Supplementary Material

'WildLift': An open-source tool to guide decisions for wildlife conservation

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Estimating Demographic Effects of Habitat Management

The relationship between habitat alteration (linear features and percentage of young forest) and boreal caribou λ has been previously established using empirically-derived two-variable linear regression equations (Sorensen et al., 2008 and Boutin and Arienti, 2008, which has also been outlined in Schneider et al., 2010 and Hauer et al., 2018). We chose to implement the Boutin-Ariente equation in our software because it resulted in a greater strength of relationship between empirically-estimated caribou λ (Hervieux et al., 2013) and predictive values (Boutin-Ariente equation: $r = 0.18$ vs. Sorensen equation: $r = -0.12$; Fig. S1).

Because the levels of habitat alteration vary across caribou ranges, the efficacy of habitat management is specific to each range. However, according to the Boutin-Ariente predictive equation, no habitat management action produced stable or growing caribou populations in the three subpopulations we evaluated (Cold Lake range - CLR, East Side Athabasca River range - ESAR, and West Side Athabasca River range - WSAR), which have 11,482 km, 13,119 km, and 15,707 km of linear feature as of 2017, respectively. The predicted cumulative growth rate for CLR was 0.32 if no action was taken (i.e., status quo), 0.64 for LFD, and 0.42 for LFR. ESAR's cumulative growth rates (over the 20-year simulation) were 0.17 if no action was taken, 0.39 for LFD and 0.23 for LFR, and WSAR's cumulative growth rates were 0.46 if no action was taken, 0.90 for LFD and 0.59 for LFR.

Estimating Economic Costs for Demographic Augmentation Actions

Predator Exclosure (PE) has not yet been tested for caribou, though small scale pilot trials have been attempted to test the ability to exclude predators and to estimate costs (Serrouya et al., 2015a). Maternal Penning (MP) has been tested for woodland caribou, with mixed evidence from four projects: the Chisana subpopulation in the Yukon Territory (4 years of trials; Adams et al., 2019), the Little Smoky subpopulation in Alberta (1 year; Smith and Pittaway, 2011), the Columbia North subpopulation in Revelstoke (RCRW), British Columbia (4 years; see RCRW.ca), and the Klinse-za subpopulation (KZA) in British Columbia (3 years; McNay et al., 2016). The Chisana project produced strong positive effects on annual calf survival (a 3-fold increase; Adams et al., 2019), but the Little Smoky project showed no improvement (Smith and Pittaway 2011). The Revelstoke project resulted in an increase in calf survival by a factor of 1.8 (from 23 % to 41%; Serrouya et al., 2019). The KZA project has been the most successful, because it helped to double the size of this subpopulation (from approx. 32 to > 70 animals in three years; McNay et al., 2016), due to reduced predation of bears on neonates (via MP) and wolves on other age classes (via Wolf Reduction - WR). Given the extremely small population size of KZA, we did not use parameters from this subpopulation to parameterize combinations between MP and WR.

We assumed a one-time set-up cost of $500,000 for each maternal pen with the capacity of 35 adult females, which includes fence construction (based on empirical costs provided by RCRW and KZA), along with annual maintenance costs of $300,000 for a team of shepherds to monitor the health of caribou in the pen, to collect lichen, and for unexpected expenses and/or repairs to the fence. Additionally, $80,000 for a project manager and $250,000 for caribou monitoring outside of the pen (including cow captures, surveys of wild caribou, calf collaring and monitoring, and mortality investigations). All MP costs are based on best estimates obtained by contacting current and previous penning projects (one of our authors is the science advisor on two of the MP projects, so this information was readily obtainable).

Costs for the PE were calculated based on a pilot construction trial (Serrouya et al., 2015a). For each PE area, these include a cost of initial set-up of a 36 km^2 pen, with a perimeter of 24 km and a capacity of 35 adult females, at a fencing cost of $77,000/km ($1,848,000 total), along with additional $20,000 for additional costs with initial removal of predators ($1,868,000 total setup cost). Annual predator removal was assumed to cost $80,000, while annual caribou monitoring was assumed to cost $200,000/yr, less than for MP because adult females remain in the pen throughout their lives. The annual cost of patrolling and repairing the fence, as well as annual contingency was assumed to be $600,000. As with MP, a cost of $80,000/yr was also included for a project manager.

CB costs were based on initial estimates for a new CB facility in Alberta that would hold approx. 40 adult females (Hayek et al 2016), with initial set-up cost estimated at $9 million. Annual costs include caribou capture ($50,000), project management ($80,000), and maintenance ($280,000). All costs were estimated in $CAD 2020 (Table S4).

Sensitivity Analysis

Our sensitivity analysis revealed that all else being equal, female survival needs to be high, with a high proportion penned, to achieve population stability or growth (i.e., $\lambda \geq 1$). Changes to fecundity do not lead to a higher population growth, and calf survival rates leads to stability (i.e., $\lambda = 1$) only if values are improved greatly (e.g., from <0.2 to > 0.6), and if the proportion of adult females in MP or PE is > 0.4 (Fig. S3).

