BRITISH COLUMBIA

June 28, 2013

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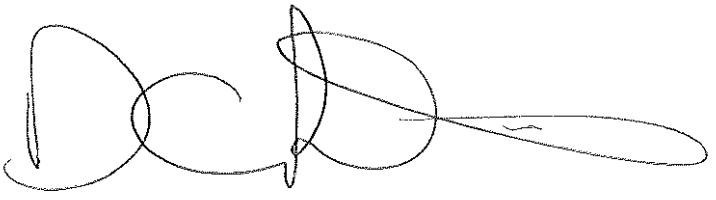
To the reader:

On October 16, 2007, government announced the Mountain Caribou Recovery Implementation Plan (MCRIP) with a goal to restore the mountain caribou population to the pre-1995 level of 2,500 animals within 20 years. One of the management actions in the MCRIP is to manage predator populations of wolf and cougar where they are preventing the recovery of mountain caribou populations.

The attached document, "QUESNEL HIGHLAND WOLF STERILIZATION PILOT ASSESSMENT 2012 - An Independent Evaluation of the Response of Mountain Caribou" provides the technical review of the wolf sterilization pilot project that supports that management action. This report was completed under contract and was peer reviewed. Government will need to consider recommendations in the report and decide where and when they are appropriate for use. The recommendations for predator and prey management will be balanced with other recovery objectives and incorporated into caribou recovery activities. This document has been approved by ministry executive.

For more information on Mountain Caribou Recovery in British Columbia, please visit the recovery website at:
http://www.env.gov.bc.ca/sarco/mc/index.html
If you have any questions on the attached review of the wolf sterilization project or Mountain Caribou recovery, please feel free to contact me (250-614-9917).

Sincerely,



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QUESNEL HIGHLAND WOLF STERILIZATION PILOT ASSESSMENT 2012

An Independent Evaluation of the Response of Mountain Caribou

Prepared by:

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BOX 3953

SMITHERS, BRITISH COLUMBIA

V0J 2N0

February 2013

Table of Contents

Executive Summary

The Quesnel Highland wolf sterilization pilot project (2001-2012) showed a combination of fertility-treatment and lethal methods effectively reduced wolf abundance. The temporary cancellation of the project in 2004, and the lack of predicted responses and proper experimental design, limited the assessment of wolf fertility-control on caribou responses. Wolf study methods provided reliable information about the distribution in wolf pack home ranges from year to year, and the effects of fertility-control on pup production. Wolf radio-telemetry studies showed sterilized adult wolves maintained their territories, displayed normal survival rates, and sustained sexual pair bonds. Sterilization of adult male and female wolves effectively stopped reproduction, strongly limiting the wolf rate of increase. Since 2008, 39-77% of wolf packs were fertility-treated, and wolf densities were reduced by 39-48% from 2009-2012. Sterilization alone maintained wolves at low density in 2011 and 2012.

There was no change in Quesnel Highland caribou recruitment with reduced wolf densities. Recruitment trend was not different than comparison herds. The number of Quesnel Highland caribou increased since 2001, but comparison herds also increased until 2006. From 2006 to 2012 Quesnel Highland was the only group that showed an increase, with most caribou added in 2012. There was no statistical evidence, however, that the increase was different than comparison herds. Moose harvest was increased after 2001 in an attempt to reduce prey biomass for wolves, but there was inadequate monitoring to assess moose response.

March caribou counts provided reliable information on calf recruitment and changes in caribou abundance. The absence of adult survival rate information limited my ability to assess the cause of the recent increase in Quesnel Highland caribou, or project the estimated number of caribou currently in the treatment area.

I recommend the sterilization project continue for three more years to allow for sufficient time to assess responses of caribou. Previous methods for monitoring caribou should be continued each year. A sample of radio-tagged adults should be added to monitor changes in adult survival, provide seasonal calf/cow ratios, and supply annual

sightability correction to better estimate caribou abundance. Moose counts should be conducted by 2016 to measure response to human harvest since 2008 and reduced wolf densities since 2009.

Purpose

This report evaluates the benefit of wolf (*Canis lupus*) fertility control as a tool to increase mountain caribou (*Rangifer tarandus caribou*) in the Quesnel Highland in the Cariboo Region, from 2001 to 2012. Arresting reproduction and maintaining infertility of wild wolves is costly and requires high staff support to deliver. Before committing to further efforts to demonstrate wolf sterilization benefits, I was contracted to complete an independent review of the project as part of *The Mountain Caribou Recovery Implementation Plan* (MCRIP). This scientific review examines the wolf sterilization trial to reach one of three recommendations:

- Continue sterilization work using the existing protocol and techniques because the pilot is moving towards MCRIP recovery objectives for the treatment area in the Quesnel Highland planning unit, and has a reasonable likelihood of success.
- Suspend further work as the results to date demonstrate that the technique is not successful at achieving MCRIP recovery objectives in the treatment area.
- Suspend further work unless specific changes/modifications can be made to the technique. Although the current approach is not likely to achieve MCRIP recovery objectives, a modified approach has a reasonable likelihood of success.

I evaluated the objectives, activities, delivery, performance and results for the wolf sterilization pilot study since it began in 2001. My review includes recommendations on wolf sterilization and lethal removal; wolf, caribou and moose monitoring; the intensity and timing of the activities; and performance measures to enable an assessment of wolf sterilization to achieve MCRIP recovery objectives. I also recommend the time lines necessary to assess performance of modified techniques.

Ecological Setting

Mountain caribou in the Quesnel Highland of central British Columbia are part of complex predator-prey system where caribou, moose (*Alces alces*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and mountain goat (*Oreamnos americanus*) are the suite of ungulate prey to various predators including: wolf, grizzly bear (*Ursus arctos*), black bear (*U. americanus*), cougar (*Pumas concolor*), coyote (*Canis latrans*), wolverine (*Gulo gulo*) and golden eagle (*Aquila chrysaetos*).

