Boreal Caribou Science to Inform Recovery
Science Summary Sheet #1

Background

The Boreal population of Woodland Caribou (*Rangifer tarandus caribou*) (hereafter 'boreal caribou') is listed as threatened under the *Species at Risk* Act and is distributed broadly throughout the boreal forest.

Boreal caribou require continuous tracts of undisturbed habitat rich in mature to old-growth coniferous forest, muskegs, peat lands, and upland or hilly areas. Large areas with suitable quality habitat allow boreal caribou to disperse across the landscape when conditions are unfavorable (e.g. natural fire disturbance, anthropogenic disturbance) and to maintain low population densities to reduce their risk of predation.

In 2011, Environment and Climate Change Canada (ECCC) released a Scientific Assessment that evaluated the contribution of natural and anthropogenic disturbances to boreal caribou range condition and the likelihood of various range conditions supporting self-sustaining populations across Canada (Environment Canada, 2011). A national meta-analysis based on 24 boreal caribou study areas investigated the relationship between calf recruitment and a range of predictor variables hypothesized to influence boreal caribou population dynamics.

Analyses found a clear negative relationship between recruitment and the proportion of non-overlapping total disturbance within a range (anthropogenic disturbance buffered by 500m and unbuffered fire). The recruitment-disturbance relationship was a major component of the model developed for quantifying the capacity of a range to maintain a self-sustaining caribou population based on habitat condition described in the Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population in Canada (EC 2012).

Since 2011, new demographic data has been collected by provinces, territories, academics and Manitoba Hydro giving ECCC researchers the opportunity to explore a key knowledge gap identified in the Schedule of Studies in the Recovery Strategy regarding the need to further investigate the applicability of the disturbance model in Saskatchewan's Boreal Shield (EC 2012).

This summary provides a synthesis of these two science pieces completed by ECCC briefly describing – why each piece was done, key results, and how the work relates to the 2012 Recovery Strategy. For further information, please consult the 2011 Scientific Assessment and 2012 Recovery Strategy documents available on the SAR Public Registry.

2011 Meta-Analysis of Boreal Caribou Population and Habitat Condition

Background

The 2011 Scientific Assessment was prepared to help inform critical habitat identification in the 2012 Recovery Strategy for the Boreal population of Woodland Caribou. The goal of the assessment was to better understand the relationship(s) between boreal caribou population condition and the condition of the range to determine the amount of habitat required to support a self-sustaining population.

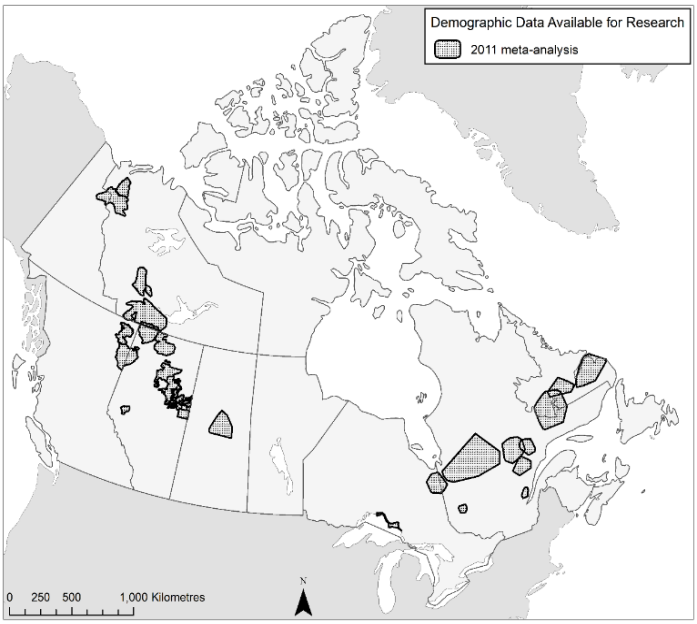

Figure 1. Map showing the location of 24 caribou study areas across the Canadian boreal region used in the 2011 meta-analysis.