Supplementary Tables

Table S1. Annual survival estimates used in 'WildLift' for wild subpopulations of woodland caribou.

Subpopulation*	Caribou Ecotype	Calf Survival (Sc)	Adult Survival (Sy=Sj=Sa)	Recovery Action
East Side Athabasca	Boreal	0.163[a]	0.853[a]	MP, PE, CB, MR
Columbia North	Southern Mountain	0.217[b]	0.784[b]	MP, PE, CB, MR
Columbia South	Southern Mountain	0.285[b]	0.767[c]	MP, PE, CB, MR
Frisby-Queest	Southern Mountain	0.363[b]	0.853[d]	MP, PE, CB, MR
Wells Grey South	Southern Mountain	0.239[b]	0.868[b]	MP, PE, CB, MR
Groundhog	Southern Mountain	0.234[b]	0.853[d]	MP, PE, CB, MR
Parsnip	Southern Mountain	0.163[d]	0.875[c]	MP, PE, CB, MR
Kennedy Siding	Southern Mountain	0.283[e]	0.844[e]	MP, WR
Klinse-za (Moberly)	Southern Mountain	0.308[e]	0.748[e]	MP, WR
Quintette	Southern Mountain	0.294[e]	0.810[e]	MP, WR
Default WR	Southern Mountain	0.295[f]	0.801[f]	WR
Average subpopulation	-	0.259[g]	0.823[g]	All

MP = Maternity Penning; CB = Conservation Breeding; PE = Predator Exclosures; MR = Moose Reduction; WR = Wolf Reduction. Ecotype classification based on federal recovery strategies and management plans (Environment Canada, 2012; Environment Canada, 2014). Fecundity (*F*) was set at 0.92 for all subpopulations (Wittmer et al., 2005). Average subpopulation estimates were obtained by averaging the parameters of all subpopulations.

*As defined in the Federal recovery strategy for Southern Mountain caribou (Environment Canada, 2014) and the COSEWIC Wildlife Species Assessments (COSEWIC, 2014). This term is analogous to "range" in the Federal recovery strategy for Boreal caribou (Environment Canada, 2012).

[a]Empirical values from Hervieux et al., 2013. [b]Empirical values from Serrouya et al., 2017a. [c]Empirical values from Serrouya et al., 2017b and Serrouya, unpub. data. [d]Based on values from East Side Athabasca (Hervieux et al., 2013). [e]Empirical values from Bridger, 2019. [f]Based on average parameters from Kennedy Siding, Klinse-za (Moberly), and Quintette before wolf reduction treatments (Serrouya et al., 2017a, Seip and Jones, 2017). [g]Based on average parameters of all subpopulations.

Table S2. Annual survival estimates used in 'WildLift' for subpopulations of woodland caribou under single recovery actions.

Recovery Action	Subpopulation[*]	Calf Survival (Sc)	Adult Survival (Sy=Sj=Sa)
MP[1]	East Side Athabasca[**]	0.598[a]	0.903[a]
	Columbia North	0.598	0.834
	Columbia South	0.598	0.817
	Frisby-Queest	0.598	0.903
	Wells Grey South	0.598	0.918
	Groundhog	0.598	0.903
	Parsnip	0.598	0.925
	Kennedy Siding	0.598	0.894
	Klinse-za (Moberly)	0.598	0.798
	Quintette	0.598	0.860
	Average subpopulation	0.598	0.876
PE[2]	East Side Athabasca[**]	0.72	0.95
	Columbia North	0.72	0.95
	Columbia South	0.72	0.95
	Frisby-Queest	0.72	0.95
	Wells Grey South	0.72	0.95
	Groundhog	0.72	0.95
	Parsnip	0.72	0.95
	Average subpopulation	0.72	0.95
CB[2]	East Side Athabasca[**]	0.72	0.95
	Columbia North	0.72	0.95
	Columbia South	0.72	0.95
	Frisby-Queest	0.72	0.95
	Wells Grey South	0.72	0.95
	Groundhog	0.72	0.95
	Parsnip	0.72	0.95
	Average subpopulation	0.72	0.95
MR[3]	East Side Athabasca[**]	0.163	0.879
	Columbia North	0.233	0.879
	Columbia South	0.266	0.879
	Frisby-Queest	0.227	0.879
	Wells Grey South	0.313	0.879
	Groundhog	0.434	0.879
	Parsnip	0.163[a]	0.879
	Average subpopulation	0.257	0.879
WR[4]	Kennedy Siding	0.554	0.962

Klinse-za (Moberly)	0.506	0.860
Quintette	0.489	0.917
Average subpopulation**	0.513	0.912

MP = Maternity Penning; CB = Conservation Breeding; PE = Predator Exclosures; MR = Moose Reduction; WR = Wolf Reduction. Fecundity (*F*) was set at 0.92 for 3+ years old in all treatments (Wittmer et al., 2005) and 0.57 for 2 years old (Adams et al. 2019) under CB if users choose the age at first reproduction to be 2 instead of 3. Average subpopulation estimates were obtained by averaging the response of all subpopulations to each recovery action.