Caribou distribution in south-central British Columbia contracted substantially during the 1900s due to a combination of over-hunting, disturbance, loss of important seasonal ranges, and predation (MCTAC 2002). Some local herds have been extirpated, some are at risk of extinction in the future, and others sharply declined in the last decade (Hatter 2006). Mountain caribou declines throughout B.C. are coincidental with the eruption of moose and mule deer. Both species have benefited from the extensive production of seral vegetation following wildfire and forest removal activities throughout the 1900s. In turn, wolves - the main predator of moose - have also increased, raising their predation rate on sympatric mountain caribou. Compared to moose, mountain caribou are at high risk to predation because they are small and easier to kill, they live at much lower densities, they have large home ranges exposing them to more wolf packs, and caribou have a lower reproductive rate than moose (MCATC 2002). Seip (1992a) and Seip and Cichowski (1996) suggested wolf predation could eliminate some mountain caribou herds because there is no feedback on wolf numerical response as caribou numbers decline. In short, wolves persist on moose, elk or deer while they eventually extirpate local caribou herds (MCATC 2002). Dale Seip's (1992a, 1992b) early wolf-caribou research in the Quesnel Highland region was a catalyst for the selection of area for the wolf fertility control study, and his study deserves some detail here.

During the 1980s, Seip conducted the first radio-telemetry study on caribou in Quesnel Highland, observing a 25% annual decline in herd size, high adult mortality, and low calf survival rates. Half of the calves born to radio-collared cows died during the

calving period, but wolves were not the main cause. Seip conducted a short-term and small-scale wolf reduction trial, comparing before and after responses in calf survival. Before wolf reduction, no calves survived the summer. When wolves were reduced, all calves that survived to June lived through the summer. In four years before wolf reduction, calf survival was about 3% for radio-collared cows to October. During two years of wolf reduction, average calf survival was 29%. March herd counts showed little difference in recruitment, averaging about 7 calves for every 100 cows before, and about 9 calves during wolf reduction - below the recruitment of 30 calves for every 100 cows needed to stabilize most caribou populations (Bergerud 1992).

Factors limiting calf recruitment are poorly understood for interior mountain caribou herds. Gustine et al. (2006) unexpectedly found wolverine were the most important predator of neonatal calves of in the Prophet River in northern British Columbia. Wolves were most important during summer, supporting Seip (1992a). Bergerud and Elliot (1986) found a strong increase in recruitment after wolves were reduced in one herd in northern British Columbia, while recruitment in two control herds did not change. Mountain caribou herds have continued to sharply decline in British Columbia from 2,500 animals in 1995 to 1,700 caribou in 2007 [Mountain Caribou Science Team (MCST) 2007], prompting intensive recovery planning since 2000.

Mountain Caribou Recovery Planning

The Mountain Caribou Strategy: Cariboo-Chilcotin Land Use Plan (*CCLUP*) recommended ways to protect remaining mountain caribou range and promote the increase of herds in the Cariboo Region, including the Quesnel Highland (CSC 2000). Substantial actions were taken in the last decade including road access and backcountry recreation restrictions, modifying timber harvest to protect diminished caribou winter range, protection of existing winter range, reducing moose abundance, and this wolf sterilization study (CSC 2007)**.**

In 2000, mountain caribou in south and central British Columbia were listed as threatened by COSEWIC. In 2002 the Government of British Columbia produced *A*

Strategy for the Recovery of Mountain Caribou in British Columbia (MCTAC 2002), followed in 2005 by an implementation plan for the Hart and Cariboo Mountains (RIG 2005). That plan followed many of the recommendations contained in the innovative CCLUP. In 2007, the provincial *Mountain Caribou Recovery Implementation Plan* (MCST 2007) was completed, with a 20-year goal to restore the mountain caribou population to the pre-1995 level of 2,500 animals. The MCRIP includes novel recovery actions for threatened herds including translocation, maternal penning, reduction of wolf primary prey, wolf control, and the remediation of caribou habitat. The MCRIP goal for the Quesnel Highland area is 400 caribou: 300 in Wells Gray North, and 50 in each of the Barkerville and Bowron groups (RIG 2005).

Caribou Recovery Objectives

Except for the 20-year goal described above, no quantitative responses were predicted for caribou until 2008. The provincial goals for mountain caribou (Government of BC 2008) are to stimulate growth within three years and sustain growth over the long-term. Three measurable responses to achieve short-term growth include: calf recruitment greater than 15%, adult survival greater than 88%, and herd growth more than 7% per year. I used these expected responses to test against observed changes, following Roorda and Wright (2012).

Wolf Fertility Control Studies

Wolf sterilization has been used in two previous caribou recovery programs. Up to 15 wolf pairs were treated on the summer range of the Fortymile caribou herd in Alaska, in conjunction with live translocation of subordinate wolves, and winter trapping (Boertje and Gardner 2003). Herd size grew from about 22,000 to 45,000 caribou over eight years, the first increase in the Fortymile herd in decades. Up to six wolf pairs were sterilized in the Aishihik area (Spence 1999, Hayes et al. 2003) during 3 of 5 years of intensive aerial control. Sterilization substantially reduced wolf rate of increase in later years, while caribou abundance continued to rapidly increase. Before this study, there

had been no previous attempt to increase mountain caribou herds in British Columbia using wolf sterilization methods.

Wolf Treatment 2001-2012

Roorda and Wright (2004, 2010, 2011, 2012) provide a detailed history of wolf treatment in the Quesnel Highlands area (Figure 1). Please refer to these reports for details of annual activities. Both lethal and non-lethal methods were used to reduce wolf numbers. Attempts were made to capture, radio-collar and sterilize both the dominant male and female in packs. Breeding age females were given tubal ligations and mature males were vasectomized at a veterinary clinic then released. Other pack members were captured and killed if they were judged to be subordinate based on age and behavior. In some packs, a subordinate wolf was also fertility-treated, radio-collared and released, in case one of the adults died or dispersed. Other wolves were taken by ground trapping. Efforts to identify the wolf population and radio-collar packs began in the winter 2001-2002. Wolf reduction began in winter 2002-2003, and continued through 2003-2004. For the purpose of my analysis, I divided wolf treatment into two phases.

Phase 1: 2001-2004

Phase 1 wolf studies began July 2001 and ended March 2004 when the project was unexpectedly cancelled. In each year, crews searched for wolves from fixed wing aircraft during winter, or on the ground in summer. When a pack was located from the air, wolves were captured with a net gun from helicopters. Other wolves were live trapped year-round. By 2004, twenty-six wolves were radio-collared in 11 packs, and one lone wolf was collared. Eleven known packs occupied the 8,830 sq. km study area during Phase 1. March wolf density declined from 9 to about 6 wolves /1000 sq. km during Phase 1 (Figure 2). Mean pack size fell from 8 ± 4.6 (SD) before treatment, to 4.5 ± 3.3 by March 2004. Nine males were given vasectomies and seven females were given tubal ligations. At the end of Phase 1, five resident packs were sterilized, averaging 3.4

wolves per pack (SD 1.5, range 2-6).