Meta-Analysis Methodology

To understand the relationship between range condition and caribou population status, ECCC conducted a national meta-analysis across 24 study areas in Canada (Figure 1). Boreal caribou calf recruitment (calves/100 cows) was selected as an indicator for population status for assessment against predictor variables quantifying the amount, type and configuration of disturbance and habitat attributes. The analysis built on previous work that demonstrated the relationship between calf recruitment and elements of disturbance (EC 2008).

A standardized mapping methodology was developed and applied by Environment and Climate Change Canada to provide a nationally consistent, detailed geospatial anthropogenic disturbance mapping layer across all boreal caribou ranges as an input for the analysis (Pasher et al. 2013). The new layer, along with other geospatial datasets, provided the basis for exploration of a range of factors that might influence boreal caribou population condition including linear and polygonal disturbances, fire, habitat configuration and high quality habitat.

An analysis of the additional zone of influence beyond the visible footprint of human disturbance quantified the ecological effects of human development on boreal caribou (e.g. increased risk of predation in areas close to disturbance). The model evaluation revealed a set of candidate buffer widths (range: 500m up to 2000m). The most conservative buffer in the set from a land-use management perspective (500m) was selected to represent the ecological footprint of human disturbance on caribou recruitment in subsequent analyses.

Thirteen models were developed to test:

- the relative effects of different types of disturbance (M0-8);
- the effects of anthropogenic disturbance and the configuration of disturbance (M9); and
- the influence of undisturbed habitats, including high quality habitat (M10-12).

Models were run at the national scale (all data). Ecozone was included as a predictor variable to explore whether regional variation existed in the relationship between caribou demography and range condition.

Key Findings

While a number of models were explored, total non-overlapping disturbance (M3 model) was the best predictor of boreal caribou recruitment rates (Table 1; Figure 2). This model explained almost 70% of the variation in boreal caribou calf recruitment across 24 study areas. Although the M7 model was not a candidate model within $2\Delta AIC_c$, fire did have a significant negative effect on recruitment in addition to anthropogenic disturbance (P=0.01). Moreover, fire was integral to the calculations of total disturbance.

Table 1. Descriptor variables and results of models of disturbance effects on estimated recruitment ranked from the lowest to highest AICc values.

Model	Predictor variables	Description	Recruitment models (N=24)					
			R^2	AIC_c	$dAIC_c$	w	with Ecozone R^2	with Ecozone AIC_c
M3	total_dist	Percent total non-overlapping fire and anthropogenic disturbance (500 m buffer on anthropogenic; reservoirs removed)	0.69	169.81	0.00	0.44	0.70	178.70
M7	anthro + fire_excl_anthro	M1 + percent fire exclusive of anthropogenic disturbances	0.70	172.50	2.69	0.11	0.70	182.76
M12	total_dist + hqh	M3 + proportion of high quality habitat	0.70	172.56	2.74	0.11	0.70	177.83
M9	total_dist + ln_nn	M3 + area-weighted mean nearest neighbour distance (500 m buffer)	0.69	172.66	2.85	0.11	0.70	182.72
M8	total_dist + fire_prop_dist	M3 + fires as proportion of total disturbance	0.69	172.66	2.85	0.11	0.70	182.67
M4	lnlinear	Percent linear anthropogenic disturbance (500 m buffer); log transformed	0.65	173.19	3.38	0.08	0.65	182.35
M6	lnlinear + poly	M4 + M5	0.65	175.72	5.91	0.02	0.65	186.15
M1	anthro	Percent anthropogenic disturbance (500 m buffer; reservoirs removed)	0.60	176.32	6.51	0.02	0.65	182.45
M0	total_dist_Ph1	Percent total non-overlapping disturbance (Phase 1)	0.57	178.18	8.37	0.01	0.57	186.70
M11	ifl_nofire	Proportion intact forest landscape exclusive of anthropogenic disturbance and fire	0.47	182.76	12.95	0.00	0.50	189.45
M10	ifl	Proportion intact forest landscape exclusive of anthropogenic disturbance	0.35	187.81	18.00	0.00	0.47	190.51
M5	poly	Percent polygonal anthropogenic disturbance (500 m buffer; reservoirs removed)	0.30	189.68	19.87	0.00	0.55	186.95
M2	fire	Percent fire (unbuffered)	0.05	196.98	27.17	0.00	0.26	193.51

Please note that this table provides an update to the results of the original analysis published in the 2011 Scientific Assessment. Of note, the total disturbance model is the only candidate model with no other models falling within 2 Δ AIC_c. Results remain consistent with the information used to inform Critical Habitat Identification in the Recovery Strategy.