[*] As defined in the Federal recovery strategy for Southern Mountain caribou (Environment Canada, 2014) and the COSEWIC Wildlife Species Assessments (COSEWIC, 2014). This term is analogous to "range" in the Federal recovery strategy for Boreal caribou (Environment Canada, 2012). [**] Default subpopulation for recovery action.

[1] Sc set to 0.598, which is intermediate empirical values from McNay, 2018 (0.618), Adams et al., 2019 (0.686), and Serrouya et al., unpub. data (0.49). Sa for treatment set 0.05 higher than Sa for wild subpopulation based on Serrouya et al., 2015b. [2] Demographic modeling approach was the same as for the MP, but with higher Sa assumed due to year-round penning (0.95), and higher first-year survival of offspring (0.9 for the first month of life, × 0.8 for the remaining 11 months; Sc = 0.72). [3] Sc are empirical values and Sa are predicted changes based on the response of Columbia North subpopulation to moose reduction (Serrouya et al., 2017a). [4] Sa are empirical values from Bridger (2019) and Sc were estimated based on empirical recruitment data from Bridger, 2019 and adult sex ratios and pregnancy rates from Serrouya et al., 2017b, Seip and Jones, 2017, Seip and Jones, 2018, and Bridger, 2019; [a] Based on values from East Side Athabasca River (Hervieux et al., 2013).

Table S3. Annual survival estimates used in 'WildLift' for subpopulations of woodland caribou under multiple recovery actions. Parameters for non-captive individuals were derived from average subpopulation response to either WR or WR (Table S2). Parameters for PE and CB captive individuals were derived from average responses to each action in isolation (Table S2). Parameters for MP were adjusted based on assumed additive effects*.

Recovery Action	Non-captive individuals		Captive individuals	
	Calf Survival (Sc)	**Adult Survival (Sy=Sj=Sa)**	**Calf Survival (Sc)**	**Adult Survival (Sy=Sj=Sa)**
MP+WR	0.513	0.912	0.683	0.938
MP+MR	0.257	0.879	0.598	0.905
PE+WR	0.513	0.912	0.72	0.95
PE+MR	0.257	0.879	0.72	0.95
CB+WR	0.513	0.912	0.72	0.95
CB+MR	0.257	0.879	0.72	0.95

MP = Maternity Penning; CB = Conservation Breeding; PE = Predator Exclosures; MR = Moose Reduction; WR = Wolf Reduction. Fecundity (*F*) was set at 0.92 for 3+ years old in all treatments (Wittmer et al., 2005) and 0.57 for 2 years old (Adams et al. 2019) under CB if users choose the age at first reproduction to be 2 instead of 3.

*For combinations with MP, because individuals under MP stay inside the enclosures only for a short period of time, we assumed annual survival rates of captive individuals to result from an additive effect of MP over WR- or MR-only parameters. The additive effect of MP was calculated by setting captive adult female survival rate 0.026 higher than non-captive individuals under WR or MR. An increase of 0.026 represents ½ of the effect of MP-only over status quo adult female survival (Table S2). While WR and MR decrease predator density outside the enclosures, additional effects of MP over WR and MR include protecting individuals against other predators (e.g., bears and cougars) and improving nutritional conditions (Adams et al. 2019). Captive calf survival under MP+WR was calculated using the same demographic modeling approach but using a 0.17 increase (½ of the effect of MP alone over status quo calf survival). Captive calf survival under MP+MR was kept the same as calf survival under MP-only because MR is assumed to affect adult female survival only (Serrouya et al., 2017a). For combinations with PE we assumed annual survival rates of captive individuals to be independent from the recovery action implemented outside the enclosures because captive individuals stay year-round within the enclosures. Furthermore, we assumed annual survival rates of captive individuals for CB to be independent from recovery actions implemented in recipient subpopulation, given the CB facility is independent of the recipient subpopulation. Parameters for captive individuals under PE or CB were derived from average subpopulation response to either PE or CB (Table S2).

Table S4. Cost estimates (x1,000 $CAD 2020) used in 'WildLift'.

	Item	**MP**[a]	**CB**[b]	**PE**[c]	**WR**[d]	**LFD**[e]	**LFR**[e]
One-time	Initial set-up[1]	500	9000	1868	-	12/km	12/km
Annual	Project manager	80	80	80	-	-	-
	Capture/monitoring[2]	250	50	200	-	-	-
	Maintenance[3]	300	280	600	-	-	-
	Predator removal	-	-	80	5.1/wolf	-	-
	Total annual costs	630	410	960	5.1/wolf	0	0

MP = Maternity Penning; CB = Conservation Breeding; PE = Predator Exclosures; WR = Wolf Reduction; LFD = Linear Feature Deactivation; LFR = Linear Feature Restauration. Moose reduction costs were not included in 'WildLift' as it can be achieved at no cost by increasing moose hunter harvest (Serrouya et al., 2017a).

