 to 0.44 km/km^2). During that time, major highways were constructed to improve access to the communities of La Ronge, Montreal Lake First Nation, Sled Lake, and Dore Lake. In addition, highways and logging roads were built as travel corridors to the pulp mills in Prince Albert, to the south, and to the saw mills in Big River and Nipawin, to the southwest and southeast, respectively. Finally, land was converted from forest to commercial/residential with the moving of Molanosa residents from the east side to the west side of Montreal Lake and the formation of a new community, Weyakwin. This change was further augmented with the expansion of residential areas on reserve lands of Montreal Lake First Nation and the Lac La Ronge Indian Band, and with development of the Ramsey Bay subdivision at Weyakwin Lake.

Landscape metrics include various measures of distribution, spacing, types, sizes and shapes of forest stands. The increased amount of mature coniferous stands shown in the previous results (Figs. 3, 4, 5) is further described in the landscape metrics analysis as an increased number of mature coniferous patches, from 436 to 544 in the Park and from 4874 to 5398 on crown land (Table 2, 3). The area-weighted mean patch sizes also increased significantly and the mean nearest neighbor distances decreased significantly indicating larger patches occurring closer together. Mean shape index describes patch shape and complexity and a significant decrease in the mean shape index outside the Park, indicating a drop in shape complexity, which often results from logging activities.

Change in coniferous young/burn stands between 1966 and 2006 also followed a similar trend in both portions of the PAGE, with the exception of area-weighted mean patch size (Table 2, 3). The decreased number of patches between 1966 and 2006 was again likely a reflection of changes in the amount of young coniferous/burn forest on the landscape. The change in area-weighted mean patch size of coniferous young/burn differs between the Park and provincial crown land; the observed increase in the National Park and decrease on crown land is likely due to natural disturbance in the Park and a combination of natural and anthropogenic disturbance on crown land. An increased mean nearest neighbor distance was also detected for both areas indicating patches of the same cover type occurred farther from one another.

Treed muskeg was the habitat type exhibiting the least amount of change in the PAGE. The area covered by treed muskeg and the number of patches were comparable between 1966 and 2006 in both the Park and on crown land and there were no sig-

Table 3. Changes in habitat patch metrics ($\bar{x}$ ± s.e.) between 1966 and 2006 for the provincial crown land portion of Prince Albert Greater Ecosystem.

Landscape metrics and habitat types	1966	2006	*P*
Area-weighted mean patch size (ha)			
Coniferous Mature	4013 ± 449	4043 ± 450	<0.0001
Treed Muskeg	14822 ± 1232	8880 ± 902	<0.0001
Hardwood	3886 ± 497	340 ± 95	<0.0001
Coniferous Young/Burn	3353 ± 426	2154 ± 372	<0.0001
Cutblocks	n/a	121 ± 47	n/a
Mean nearest neighbour (m)			
Coniferous Mature	217 ± 220	184 ± 162	<0.0001
Treed Muskeg	200 ± 170	196 ± 171	0.3154
Hardwood	265 ± 354	254 ± 354	0.2514
Coniferous Young/Burn	275 ± 392	333 ± 636	0.0015
Cutblocks	n/a	169 ± 295	n/a
Mean shape index			
Coniferous Mature	1.81 ± 1.08	1.77 ± 1.19	0.0453
Treed Muskeg	1.83 ± 1.24	1.79 ± 1.19	0.0697
Hardwood	1.69 ± 1.02	1.79 ± 0.66	0.0991
Coniferous Young/Burn	1.76 ± 1.07	1.79 ± 1	0.6443
Cutblocks	n/a	1.90 ± 1.2	n/a
Number of patches			
Coniferous Mature	4874	5398	
Treed Muskeg	3543	3760	
Hardwood	2830	3845	
Cutblocks	0	2526	

Table 4. Landscape configuration changes. Distance ($\bar{x}$ ± s.e.) between selected and avoided habitat types in1966 and 2006 for the provincial crown land and Prince Albert National Park areas of the Prince Albert Greater Ecosystem

Distance Variables	1966	2006	*P*
Provincial Crown Land			
Coniferous Mature to Hardwood (m)	344 ± 714	283 ± 721	<0.001
Treed Muskeg to Hardwood (m)	280 ± 507	191 ± 620	<0.001
Prince Albert National Park			
Coniferous Mature to Hardwood (m)	73 ± 299	80 ± 330	0.712
Treed Muskeg to Hardwood (m)	69 ± 269	74 ± 237	0.689

nificant changes in mean nearest neighbour or mean shape index (Table 2, 3). The only noticeable change in treed muskeg was a significant decrease in area-weighted mean patch size, both in the Park and on the provincial crown land.

Similar to treed muskeg, limited changes were observed for hardwood mixedwood stands between 1966 and 2006. The only changes detected were a decrease in area covered by hardwood mixedwood stands (174643 ha to 108063 ha), an increase in number of patches (Table 2) and a decrease in area-weighted mean patch size, all on the crown land portion of the PAGE. These changes coincided with a history of logging that accelerated over the study period along with the construction of a road network.