The analysis indicated that there was some regional variability in the effect of different factors on caribou recruitment (illustrated by changes in AIC_c between national scale analysis and analysis with Ecozone). There was some indication of regional differences in the effects of fire, polygonal disturbance types, high quality habitat as well as the proportion of intact forest (≥ 5 000 hectares) on caribou recruitment. However, none of the regional models including these variables were within 2 ΔAIC_c of the national total disturbance model.

The disturbance-recruitment model represents the effects of a combination of factors driving caribou population dynamics across the boreal forest and is supported by a wide range of studies in the scientific literature. Total disturbance captures both: the direct effects of habitat loss causing range contraction and isolation; and, the indirect effects from elevated predation risk associated with the influence of the amount and configuration of disturbed habitat on the distribution and density of alternate prey species and shared predators.

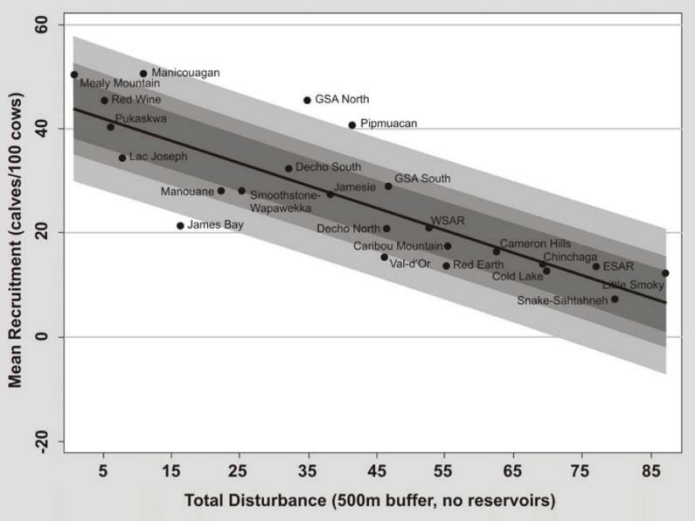

Figure 2. Graph showing 50, 70 and 90 % prediction bands for the best univariate regression model (M3) of caribou recruitment and landscape disturbance.

Management Decisions

To estimate probability of achieving self-sustaining boreal caribou populations relative to total disturbance in a boreal caribou range (self-sustaining defined as a population showing a stable or increasing population trend over 20 years), the empirical relationship between total disturbance and recruitment from the top model (M3) was combined with a national average of adult female survival (85% survival).

The total amount of disturbance was used to establish a disturbance management threshold of 65% undisturbed habitat within each range (Figure 3). The threshold provides the basis for critical habitat identification in the Recovery Strategy (EC 2012) for all local populations of boreal caribou in Canada except for Saskatchewan's Boreal Shield (SK1), which is subject to high fire disturbance (55%) with very little anthropogenic disturbance (3%) and lacked recruitment data to evaluate if the recruitment-disturbance relationship applied under these conditions.