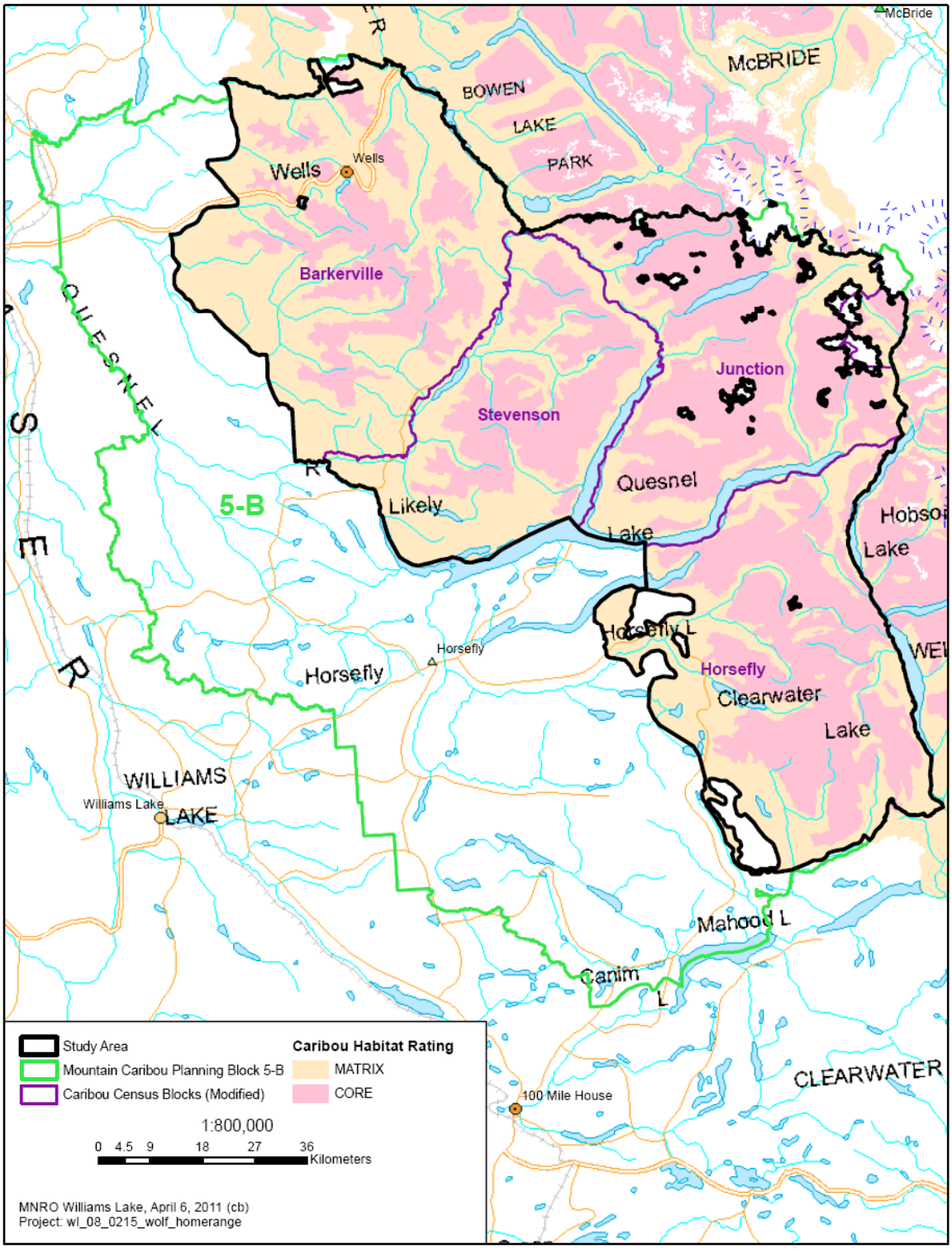

Figure 1. Location of Quesnel Highland wolf treatment area, caribou census blocks, and caribou habitat ratings (from Roorda and Wright 2011).

Phase 2: 2007-2012

The study resumed in December 2007 after the project was endorsed by the MCRIP, and funding was reinstated. No known sterilized wolves from Phase 1 were alive in Phase 2, and wolf density had recovered to 9.2 wolves/ 1000 sq. km – similar to the original unexploited density in 2001 (Figure 2). Phase 2 study goals were to radio-collar packs, sterilize three wolves in each group, and reduce pack sizes to 3-4 wolves. There were 13 resident packs in the study area during Phase 2, including two that sometimes ranged outside the boundary. After 2008, between 54-77% of study packs were fertility-treated (Figure 3). After 2009, March wolf density was reduced by 39-48%. Mean pack size fell from 7.15 ± 2.1 (SD) wolves in 2007 to 4.8 ± 2.9 by 2011.