Finally, changes in landscape configuration measured through distance metrics were only significant on the provincial crown land portion of the PAGE. Distances between habitat classes selected by boreal caribou (mature coniferous and treed muskeg) and those avoided (hardwood mixedwood) were significantly less on provincial crown land in 2006 when compared to 1966 (Table 4).

Discussion

The historical compilation of caribou observations indicates that the southern boundary of caribou distribution (in central Saskatchewan) has not changed over the last 50 years, although range retraction has occurred in other parts of the Province (Arseanult 2003, 2005; Saskatchewan Environment, 2007). Also, very few caribou observations have been made in the National Park since the 1980s despite significant survey and collaring efforts. In 2007, caribou tracks were seen in the northeast sector of the Park, north of Crean Lake, fecal pellets were collected and 3 unique genotypes profiled (unpublished results). Other tracks were seen east of the Park along Highway 2, near Crean River. These results along with habitat modeling work done by Dyke (2008) and Arlt (2009) suggest that the Park area corresponds to only a small portion of the population range, the northern sector of the Park primarily consists of winter habitat and recent landscape changes may be affecting a seasonal range use pattern. Results of Dyke (2008) suggest that calving and summer habitats are primarily found north of the Park boundaries, with some of the core areas north of Montreal Lake. Reduced movement and a more clustered distribution of adult females were also quantified through telemetry work for the period of 1992-1995 to 2004-2008 (Arsenault & Manseau, 2011).

For both the National Park and the provincial crown land portions of the PAGE, our results showed an ageing landscape which is also reported in other regions of the boreal forest (Johnson *et al.*, 1998, Walker, 1999; Harvey *et al.*, 2002) and most often attributed to changes in fire incidence and fire management strategies (Walker, 1999). As observed in other regions of the boreal forest, anthropogenic activities also increased over the last 40 years and particularly over the last 20 years. As expected, the changes primarily occurred on the provincial crown land portion of the PAGE and are the direct response of commercial logging activities and associated roads and trails network. Interestingly, both the results from the 1992-1995 and the 2004-2009 collaring work showed that animals north of Montreal Lake, west of Bittern Lake and near Weyakwin Lake never crossed Highway 2. Animals west of Lawrence Lake never crossed Highway 922. In both locales, the animals moved within a few meters of the road but did not cross the road.

The National Park was established in 1927 and it is only in the 1960s that major landscape changes occurred with the beginning of commercial forest harvesting, the development of road network and increase infrastructure. The commercial interest in forest timber, the development of roads, cottaging areas and settlements have all contributed to the current fire suppression efforts (Arsenault & Manseau, 2011). In the early 1940s, many fires burned unsuppressed in both the Park and surrounding area (Weir, 1996) as fire prevention and fire suppression were not practiced (R. Davies, pers. comm.). Changes in fire interval following settlement and industrial development have also been observed in other regions including Ontario and Québec (Bergeron, 1991), British Columbia (Johnson & Larsen, 1991), Alberta (Larsen, 1997) and Minnesota (Clark, 1988).

In the Park, fire suppression still occurs to protect residences, neighboring communities, park facilities and adjacent provincial forests (Prince Albert National Park, 2008). Research on fire frequency in Prince Albert National Park documented a fire cycle of 25 years from 1760 to 1890, an increased fire cycle of 75 years from 1890-1945 and 645 years from 1945 to 1995 (Weir, 1996; Weir *et al.* 2000). They explained that the short fire cycle of the early period coincided with the Little Ice Age, the longer cycle of the early 1900s with the end of the Little Ice Age and a change of climate and the more recent longer fire cycle to be likely due to fire suppression. Extending fire intervals beyond long-term norms is detrimental in the boreal forest because fire is a natural disturbance and essential to maintaining lichen rich coniferous stands (Klein, 1992; Johnson *et al.*, 2001). The National Park recently initiated controlled burns along the Park boundaries in order to create a fire break, enabling them to let wildfires burn in the Park and reestablishing a natural fire frequency (Prince Albert National Park, 2008). Our results clearly showed that increased anthropogenic activities over the last 40 years have led to a different landscape and significant habitat fragmentation. The roads and trails network increased 14-fold on the provincial crown land portion of the PAGE, from 342 km to 4730 km. Fragmentation as characterized by an increased number of patches and mean nearest neighbor distances (Forman & Godron, 1986; Heggm *et al.*, 2000; Turner *et al.*, 2001) was detected for most habitat types except mature coniferous stands. A decrease in mean shape index for the mature coniferous stands suggests a drop in complexity of patch shape which is often associated with logging activities (McGarigal & Marks, 1995). Aside from the development of a road network, the most significant indicators of fragmentation for caribou are the distance metrics which capture the functional attributes of high quality habitat patches. Along with a larger number of patches and larger patch sizes of mature coniferous stands in 2006 (which is favorable to caribou), we observed a greater proximity of habitat classes selected by boreal caribou (mature coniferous and treed muskeg) and those avoided (hardwood mixedwood) on provincial crown land in 2006 when compared to 1966. The interspersion of avoided habitat types and roads and trails network impacted the functional attributes of selected habitat types for caribou and resulted in reduced habitat connectivity at landscape scales (see Arlt (2009) for more results of landscape connectivity analysis).