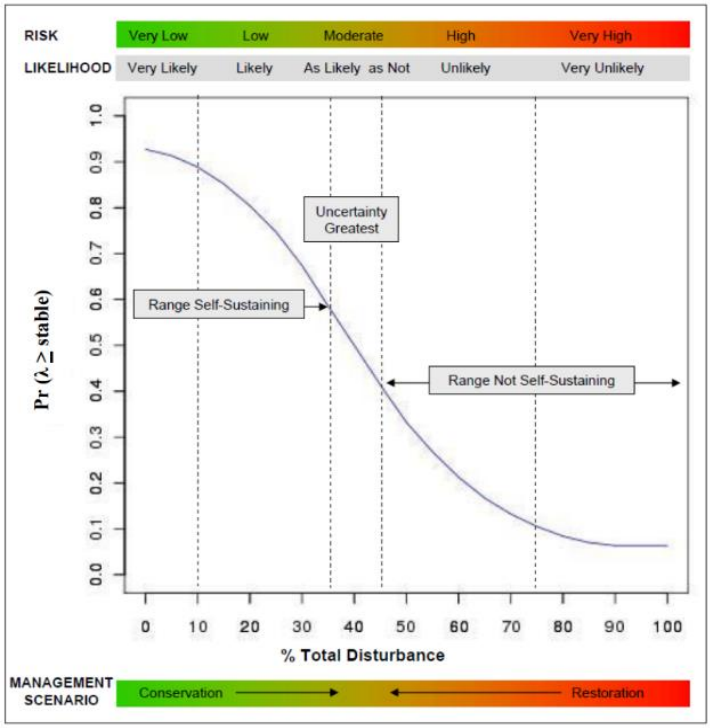

Figure 3. Graph showing the probability of stable or positive population growth relative to total disturbance in a range (used to establish the risk based disturbance management threshold).

Scientific Research to Inform Critical Habitat Identification in Saskatchewan's Boreal Shield (SK1)

Background

Critical habitat for Saskatchewan's Boreal Shield (SK1) was not identified in the 2012 Recovery Strategy since population size and trend were unknown, and the high fire (55%) and low anthropogenic (3%) disturbance conditions were not well represented in the data used to define the disturbance management threshold of 65% undisturbed habitat in each range (Figure 4). This section of the summary outlines research conducted by ECCC scientists since the release of the 2012 Recovery Strategy to address key knowledge gaps identified in the schedule of studies to inform the identification of critical habitat in SK1.

A New National Boreal Caribou Dataset

The 2011 meta-analysis of caribou demography in relation to range-level disturbance was conducted with 24 caribou study areas. Since then, 3 years of data have been collected for SK1 (Table 2) and a number of other jurisdictions have acquired additional recruitment and adult survival data, allowing ECCC scientists to work with provincial/ territorial and academic partners to build a dataset with more than double the number of study areas for recruitment (N = 57) and 45 study areas for adult survival (Figure 5). ECCC also updated its disturbance data based on 2015 imagery to allow for temporal correspondence with new demographic data.