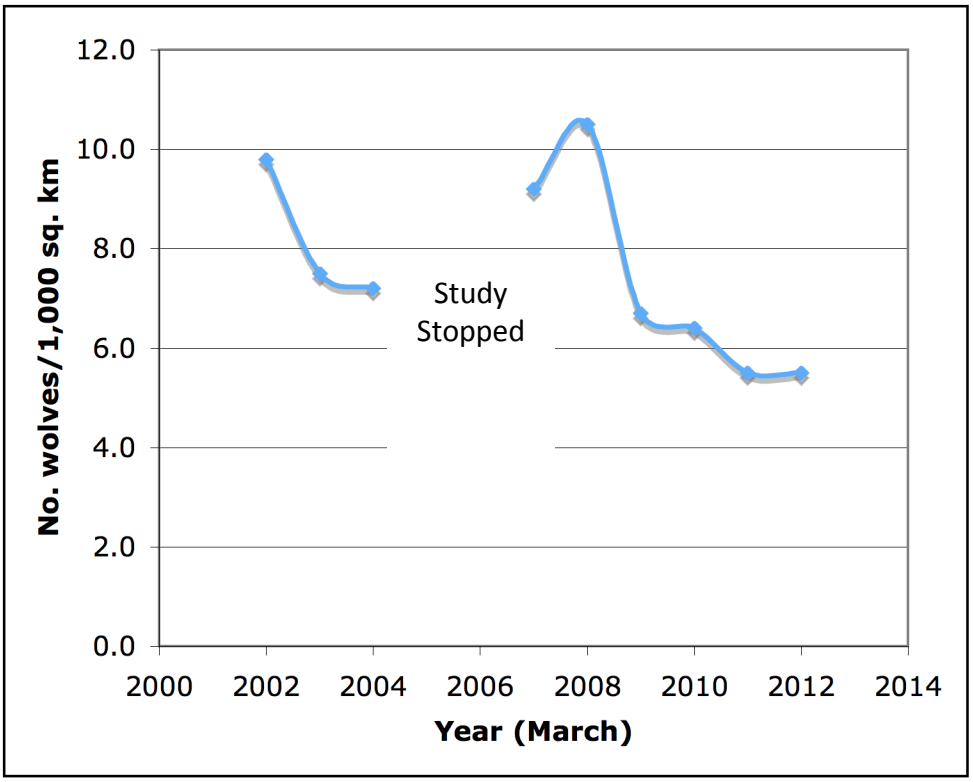

Figure 2. Change in wolf density in the Quesnel Highland Treatment area, 2001 through 2012.

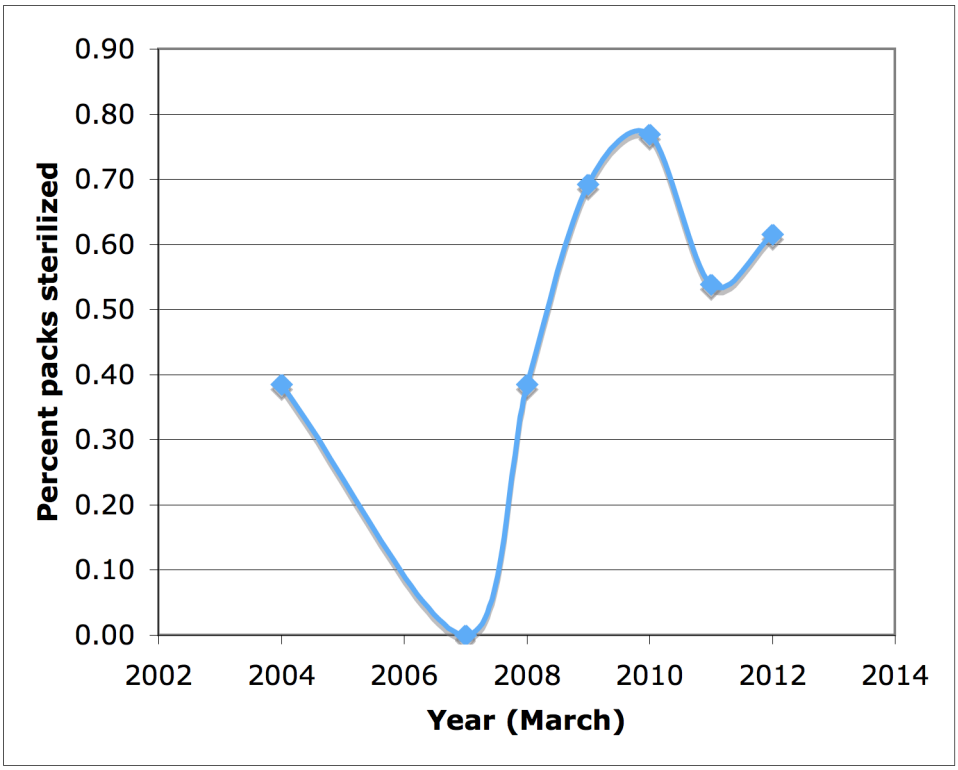

Figure 3. The proportion of sterilized wolf packs in the Quesnel Highland Treatment Area during the pilot study.

Moose Treatment 2001-2011

Permit Hunt Authorizations were increased after 2001, including permits for cow moose after 2004 (CSC 2007). Hunters annually killed an average of 119 moose (SD = 11) in Game Management Unit 15 (Figure 4, Table 1: R. Stewart, unpublished data). In 2008, moose abundance was estimated for the first time in the study area using a stratified random block design (Gasaway et al 1986). Average density in Management Unit 15a was 290 moose/1000 sq. km (MacKay 2008), 170 moose in Unit 15B (MacKay and Borthwick 2008), and 110 in Unit 15C (Borthwick and MacKay 2008). These densities were well below the average of 440 moose/1000 sq. km for areas east of the Fraser River from 1994-2008 (MacKay 2008). The estimated adult sex ratio ranged from 36-59 bulls for every 100 cows in the three units. Estimated recruitment ranged from 8-20 calves for every 100 cows, below the 30 calves that are required to stabilize most moose populations (Gasaway et al. 1986). There has been no follow up counts to assess moose

population size after 2008.

Table 1. The estimated number of moose killed by hunters in the Quesnel Highland area, 2001 through 2011.

	Management Unit 15				
Year	**A**	**B**	**C**	**D**	**Grand Total**
2001	30	9	34	44	117
2002	30	4	32	44	110
2003	33	8	40	37	118
2004	40	12	42	38	132
2005	36	10	40	25	111
2006	26	17	41	42	126
2007	35	17	25	53	130
2008	18	14	25	63	119
2009	20	16	24	34	94
2010	26	7	34	56	123
2011	21	20	45	42	127
Grand Total	316	134	381	475	1,306