[1]Costs include fence construction. [2]Costs include GPS collars, aerial fixed wing, helicopter for mortality investigations, personnel, biological samples (DNA, cortisol, morrow, parasites), and supplemental feed. [3]Costs include shepherd and contingency (unexpected expenses and/or repairs to the fences).

[a]Costs for construction, maintenance, and operation of a single maternal pen, which holds up to 35 adult females. Based on empirical estimates from maternity pens constructed in British Columbia, Canada (Klinse-za and Revelstoke). [b]Costs for construction, maintenance, and operation of a single conservation breeding facility, which holds approx. 40 adult females. Based on initial estimates for a new CB facility in Alberta (Hayek et al., 2016). [c]Costs for construction, maintenance, and operation of a single predator exclosure area, which holds up to 35 adult females. Based on a pilot construction trial (Serrouya et al., 2015a). [d]Average costs per wolf removed (through aerial shooting) over five years of WR program (Bridger, 2019). [e]Costs assuming that all linear features require treatment (i.e., no natural regeneration occurred).

Table S5. Description of terms found in 'WildLift'. MP = Maternity Penning; CB = Conservation Breeding; PE = Predator Exclosures; MR = Moose Reduction; WR = Wolf Reduction; LF = Linear Feature.

Section	Recovery Action	Term	Definition
Main dashboard	All	Number of years to forecast	Number of years in which the population is simulated.
	All	Initial population size	Number of females (from all stage classes) in the starting population.
	All	How to provide females penned (Percent or Number of individuals)	Within the MP, PE, and MR tabs this allows users to specify if the females penned setting is based on the percent of the population (0-100%), or a number value.
	All	Documentation	Documentation describing the software.
	Single lever	Maternity penning	Seasonal pen to protect adult females and their calves during vulnerable neonate period.
	Single lever	Predator exclosure	Large year-round pen to protect calves for the first year, and adult females year-round.
	Single lever	Moose reduction	Hunter harvest to reduce moose populations.
	Single lever	Wolf reduction	Wolf reduction program to decrease predation pressure on population.
	Single lever	Linear feature	Linear feature deactivation or restoration to reduce wolf use and/or travelling speed.
	Single lever	Conservation breeding	Breeding facility used to supplement recipient populations with additional juvenile females.
	Multiple levers	Demographic augmentation	Combination of two demographic augmentation recovery actions (MP and PE) with predator-prey management actions (WR and MR).
	Multiple levers	Conservation Breeding	Combination of CB with predator-prey management actions (WR and MR).
		Single Lever	
Settings	All	Subpopulation	Pre-set conditions based on caribou subpopulation-level data.
	MP, PE	Percent of adult females penned (or number of adult females penned)	Percent or number of the adult female population placed in maternity pens or predator exclosure areas.
	MP, PE	Compare scenarios	Compare two scenarios within a single lever. Users choose their settings of interest, click on “compare scenario” and can then change settings to see the expected impact on the population.
	CB	Proportion of juvenile females transferred	The proportion of juvenile females within the CB facility that are transferred to the recipient

			population. This slider should be used after setting other demographic parameters and the population inside the facility should be kept stable (i.e., λ = 1).
	CB	Number of females put into facility each year (max)	The maximum number of adult females that are transferred into the CB facility each year.
	CB	Number of years females are added to the facility	The number of years in which adult females (# of females per year specified above) are transferred into the CB facility.
	CB	Adult female survival during capture/transport	Annual survival of adult females during capture and transportation into the CB facility.
	CB	Number of years to delay juvenile transfer	Number of years in which juveniles are not transported out of the CB facility in order to build up the CB population.
	CB	Juvenile female survival during capture/transport	Annual calf survival during capture and transportation out of the CB facility and into the recipient population.
	CB	Relative reduction in survival of juvenile females transported to recipient population for 1 year after transport	Annual juvenile survival of the individuals transferred into the recipient population for 1 year after transport, relative to the annual juvenile survival of the recipient population.
	CB	Females inside the facility reproduce at 2 yrs age with fecundity rate 0.57	Check box to set age at first reproduction at 2 years old instead of 3. Fecundity at 2 years old is assumed to be 0.57.
	LF	Range area (sq km)	Range area of the population (in km^2).
	LF	Linear feature length (km)	Total length of linear features within the range of the population. This is calculated by summing the extension of roads, pipelines, and conventional seismic lines (i.e., all linear features except for low-impact seismic lines).
	LF	Conventional seismic length (km)	Total length of conventional linear features within the range of the population.
	LF	Percent young forest (<30 yrs; %)	The percentage (0-100%) of the range made up of any habitat that has been burned or cut within the last 30 years.
	LF	Years for 100% deactivation	Number of years following action implementation to achieve complete deactivation of linear features.
	LF	Years for 100% restoration	Number of years following action implementation to achieve complete restoration of linear features.
Demography	MP, PE	Calf survival, wild	Annual survival of calves within the wild portion of the population (i.e., outside maternal pens and predator exclosure areas).