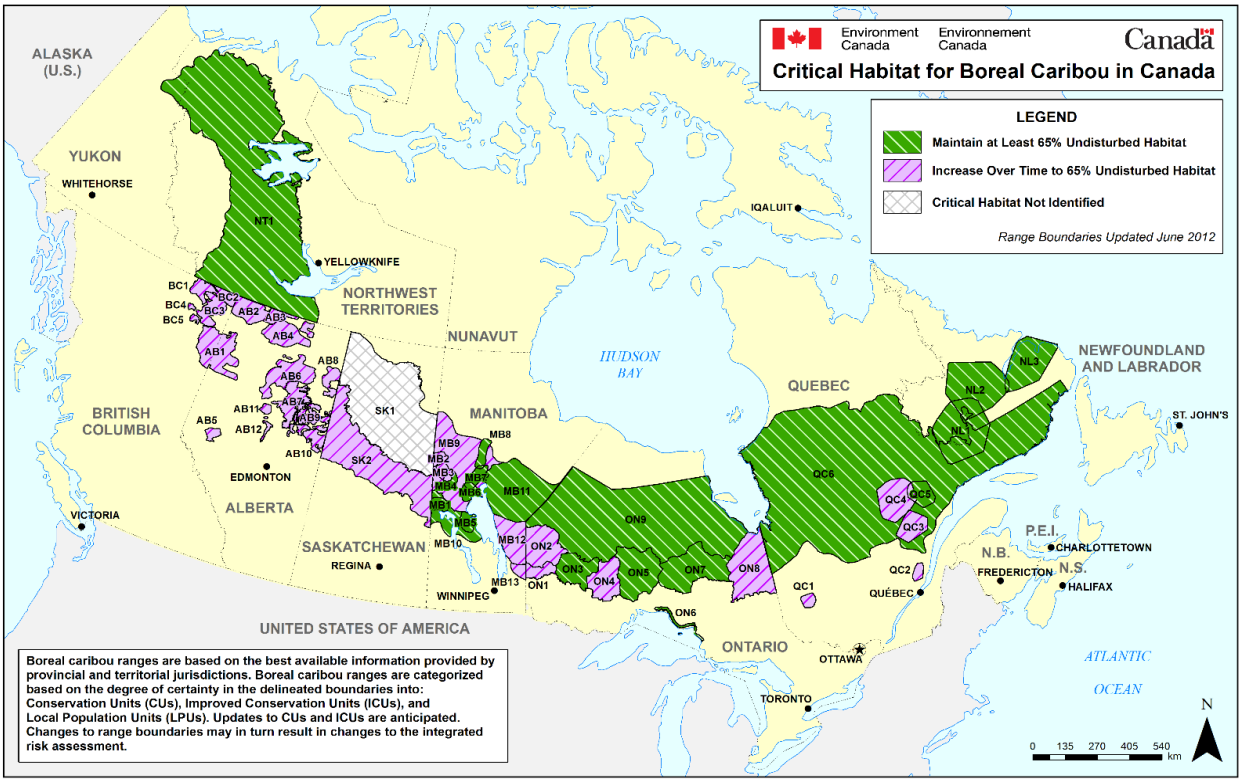

Figure 4. Map indicating critical habitat for boreal caribou in Canada as identified in the 2012 Recovery Strategy. Critical habitat was not identified in Saskatchewan's Boreal Shield (SK1).

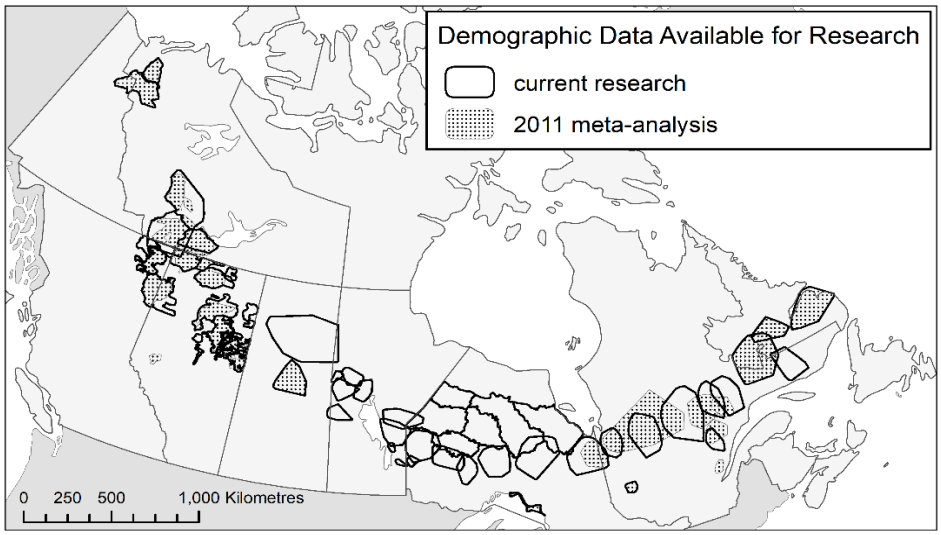

Figure 5. Map showing the locations of the expanded dataset of caribou study areas across the Canadian boreal region.

This new larger dataset facilitated an evaluation of a subset of the models tested in 2011 to further investigate the potential different effects of fire and anthropogenic disturbance on caribou populations. It also allowed newly collected demographic data from SK1 to be evaluated in the context of the national models that predict recruitment as a function of disturbance.

The updated dataset also had better coverage of the spectrum of combinations between anthropogenic disturbance and fire – including high fire and low anthropogenic disturbance (Figure 6).