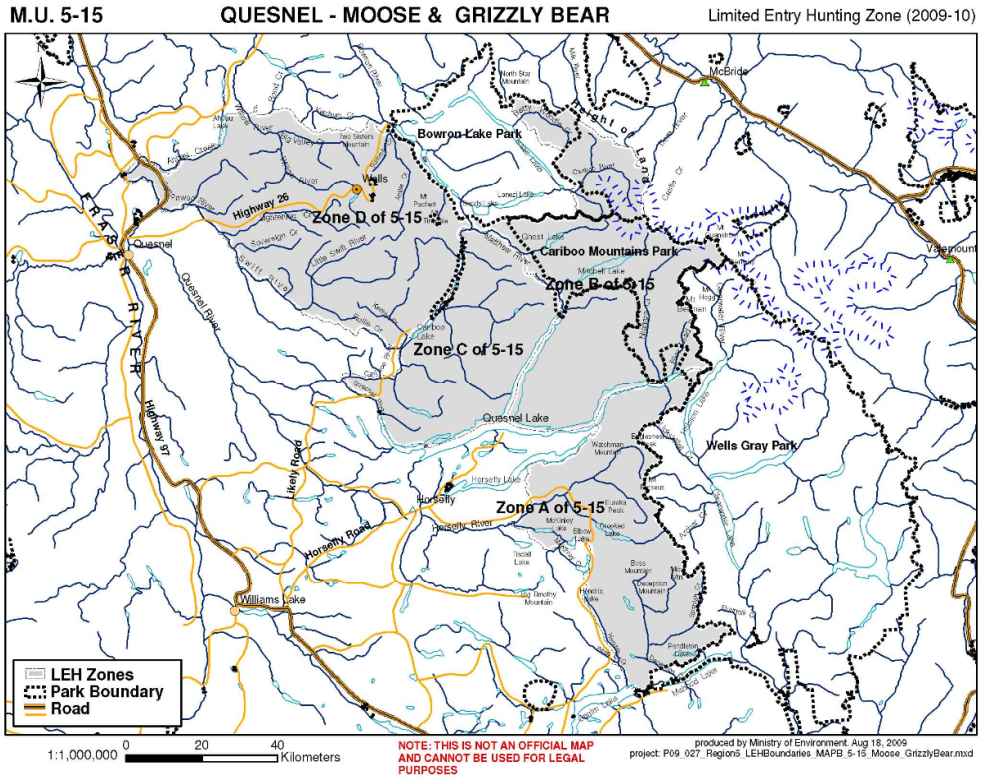

Figure 4. Locations of Management Unit 15 subzones where moose harvest was increased, 2001-2012.

Quesnel Highland Caribou Treatment

Initially I considered three mountain caribou groups for my evaluation of responses to wolf sterilization and removal (treatment).

1. The Wells Gray North group was declining at an annual rate of 0.98 between 1993 and 2001 (Young and Freeman 2001), prompting the wolf sterilization pilot study. This is the largest group of caribou in the Quesnel Highland. Wolf reduction was consistently applied across the Wells Gray North caribou range during the study.
2. The Bowron group is part of the North Cariboo Mountains herd that borders the Quesnel Highland. There was minimal wolf reduction in the Bowron caribou range during the study (see maps in Roorda and Wright 2010, 2011, 2012). As a consequence, I excluded Bowron caribou data from the analysis. Information from this group is included in the North Cariboo Mountains comparison herd.
3. The Barkerville group was 35 caribou in 2001 and thought to be declining (Young and Freeman 2001). I combined counts of the Barkerville and Wells Gray North because the wolf treatment was applied across both groups. With no interspersion of treatment, comparing responses between Barkerville and Wells Gray North caribou groups commits a pseudoreplication error, increasing the risk of bias and stochastic effects (Hurlbert 1984). For the purpose of this report, the Barkerville and Wells Gray North caribou are called Quesnel Highland caribou.

The Quesnel Highland caribou were counted in 2001, 2002, 2004, 2005, 2006, 2011, and 2012. Only the Wells Gray North group was counted in 2010, so I did not include that count in my analysis. Observed caribou were reported in all survey years, but estimates of herd sizes were not available after 2006. The number of caribou seen on an aerial survey depends on weather, and the experience and biases of observers and pilot. I had no reason to assume differences in these biases were important among years. I used total caribou seen as the measure of abundance.

There were no pre-selected ‘control’ herds as part of the study design.

Nevertheless, I compared the results of the Quesnel Highland caribou response with four herds in central and northeast British Columbia that numbered between 100-500 animals to evaluate differences in population trends. Wolf numbers were not reduced in any of these herds. Moose were substantially reduced in the Parsnip in an attempt to indirectly reduce wolf predation, but wolf numbers did not change by 2011 (D. Heard, pers. comm.). Two herds bordered the treatment area, the Wells Gray Park herd to the east and the North Cariboo Mountains herd to the northeast. Both herds may have been affected by the Quesnel Highland treatment along their boundaries in some years, but there was probably no measurable effect on overall wolf density from year to year. The Hart South herd was apparently naturally regulated. Comparison herds were counted at least five times between 2001 and 2012, providing reasonable trends in abundance and calf recruitment rates to compare to the Quesnel Highland caribou.

Wolf Response

Roorda and Wright (2010, 2011, 2012) presented changes in wolf density in two areas: throughout the study area (8,540 sq. km) and in an active control area (7,100 sq. km) where wolves were consistently reduced in core and matrix caribou habitat. For my analysis I used the entire study area densities because caribou response could not be similarly partitioned within the study area. During Phase 1, wolves were reduced by 13% in March 2003 and 27% in 2004 - less than 30-40% it takes to initiate a decline in wolf numbers the following year (Keith 1983, Gasaway et al. 1983, Peterson et al. 1984, Ballard et al. 1987, Fuller 1989, Gasaway et al. 1992, Hayes et al. 1991). During Phase 2, wolves were reduced by 36-48% after 2009, sufficient to reduce wolves the following year. The number and distribution of packs remained fairly constant in all years, showing wolf treatment did not disrupt the general organization of resident packs.

I tested fertility treatment on wolf annual rate of increase and found an effect in Phase 2, but not in Phase 1. During Phase 1, up to 5 of 11 packs were fertility treated. No wolf surveys were conducted in 2005 or 2006, so I could not calculate the effect of fertility control on the rate of increase those years. The *average* annual rate of increase

was 1.13 between 2004 and 2007, based on the difference in wolf numbers in the three years. By 2007, wolves fully recovered to 2001 pre-treatment density, similar to rates of recovery after 70-80% or more of wolves were removed from late winter populations elsewhere (Gasaway et al. 1983, Bergerud and Elliot 1986, Hayes et al. 1991, Hayes and Harestad 2000). I conclude there was no evidence treatment during Phase 1 reduced the wolf rate of increase.

Table 1. Wolf treatment results, 2001 through 2012, Quesnel Highland (compiled from Roorda and Wright 2004, 2010, 2011, 2012).

Year	Removed	No. Wolves sterilized	Fertility-controlled packs
Phase 2			
2011-2012	0	0	8-10
2010-2011	14	5	7-8
2009-2010	14	4	10
2008-2009	21	12	9
2007-2008	12	19	5
2006-2007	2	1	0
2005-2006	0	0	Unknown
2004-2005	0	0	Unknown
Phase 1			
2001-2004	30	16	5
Totals	**93**	**57**	

In Phase Two, 9 of 13 packs were fertility-treated by 2009. The wolf annual rate of increase was 1.05 to from 2009 to 2010. Fourteen wolves were killed between 2010 and 2011 so I did not calculate effect of sterilization. Between 2011 and 2012 no wolves were killed and wolf numbers were stable (rate of increase = 1.00). I conclude that fertility control successfully arrested reproduction when the majority of packs were treated, stabilizing the wolf population at a substantially lower density since March 2009.