MP, PE	Calf survival, captive	Annual survival of captive calves (i.e., those enclosed in maternity pens or predator exclosure areas).
MP, PE	Adult female survival, wild	Annual survival of adult females within the wild portion of the population (i.e., outside maternal pens and predator exclosure areas).
MP, PE	Adult female survival, captive	Annual survival of captive adult females (i.e., those enclosed in maternity pens or predator exclosure areas).
MP, PE	Fecundity, wild	Annual fecundity (i.e., pregnancy rate) of adult females of the wild portion of the population (i.e., outside maternal pens and predator exclosure areas).
MP, PE	Fecundity, captive	Annual fecundity (i.e., pregnancy rate) of captive adult females (i.e., those enclosed in maternity pens or predator exclosure areas).
MR	Calf survival, moose reduction	Annual survival of calves in a population with MR.
MR	Adult female survival, moose reduction	Annual survival of adult females in a population with MR.
MR	Fecundity, moose reduction	Annual fecundity (i.e., pregnancy rate) of adult females in a population with MR.
MR, WR	Calf survival, status quo	Annual survival of calves in a population with no recovery action.
MR, WR	Adult female survival, status quo	Annual survival of adult females in a population with no recovery action.
MR, WR	Fecundity, status quo	Annual fecundity (i.e., pregnancy rate) of adult females in a population with no recovery action.
WR	Calf survival, wolf reduction	Annual survival of calves in a population with WR.
WR	Adult female survival, wolf reduction	Annual survival of adult females in a population with WR.
WR	Fecundity, wolf reduction	Annual fecundity (i.e., pregnancy rate) of adult females in a population with WR.
CB	Calf survival, facility	Annual survival of calves within the CB facility.
CB	Calf survival, recipient & status quo	Annual survival of calves within the recipient and status-quo populations (i.e., receiving vs not receiving transferred juveniles, respectively).
CB	Adult female survival, facility	Annual adult female survival within the CB facility.
CB	Adult female survival, recipient & status quo	Annual adult female survival within the recipient and status-quo populations (i.e., receiving vs not receiving transferred juveniles, respectively).
CB	Fecundity, facility	Annual fecundity (i.e., pregnancy rate) of adult females within the CB facility.

	CB	Fecundity, recipient & status quo	Annual fecundity (i.e., pregnancy rate) of adult females within the recipient and status-quo populations (i.e., receiving vs not receiving transferred juveniles, respectively).
Cost	MP, PE	Max adult females in a single pen	Maximum number of adult females that can be kept within maternity pens or predator exclosure areas.
	MP, PE, CB	Initial set up	One-time costs associated with initial project set up.
	MP, PE, CB	Project manager	Annual costs associated with a project manager.
	MP, PE, CB	Maintenance	Annual costs associated with project maintenance.
	MP, PE, CB	Capture/monitor	Annual costs associated with capture of animals and monitoring.
	PE	Predator removal	Annual costs associated with predator removal within predator exclosure areas.
	WR	Cost per wolf to be removed (x $1000)	Annual costs to remove one wolf (x $1000).
	WR	Number of wolves to be removed per year	Annual number of wolves to be removed in order to achieve a maximum density of 2 wolves/1000km^2 within the population range.
	LF	Cost per km (x $1000)	Total costs associated with the restoration or deactivation of 1 km of linear feature (x $1000).
Summary	All	N(new)	Number of new females (from all stage classes) produced as a result of the implemented recovery action. Calculated by subtracting number of females at the end of simulation for status-quo population from the number of females at the end of the simulation for population under recovery strategy.
	All	Total cost (x $million)	Total cost (in $ million CAD, 2020) of implemented recovery action at the end of the simulation period.
	All	Cost per new female (x $million)	Cost (in $ million CAD, 2020) per new female (from all stage classes) produced as a result of implemented recovery action.
	CB, MR, WR, LF	N(end)	Number of females (from all stage classes) at the end of the simulation.
	CB, MR, WR, LF	Status quo	“Baseline” population with no recovery action taken.
	CB, MR, WR, LF	λ	Maximum annual population growth rate. Declining population ($\lambda < 1$); stable population ($\lambda = 1$); growing population ($\lambda > 1$).