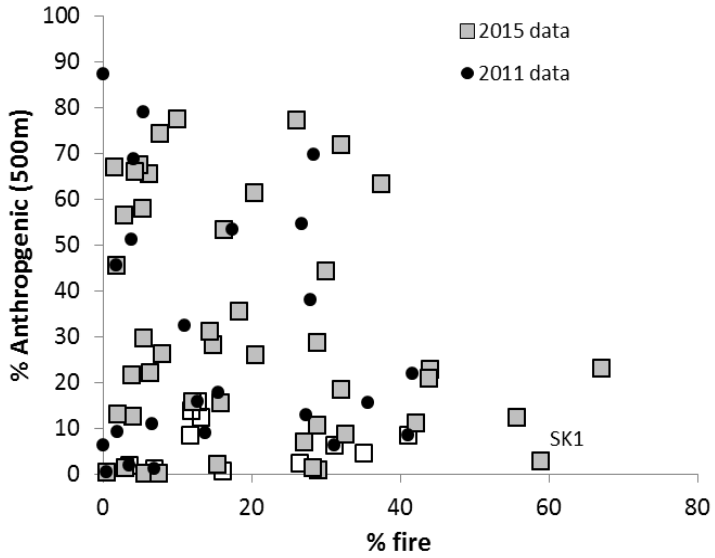

Figure 6. Graph showing the percent anthropogenic disturbance (buffered by 500m) versus the percent fire in the 24 study areas used for the 2011 analysis (●); and updated areas with both recruitment and adult survival estimates (■), and recruitment estimates only (□).

Table 2. Data collected over three years in SK1 by the University of Saskatchewan (McLoughlin pers. com.).

Year	Survival rate	Age ratio (*X*)	Recruitment (*R*)	λ
2014-2015	0.914 [0.851-0968]	0.207 [0.146-0.271]	0.094 [0.068-0.119]	1.009 [0.939-1.074]
2015-2016	0.961 [0.910-1.000]	0.216 [0.162-0.272]	0.097 [0.075-0.120]	1.065 [1.007-1.115]
2016-2017	0.872 [0.785-0.951]	0.144 [0.088-0.205]	0.067 [0.042-0.093]	0.935 [0.839-1.021]

Recruitment Analysis

ECCC researchers evaluated five of the 2011 recruitment models with the larger dataset (Table 3). The focus was on distinguishing the effects of anthropogenic disturbance from fire. As with the 2011 analysis, anthropogenic disturbance was buffered by 500m, whereas fire remained unbuffered.

The model separating the effects of anthropogenic disturbance from fire (Anthro + fire_excl_anthro) received the highest level of support explaining 39% of variation in recruitment. While both fire and anthropogenic disturbance had significantly negative effects on caribou recruitment (Ps<0.05), anthropogenic disturbance had a larger effect (standardized regression coefficients: β for anthro. = -0.623; β for fire = -0.221).

Table 3. Recruitment models (N=57)

Model	Predictor variables	R^2	AIC_c	ΔAIC_c	w
M3	Total_dist	0.35	426.39	0.78	0.28
M7	Anthro + fire_excl_anthro	0.39 (0.36)	425.61	0	0.41
M8	Total_dist+ fire_prop_dist	0.36 (0.33)	428.21	2.60	0.11
M1	anthro	0.34	427.11	1.5	0.20
M2	fire	0.02	450	24.39	0.00

The average observed recruitment for SK1 (highlighted in red) fell within the 95% confidence intervals for both the total disturbance model (Total_Dist) and the model that separated anthropogenic disturbance from fire (Anthro + fire_excl_anthro) (Figure 7) indicating that both models predict recruitment for SK1 adequately.

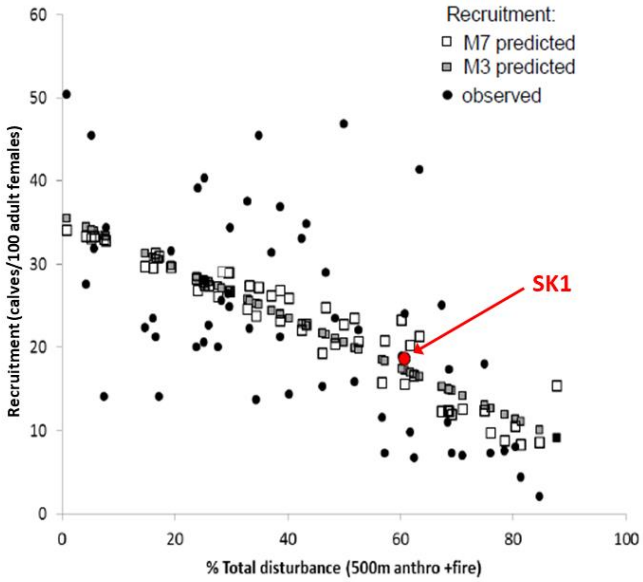

Figure 7. Graph of the observed and predicted recruitment for M3 and M7 versus total disturbance.