I found no evidence that sterilization affected the distribution or behavior of wolves in the study area. Radio-telemetry results show most treated wolves maintained sexual pair bonds, held the same general territories from year to year, and experienced

normal survival rates - supporting the few studies of sterilized wild wolves elsewhere (Spence 1999, Hayes et al. 2003, Boertje and Gardner 2003). I conclude the territorial behavior of fertility-treated adults was sufficient to defend home ranges and hold pack density constant during the study.

Caribou Response

Recruitment

There was no evidence wolf density had an effect on calf recruitment during the entire study period ($r^2 = 0.45$, df = 4, $P < 0.21$). Recruitment in the treatment area ranged from 16-19% (Figure 5) during Phase 1: above the level of 15% considered the minimum to stabilize most caribou herds (Bergerud 1992). Comparison herds showed similar recruitment levels.

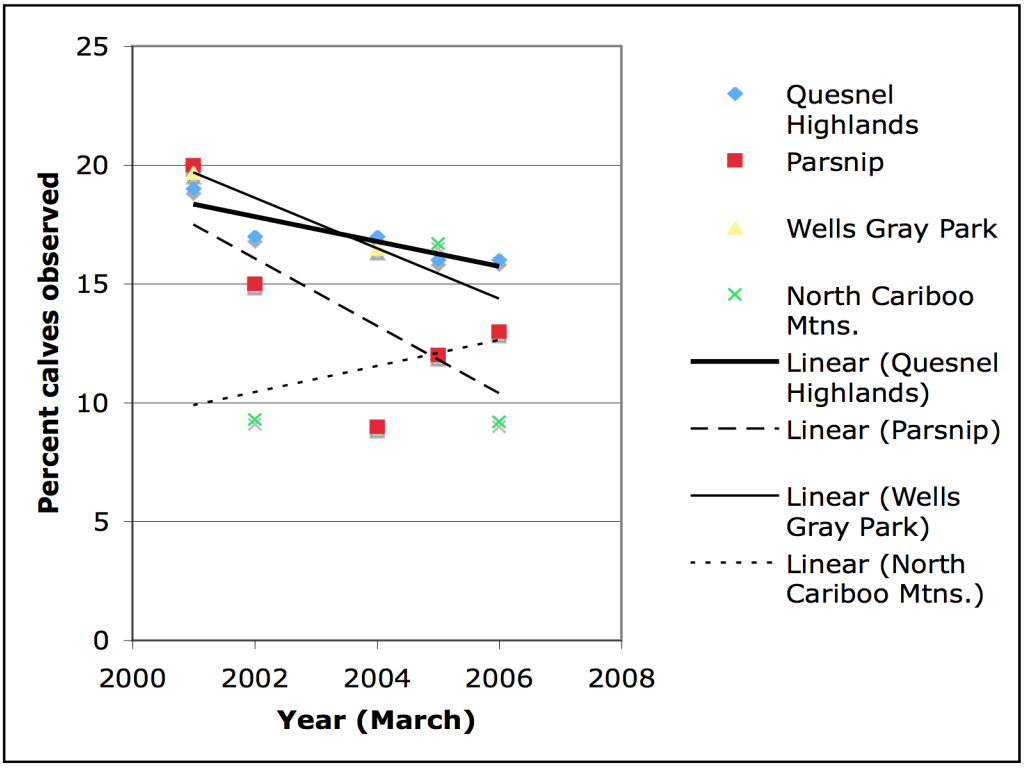

Figure 5. Percent calves observed in March in the Quesnel Highland Treatment Area, and three comparison herds, Phase 1.

During Phase 2, there was also no evidence that recruitment rate increased with

substantial wolf reduction. Recruitment remained below 16%, even after more than half the wolves were removed in 2009. Recruitment trends were similarly low in comparisons herds (Figure 6), suggesting that unknown regional factors could have more important effects on calf survival than wolf predation effect did. There was no analysis of weather information in background information I received.

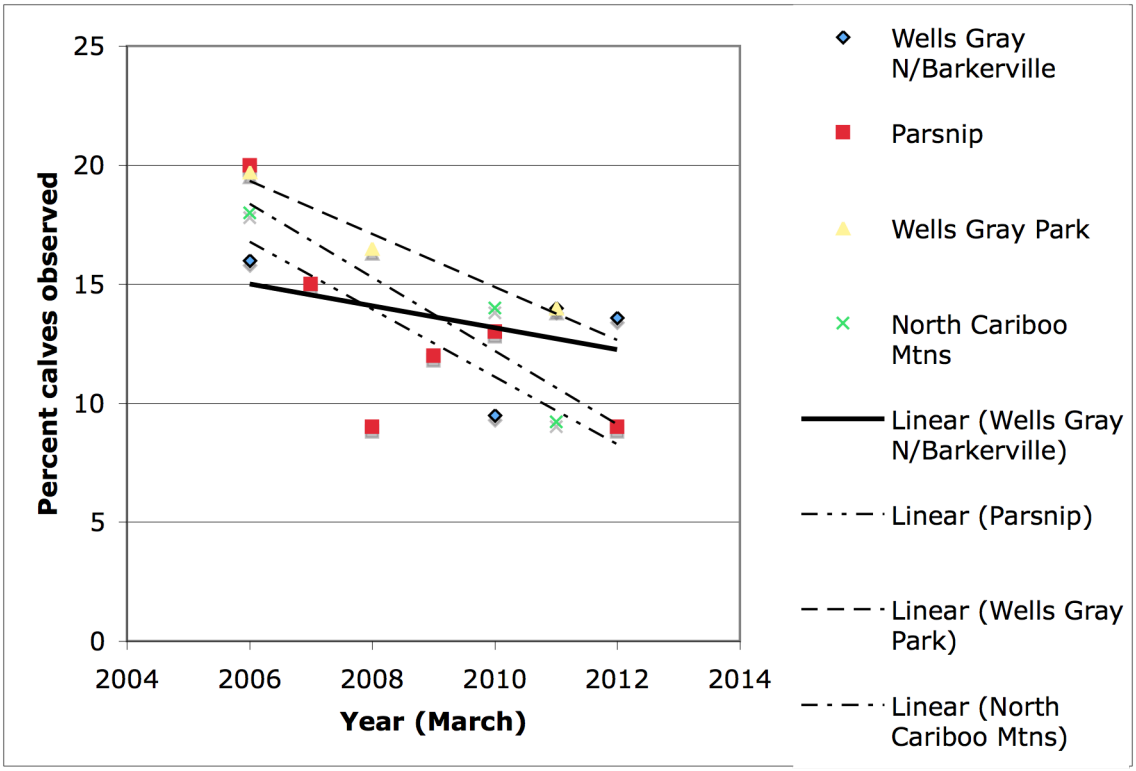

Figure 6. Percent calves observed in March in the Quesnel Highland Treatment Area, and three comparison herds, Phase 2.