Boreal caribou are sensitive to landscape changes and the long-term persistence of local populations is essential for the conservation of this species (Thomas & Gray, 2002, Environment Canada, 2007). The increased abundance of mature forest stands, in both the Park and the provincial crown land of the PAGE, should be favorable to woodland caribou (Hirai, 1998; Brown *et al.*, 2000a; Brown *et al.*, 2000b; Rettie & Messier 2000, Schneider *et al.*, 2000; Thomas & Gray 2002, Mahoney & Virgl, 2003; Lander 2006, O'Brien *et al.*, 2006) however, the increased amount of anthropogenic disturbances and resulting patchwork of selected and avoided habitat types on provincial crown land are potentially counteracting those benefits and reducing the functional values of the mature coniferous stands. O'Brien (2006) showed that woodland caribou select large clusters of high quality habitat patches over the high quality habitat patches themselves. These large clusters of well-connected habitat patches or the resulting habitat mosaic are important in providing food, cover and separation from other ungulate species and associated predators.

Anthropogenic disturbance, such as logging and access development, have detrimental effects on caribou populations (Cumming & Beange, 1987; Rettie & Messier, 1998). Increased number of patches of recently logged areas may attract greater number of other ungulate species such as moose, elk and white-tailed deer (Brown *et al.*, 2000a; James *et al.*, 2004) and subsequently, higher densities of predators such as wolves (Bergerud & Elliot, 1986; Rettie & Messier, 1998). Ultimately, increased area logged can lead to range retraction (Bradshaw *et al.*, 1997) as caribou actively avoid disturbance (Cumming & Beange, 1987; Chubbs *et al.*, 1993; Smith *et al.*, 2000; Johnson & Gilligham, 2002). A developed roads and trails network may also facilitate access to formerly isolated areas increasing mortality, from hunting and predation (Dyer *et al.*, 2001; Whittington *et al.*, 2005) and from caribou-vehicle accidents (Cumming & Beange, 1987). In an attempt to identify landscape disturbance threshold for woodland caribou, Sorensen *et al.* (2007) examined the relationship between functional habitat loss resulting from cumulative effects of natural and anthropogenic disturbances, and the rate of population change for six populations of boreal caribou in Alberta, Canada. In defining habitat loss as the percentage area of caribou range within 250 m of anthropogenic footprint and the percentage of caribou range disturbed by wildfire within the last 50 years, they obtained a strong negative correlation between these two variables and population growth rate. They also identified landscape disturbance thresholds above which a population would be declining (λ<1). When applying their equation to the PAGE area, we obtained a λ of 1.06 when the amount of disturbance was calculated as a proportion of the entire PAGE study area, 1.03 when based on a study area excluding PANP and 1.17 when based on the extent of caribou home ranges (Arsenault & Manseau, 2011). This suggests that the amount of disturbance in the PAGE is below the disturbance threshold identified by Sorensen *et al.* (2007) and the area should support a stable or growing population. Population demographic work done by Rettie & Messier (1998) for the period of 1992-1995 and the PAGE study for 2004-2009 (Arsenault & Manseau, 2011) do not support these results. The characteristics of the PAGE landscape may be different than caribou ranges studied in Alberta and work on landscape changes and disturbance thresholds is ongoing (Environment Canada, 2008).

The PAGE study area has undergone structural changes over the last 40 years from an area that presented a lesser amount of mature coniferous forest and limited access to a working landscape with older forest stands, a well developed roads and trails network and significant human activities. The National Park and provincial crown land portions of the PAGE are managed differently; the provincial crown land being accessible to forestry, offering transport corridors among communities and diverse commercial and recreational activities. The National Park area is protected from industrial activities and as seen in this study, accounts for a small portion of the population range and can only play a minor role in ensuring the long-term viability of boreal caribou. Recovery efforts will therefore require a recognition of the highly dynamic nature of this landscape, the co-occurrence of many ungulate species and their prey, and a recent but well developed access network. Recovery efforts will also require integrated landscape level management strategies (Armstrong *et al.*, 2000; Mosnier *et al.* 2003), ensuring that sufficient high quality habitat and adequate connectivity within and between clusters of habitat exist and that land use planning (forest harvesting, resource exploration, access development) is done in a way that ultimately allows caribou to move freely throughout their range (for more specific forest management recommendations, see Arsenault & Manseau, 2011).

Acknowledgements

This project was funded by Parks Canada Species at Risk Recovery Action, a program supported by the National Strategy for the Protection of Species at Risk, Saskatchewan Ministry of Environment through the Fish and Wildlife Development Fund, Weyerhaeuser Canada Ltd., and Prince Albert Model Forest. Data were provided by Prince Albert National Park of Canada, Weyerhaeuser Canada Ltd. and Saskatchewan Ministry of Environment. We thank Sonesinh Keobouasone for GIS support and field assistance and Al Arsenault, Tim Trottier and Paul Galpern for providing comments on the manuscript.

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