The new data introduced more variation into the relationship compared to the 2011 analysis, particularly at the lower end of the total disturbance spectrum (Figure 7). Several factors could have contributed to the observed pattern, including better representation of the diversity in range conditions experienced by boreal caribou across the country (e.g. environmental noise created by variation in weather conditions, disease, hunting, etc.). Methods used for estimating recruitment also vary across the country (e.g. survey techniques, assumptions about sex ratios and other measures differ among jurisdictions). Despite potential sources of variation, the recruitment-disturbance relationship still demonstrates a strong negative signal. Moreover, the reduction in variation at the high end of percent total disturbance suggests that disturbance becomes the primary factor driving caribou recruitment as disturbance levels increase. In most caribou ranges, anthropogenic disturbance is the dominant disturbance type, with an impact that outweighs that of fire by a 3:1 ratio. Fire suppression is also greater in areas with a larger human footprint.

Adult Female Survival Analysis

The same five models were used to evaluate the effect of elements of disturbance on adult female survival (Table 4). The model looking at anthropogenic disturbance (buffered by 500m) only received the highest level of support explaining about 12% of the variation in adult female survival. This suggests that adult female survival is primarily driven by anthropogenic disturbance rather than fire. Additional analyses are needed to understand other factors, beyond anthropogenic disturbance, that may be influencing adult female survival; however, the results are consistent with other studies that suggest factors affecting females may differ from those affecting calves (as they are more adept at predator avoidance and vulnerable to a smaller subset of predators compared to calves).

Table 4. Adult survival models (N=45)

Model	Predictor variables	R^2	AIC_c	ΔAIC_c	w
M3	Total_dist	0.060	-142.740	3.059	0.124114
M7	Anthro + fire_excl_ anthro	0.124	-143.497	2.301	0.181242
M8	Total_dist+fire _prop_dist	0.093	-141.944	3.855	0.083368
M1	anthro	0.122	-145.799	0.000	0.572807
M2	fire	0.010	-140.397	5.401	0.03847

Maintaining a Self-Sustaining SK1 Population

The new boreal caribou demographic information provided by partners was used to update the 2011 population model developed for assessing the probability that a caribou population was self-sustaining over 20 years (see methods described in EC 2011 for details on population model). More specifically, a beta distribution was used to characterize among year stochastic variability in adult female survival and recruitment because it provided the best fit to the updated dataset.

The population model was used to calculate the probability of maintaining a self-sustaining population in SK1 over 20 years under five different scenarios. The first scenario estimated the probability of maintaining a self-sustaining population under the current disturbance regime for SK1 (58% fire and 3% anthropogenic disturbance or 60% total non-overlapping disturbance in 2015) using the empirical estimates of recruitment and adult survival collected over 3 years provided by the University of Saskatchewan (McLoughlin pers. com.).

The remaining scenarios explored the effect of additional levels of buffered anthropogenic disturbance (i.e. increments of 5% up to a total of 20% additional anthropogenic disturbance on top of the existing footprint) on the probability of maintaining a self-sustaining population in SK1. The national models developed for recruitment and adult survival (described above) were used to forecast the effects of increasing anthropogenic disturbance. All scenarios assumed no increase in % fire disturbance over the short-term.

At current disturbance levels, the probability that SK1 is self-sustaining is 0.71. The Recovery Strategy emphasizes that some local populations may be more vulnerable to disturbance and require <35% disturbance, and others may be more resilient and able to tolerate >35% disturbance. Despite recognition that there will be variation in the relationship between disturbance and population condition, the 0.71 probability of maintaining a self-sustaining population for SK1 falls outside of the 90% confidence intervals of the model (Figure 8), largely due to adult survival rates that exceed the national average. In fact, SK1 has the highest reported average adult female survival rate for boreal caribou in all of Canada currently.

The results of the scenarios investigating increases in anthropogenic disturbance suggest that SK1 would reach the recovery threshold of a 60% chance of maintaining a self-sustaining population with an additional 2.6-2.7% of anthropogenic disturbance (Figure 9). This result in combination with other factors is being used to inform the process for critical habitat identification in SK1.