Caribou Abundance

Phase 1

The number of caribou observed in the treatment area increased by 26% between 2001 and 2006. During the same period, the Parsnip and Hart South herds also increased (D. Heard unpublished data), while the North Caribou Mountains herd declined slightly (Figure 7). There is no evidence to support wolf treatment had any effect on caribou abundance during Phase 1.

Phase 2

Quesnel Highland caribou increased 16% during Phase 2, with most the growth happening between 2011 and 2012 (Figure 8). At the same time, the Parsnip, North Cariboo Mountains and Hart South herds all declined substantially. The Wells Gray Park herd declined slightly (Figure 8). I used a Chubbs' test for outlier (*GraphPad* software) and found Quesnel Highland caribou were furthest from the rest (+47 caribou) but not a significant outlier (P>0.05, Z=1.71, mean= -36.8, SD=57.8, n=5). Nevertheless, the Quesnel Highland caribou was the only group that increased, suggesting that treatment could be reducing wolf predation rate on caribou. The absence of calf recruitment response suggests growth could be due to: 1) elevated adult survival rates in later years, 2) caribou have shifted into the study area from neighboring herds, or 3) Bergerud's (1992) average estimate of 15% stabilizing recruitment is not appropriate for these herds. In the next section I evaluate the objectives, activities, delivery, performance and results for the Quesnel Highland wolf sterilization pilot study since it began in 2001.

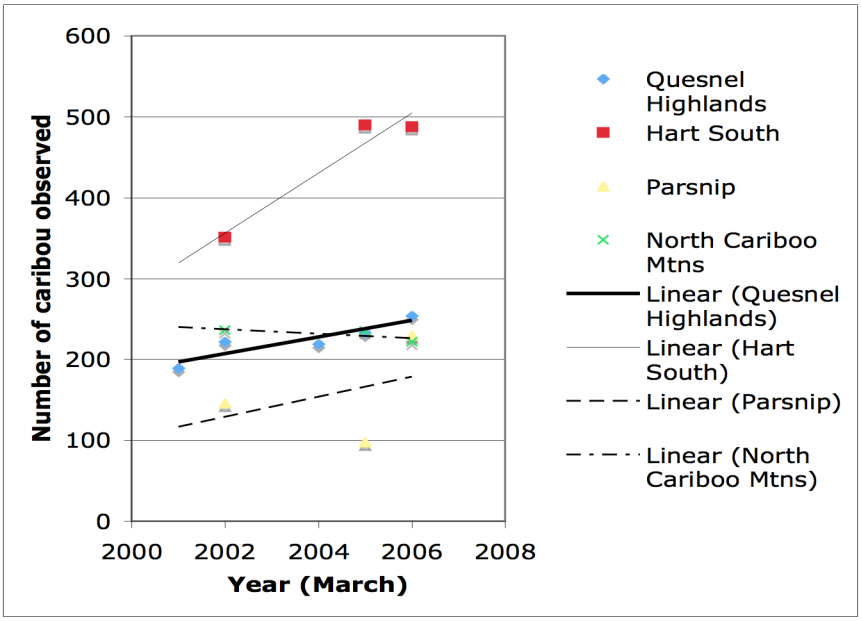

Figure 7. The number of caribou counted in the Quesnel Highland Treatment Area and three comparison herds, Phase 1.

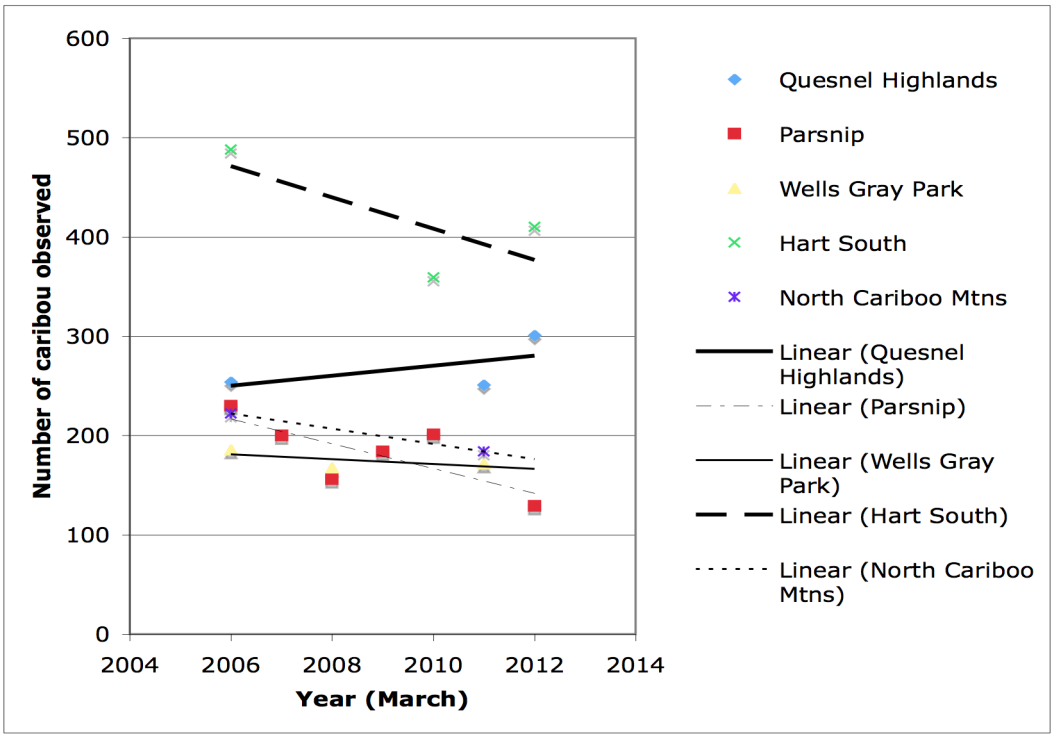

Figure 8. The number of caribou counted in the Quesnel Highland Treatment area and three comparison herds, Phase 2.