MP, PE	λ(status quo)	Maximum annual population growth rate of status-quo population (i.e., "baseline" population with no action taken). Declining population ($\lambda < 1$); stable population ($\lambda = 1$); growing population ($\lambda > 1$).
MP, PE	N(end, status quo)	Number of females (from all stage classes) in the status-quo population (i.e., "baseline" population with no action taken) at the end of the simulation.
MP, PE	% penned	Percent of the adult female population placed in maternity pens or predator exclosure areas.
MP, PE	# pens	Number of maternal pens or predator exclosure areas built at the end of the simulation.
MP, PE	Breakeven	The proportion of the population penned needed to achieve a stable population growth rate (i.e. $\lambda = 1$).
MP	λ(maternity penning)	Maximum annual population growth rate for population under MP. Declining population ($\lambda < 1$); stable population ($\lambda = 1$); growing population ($\lambda > 1$).
MP	N(end, maternity penning)	Number of females (from all stage classes) at the end of the MP simulation.
PE	λ(predator exclosure)	Maximum annual population growth rate for population under PE. Declining population ($\lambda < 1$); stable population ($\lambda = 1$); growing population ($\lambda > 1$).
PE	N(end, predator exclosure)	Number of females (from all stage classes) at the end of the PE simulation.
MR	Moose reduction	Simulation for population with MR.
WR	Wolf reduction	Simulation for population with WR (assuming the action results in 2 wolves/1000 km^2).
CB	In facility	Simulation for captive population (i.e., held in the CB facility).
CB	Recipient	Simulation for the recipient population (i.e., wild population that receives transferred juveniles from the CB facility).
LF	No linear features	Simulation in which there are no linear features within the subpopulation range.
LF	Deactivation	Simulation in which conventional linear features within subpopulation range are deactivated.
LF	Restoration	Simulation in which conventional linear features within subpopulation range are restored.
	Multiple Levers	

	Demographic augmentation	Percent of adult females penned	Percent of the adult female population placed in maternity pens or predator exclosure areas.
	Demographic augmentation	Plot design	Choose how graphs are displayed (single plot with all combinations; by demographic augmentation; by predator/prey management; or by facets).
Demography status quo	Demographic augmentation	Calf survival, wild	Annual survival of calves of status-quo population (i.e., "baseline" population with no action taken).
	Demographic augmentation	Adult female survival, wild	Annual survival of adult female of status-quo population (i.e., "baseline" population with no action taken).
	Demographic augmentation	Fecundity, wild	Annual fecundity (i.e., pregnancy rate) of adult females of status quo-population (i.e., "baseline" population with no action taken).
Demography captive	Demographic augmentation	Calf survival, MP	Annual survival of captive calves enclosed in maternity pens.
	Demographic augmentation	Adult female survival, MP	Annual survival of captive adult female enclosed in maternity pens.
	Demographic augmentation	Fecundity, MP	Annual fecundity (i.e., pregnancy rate) of captive adult females enclosed in maternity pens.
	Demographic augmentation	Calf survival, PE	Annual survival of captive calves enclosed in predator exclosure areas.
	Demographic augmentation	Adult female survival, PE	Annual survival of captive adult female enclosed in predator exclosure areas.
	Demographic augmentation	Fecundity, PE	Annual fecundity (i.e., pregnancy rate) of captive adult females enclosed in predator exclosure areas.
Demography facility	Conservation breeding	Calf survival, facility	Annual survival of calves within the CB facility.
	Conservation breeding	Adult female survival, facility	Annual adult female survival within the CB facility.
	Conservation breeding	Fecundity, facility	Annual fecundity (i.e., pregnancy rate) of adult females within the CB facility.
Demography status quo & recipient CB only	Conservation breeding	Calf survival, recipient & status quo	Annual survival of calves within the CB-only recipient population and status-quo population (i.e., CB-only receiving vs not receiving transferred juveniles, respectively).
	Conservation breeding	Adult female survival, recipient & status quo	Annual adult female survival within the CB-only recipient population and status-quo population (i.e., CB-only receiving vs not receiving transferred juveniles, respectively).
	Conservation breeding	Fecundity, recipient & status quo	Annual fecundity (i.e., pregnancy rate) of adult females within the CB-only recipient population and status-quo population (i.e., CB-only

			receiving vs not receiving transferred juveniles, respectively).
Moose reduction	Demographic augmentation, Conservation breeding	Adult female survival, MR	Annual survival of adult female of the portion of the population with MR.
	Demographic augmentation	Additive effect of MP over MR-only adult female survival, captive	Captive individuals under MP are penned for a portion of the year only, and as such, annual survival rates reflect both MP and predator-prey management. MP offers additional effects over MR (e.g., protection against predators and improvement in nutritional conditions; Adams et al. 2019). The default values were established assuming that the additive increase in captive adult female survival as a result of MP in combination with MR was ½ of the MP-only effect over status quo survival rates.
Wolf reduction	Demographic augmentation, Conservation breeding	Calf survival, WR	Annual survival of calves of the portion of the population with WR.
	Demographic augmentation, Conservation breeding	Adult female survival, WR	Annual survival of adult female of the portion of the population with WR.
	Demographic augmentation	Additive effect of MP over WR-only female survival, captive	Captive individuals under MP are penned for a portion of the year only, and as such, annual survival rates reflect both MP and predator-prey management. MP offers additional effects over WR (e.g., protection against other predators and improvement in nutritional conditions; Adams et al. 2019). The default values were established assuming that the additive increase in captive adult female survival as a result of MP in combination with WR was ½ of the MP-only effect over status quo survival rates.
	Demographic augmentation	Additive effect of MP over WR-only calf survival, captive	Captive individuals under MP are penned for a portion of the year only, and as such, annual survival rates reflect both MP and predator-prey management. MP offers additional effects over WR (e.g., protection against other predators and improvement in nutritional conditions; Adams et al. 2019). The default values were established assuming that the additive increase in captive calf survival as a result of MP in combination