Given the sensitivity of this model to slight increases in anthropogenic disturbance, to decreases in adult female survival and uncertainty with forecasting future landscape change (i.e. scenarios assumed no additional fire), the SK1 population will need to be closely monitored to ensure the recovery objective of maintaining a self-sustaining population is not compromised and that additional disturbance does not result in range contraction or isolation.

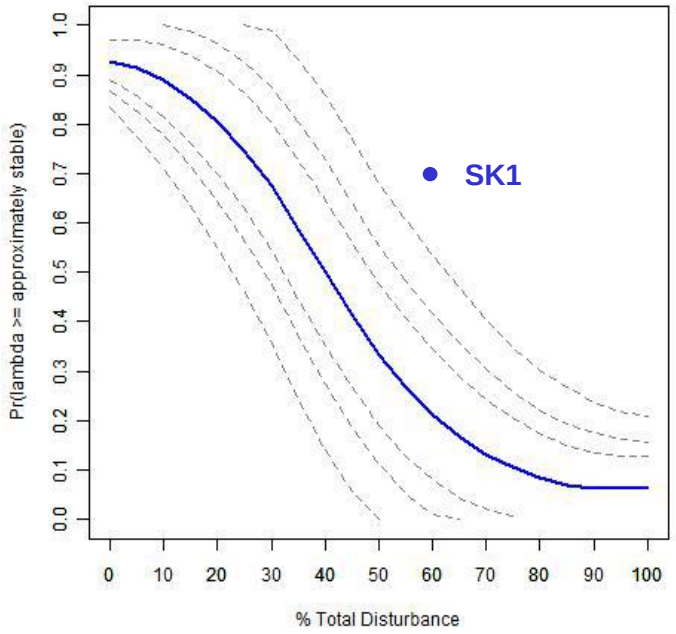

Figure 8. Probability of self sustaining population status based on total disturbance from 2011 Scientific Assessment (with 50, 70 and 90% confidence intervals). The calculated probability of self sustaining for SK1 based on current disturbance falls outside the 90% confidence interval.

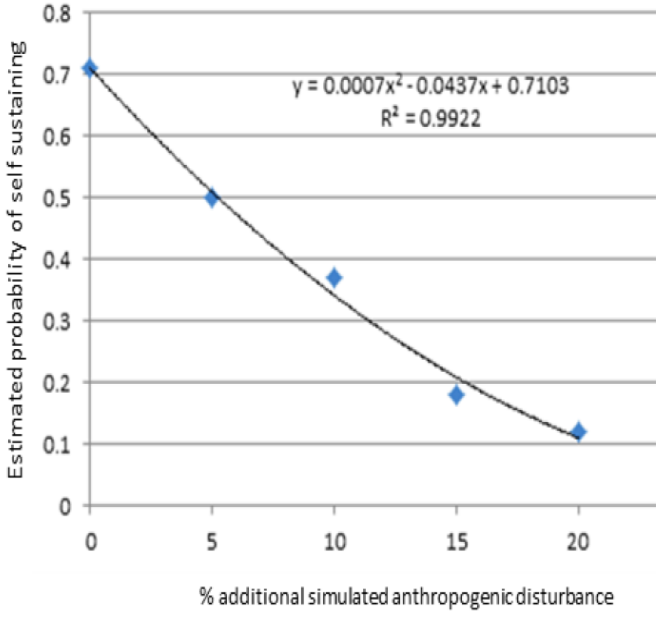

Figure 9. Graph showing the estimated probability that SK1 will be self-sustaining with increasing simulated anthropogenic disturbance.

Coming Soon

Look for the results of the scientific analysis to inform critical habitat identification in SK1 to be published in a peer-reviewed scientific journal in 2019/20.

Additional Boreal Caribou Science Summary Sheets will be posted on the SAR Public Registry in the future. Next in the series: an in-depth evaluation of the disturbance-recruitment model used to inform the management threshold; and, an enhanced analysis that further explores the relationship between boreal caribou population response and different types of disturbance (fire, anthropogenic, polygonal and linear) as well as the amount and configuration of suitable caribou habitat.

References

Environment Canada. 2011. Scientific Assessment to Support the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada. Ottawa, ON. 115 pp. plus Appendices.

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