			with WR was ½ of the MP-only effect over status quo survival rates.
Cost: MP, Cost: PE, Cost: CB	Demographic augmentation, Conservation breeding	Initial set up	One-time costs associated with initial project set up.
	Demographic augmentation, Conservation breeding	Project manager	Annual costs associated with a project manager.
	Demographic augmentation, Conservation breeding	Maintenance	Annual costs associated with project maintenance.
	Demographic augmentation, Conservation breeding	Capture/monitor	Annual costs associated with capture of animals and monitoring.
Cost: MP, Cost: PE,	Demographic augmentation	Max adult females in a single pen	Maximum number of adult females that can be kept within maternity pens or predator exclosure areas.
Cost: PE	Demographic augmentation	Predator removal	Annual costs associated with predator removal within predator exclosure areas.
Cost: WR	Demographic augmentation, Conservation breeding	Cost per wolf to be removed (x $1000)	Annual costs to remove one wolf (x $1000).
	Demographic augmentation, Conservation breeding	Number of wolves to be removed per year	Annual number of wolves to be removed in order to achieve a maximum density of 2 wolves/1000km^2 within the population range.
Cost: CB	Conservation breeding	Initial set up	One-time costs associated with initial project set up.
	Conservation breeding	Project manager	Annual costs associated with a project manager.
	Conservation breeding	Maintenance	Annual costs associated with project maintenance.
	Conservation breeding	Capture/monitor	Annual costs associated with capture of animals and monitoring.
Settings	Conservation breeding	Proportion of juvenile females transferred	The proportion of juvenile females within the CB facility that are transferred to the recipient population. This slider should be used after setting other demographic parameters and the population inside the facility should be kept stable (i.e., $\lambda = 1$).

	Conservation breeding	Number of females put into facility each year (max)	The maximum number of adult females that are transferred into the CB facility each year.
	Conservation breeding	Number of years females are added to the facility	The number of years in which adult females (# of females per year specified above) are transferred into the CB facility.
	Conservation breeding	Adult female survival during capture/transport	Annual survival of adult females during capture and transportation into the CB facility.
	Conservation breeding	Number of years to delay juvenile transfer	Number of years in which juveniles are not transported out of the CB facility in order to build up the CB population.
	Conservation breeding	Juvenile female survival during capture/transport	Annual calf survival during capture and transportation out of the CB facility and into the recipient population.
	Conservation breeding	Relative reduction in survival of juvenile females transported to recipient population for 1 year after transport	Annual juvenile survival of the individuals transferred into the recipient population for 1 year after transport, relative to the annual juvenile survival of the recipient population.
	Conservation breeding	Females inside the facility reproduce at 2 yrs age with fecundity rate 0.57	Check box to set age at first reproduction at 2 years old instead of 3. Fecundity at 2 years old is assumed to be 0.57.
Summary: Multiple levers, Summary: Conservation breeding	Demographic augmentation, Conservation breeding	N(new)	Number of new females (from all stage classes) produced as a result of the implemented recovery action. Calculated by subtracting number of females at the end of simulation for status-quo population from the number of females at the end of the simulation for population under recovery strategy.
	Demographic augmentation, Conservation breeding	Total cost (x $million)	Total cost (in $ million CAD, 2020) of implemented recovery action at the end of the simulation period.
	Demographic augmentation, Conservation breeding	Cost per new female (x $million)	Cost (in $ million CAD, 2020) per new female (from all stage classes) produced as a result of implemented recovery action.
	Demographic augmentation, Conservation breeding	N(end)	Number of females (from all stage classes) at the end of the simulation.

	Demographic augmentation, Conservation breeding	λ (or lambda)	Maximum annual population growth rate. Declining population ($\lambda < 1$); stable population ($\lambda = 1$); growing population ($\lambda > 1$).
	Demographic augmentation, Conservation breeding	Status quo	"Baseline" population with no recovery action taken.
	Demographic augmentation, Conservation breeding	WR	Simulation for WR-only.
	Demographic augmentation, Conservation breeding	MR	Simulation for MR-only.
Summary: Multiple levers	Demographic augmentation	MP	Simulation for MP-only.
	Demographic augmentation	PE	Simulation for PE-only.
	Demographic augmentation	MP+MR	Simulation for a combination of MP and MR.
	Demographic augmentation	PE+MR	Simulation for a combination of PE and MR.
	Demographic augmentation	MP+WR	Simulation for a combination of MP and WR.
	Demographic augmentation	PE+WR	Simulation for a combination of PE and WR.
Summary: Conservation breeding	Conservation breeding	In facility	Simulation for captive population (i.e., held in the CB facility).
	Conservation breeding	Recipient CB	Simulation for the recipient population under no additional recovery strategy (i.e., wild population that receives transferred juveniles from the CB facility only).
	Conservation breeding	CB+MR	Simulation for a combination of CB and MR.
	Conservation breeding	CB+WR	Simulation for a combination of CB and WR.

Supplementary Figures

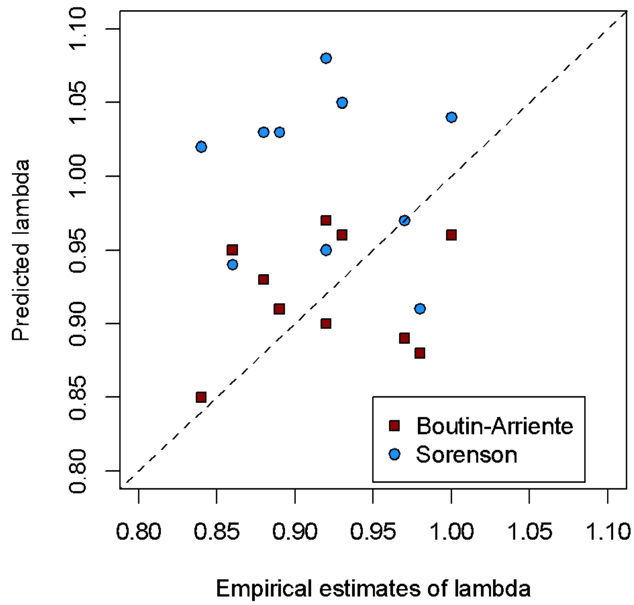

Fig. S1. Comparison of empirically-estimated caribou λ from survey data (Hervieux et al., 2013) to two predictive regressions based on landscape disturbance (Boutin and Ariente, 2008; Sorenson, 2008). The dotted line represents a 1-1 relationship.

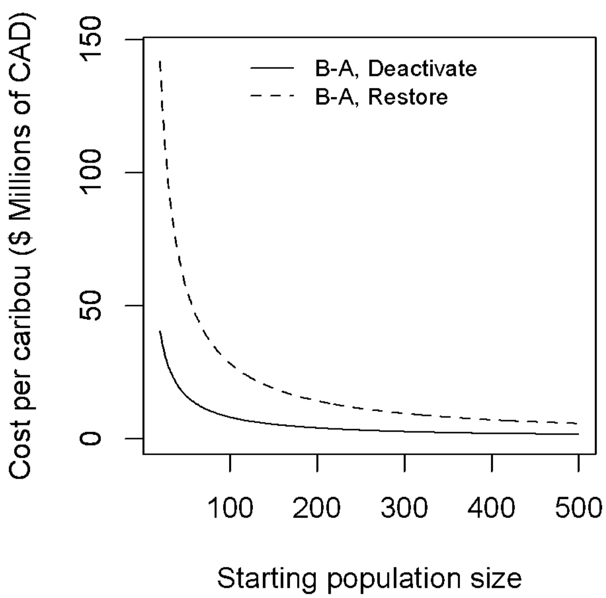

Fig. S2. The effect of starting population size on the cost per caribou gained for the Linear Feature Deactivation and Restoration, based on the Boutin-Arienti regression (2008) which predicts rate of population growth rate (λ) based on linear features and habitat disturbance. Larger starting populations, in which more individuals were present to benefit from habitat management, produced lower per-caribou costs.

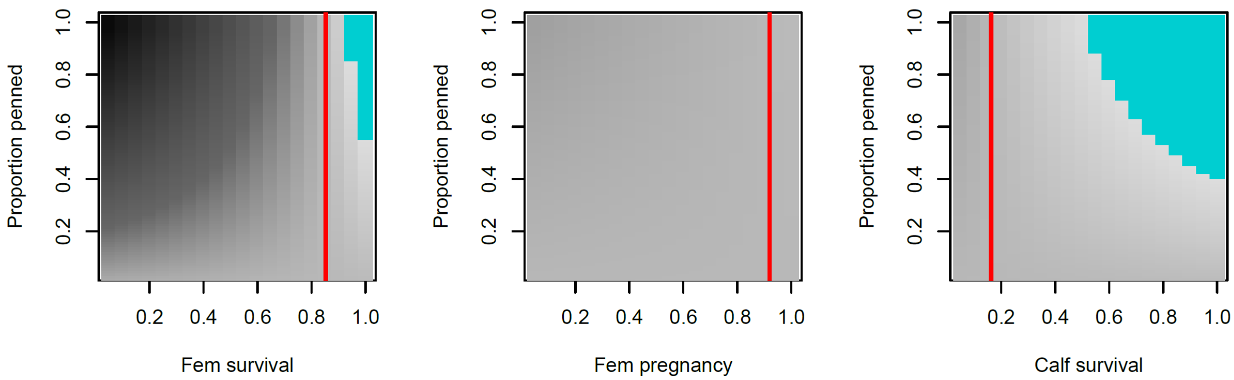

Fig. S3. Sensitivity of the finite population growth rate (λ) to the proportion of adult females that are in a maternal pen, and to variation in a) adult female survival, b) adult female fecundity (i.e. pregnancy rate), and c) calf survival. Shades of grey from darker to lighter indicate increasing lambda, while turquoise indicates lambda above 1. The red line indicates the baseline vital rate used in our models.

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