Evaluation of Objectives and Research Methods

1. Study Objectives and Design

During Phase 1, the pilot study objectives were to: 1) radio-collar and monitor how wolf habitat use and pack territories overlap mountain caribou, and 2) decrease wolf reproduction using sterilization (Roorda and Wright 2004). Objective 1 was completed with substantial information on how wolves do not use caribou habitat elevations in most seasons. The project was suddenly halted in 2004, the first year that about half the resident packs were fertility-treated, so wolf reproduction was not followed. Phase 2 showed sterilization strongly limited reproduction, completing Objective 2.

In Phase 2, there were 3 measurable caribou responses anticipated by the MCRIP (MCST 2008): calf recruitment exceeds 15%, adult survival is greater than 88%, and herd growth is more than 7% per year. Calf recruitment ranged from 10 to 16%. Between 2006 and 2012, caribou increased by about 4% per year, less than the expected growth

rate. Adult survival was not monitored during the study. Adult survival can be indirectly estimated using census interpolation, providing recruitment is known each year and herd size is known at the beginning and end of study period. Recruitment was measured in 3 of 6 years during Phase 2, not frequently enough to confidently estimate annual adult survival.

The pilot study has suffered from the absence of measurable caribou objectives from the outset, and a proper experimental design to test effects of wolf fertility-control on caribou. There were no predictions about how *much* wolf treatment would change caribou recruitment rate, adult survival, or herd size. Nor were any untreated comparison herds pre-selected and monitored to measure responses that could reveal if other factors were at play. There was also no power analysis performed to establish sample sizes for measuring effects size. Predicting the amount of population change is fundamental to testing responses to wolf treatment (Hayes et al. 2003), and for establishing feedback for adaptive management decisions as a large-scale experiment progresses (Walters and Holling 1992).

2. Wolf Monitoring

The field monitoring of wolf response was sufficient to provide convincing total counts for wolves, and provide density estimates among years. Monitoring of wolf GPS radio-collars provided good information on home range and seasonal use of landscapes. This allowed researchers to determine degree of wolf overlap in annual caribou ranges, showing wolves spend little time hunting caribou year-round (Roorda and Wright 2004, 2010). Visual monitoring of VHF collars was inconsistent especially in later years, but it did provide reliable information about changes in pack composition and sizes in all years. It seems to me that the wolf project benefited greatly by the involvement of Randy Wright and Lara Roorda, who provided continuity, growing expertise, and strong commitment to the wolf research in all years. The skills of these two staff helped the project successfully restart in 2007, after contact was lost with most wolves that were collared in Phase 1.

2. Wolf Treatment

a. Lethal

Wolves were killed by ground trapping, and subordinate wolves were aerial captured and killed by helicopter crews if they were assessed to be non-breeders. Direct shooting of wolves from helicopters was not allowed. Aerial capture-then-kill method requires multiple visits to packs to select out captured subordinates. The continued stress of the aerial capture-then-kill is more disturbing to wolves than one-time pass by aerial shooting. Capture-then-kill is expensive and inefficient and should be ended. The *2012 Draft Management Plan for the Grey Wolf in British Columbia* (MFLNR 2012) is seeking public comment on the limited use of aerial shooting of wolves to reduce predation on threatened mountain caribou herds. Use of one-time pass shooting would make the Quesnel Highland caribou recovery project more humane and efficient, in my opinion.

b. Fertility Control

The sterilization of wolves using vasectomy and tubal ligation was an effective method for reducing reproduction. Sterilization arrested pup production, and treatments usually lasted more than one breeding period. Adult wolves were successfully targeted and small pack sizes were maintained without having to annually search for and remove colonizing pairs the following year (see Hayes et al. 1991, Hayes and Harestad 2000). By 2009, most packs were radio-collared and treated, reducing the cost of field searching for new groups, and providing reliable population estimates for the last three years of study.

3. Moose Reduction and Population Monitoring

Sustaining mountain caribou in the Quesnel Highland is unlikely unless long term wolf management is accompanied by efforts to reduce moose that depend on early seral vegetation after logging (CSC 2007). The CCLUP Mountain Caribou Strategy

recommended to over-harvest in order to reduce moose abundance in the Quesnel Highland (CSC 2000, 2007). The objective was to manage moose at a lower, stable density until caribou recover to levels that can sustain wolf predation rates. Moose harvest was increased in 2001, but there is no information on moose response. Moose were first counted in the area in 2008, followed by more than 50% reduction in wolf numbers after 2009. To understand response to increased harvest, stratified random block surveys should have been carried out at the beginning of the study and response measured again in 2008. Because wolf reduction has been significant since 2009, it is not possible to separate the effects of wolf predation and human hunting on moose response.

4. Caribou Monitoring

Caribou were counted 9 years including the first and last year of the study, providing reliable information to measure responses from 2001 through 2012. Surveys were all conducted in late winter, and aerial methods were consistent among years. All treated blocks were counted in all years, except 2010 when one block was missed.

Herd estimates were available from 2001 through 2006, with radio-tagged samples used to estimate sightability using a Lincoln-Peterson index. I was not provided caribou counts after 2006, and relied on summary information in Roorda and Wright (2010, 2011, 2012).

The observed caribou totals were reasonable measures of population trend. However, observed counts underestimate actual abundance because there is no measure of precision from year to year. There were 301 caribou seen in the treatment area in 2012. The projected goal is for 350, which the herd may have already reached in 2012. A sample of radio-tagged adults is the most accurate method to correct for sightability, providing a replicable herd size estimate each year.

Except for calf recruitment, the internal dynamics of Quesnel Highland caribou are poorly understood. Age distribution, adult sex ratio, calf production, calf mass at birth, adult and calf survival can have strong antiregulatory effects on caribou responses

(see Adams et al. 1995, Boertje et al. 1996, Hayes et al. 2003). Some of these conditions could be affecting Quesnel Highland caribou. None of these parameters were monitored. In the early years, adult survival rates were estimated using a Kaplan-Meier model (Young and Freeman 2001). Freeman and Stahlberg (2006) provided no survival estimates for 15 radio-collared caribou in 2006, nor could I find information for later years. Given the observed increase could be due increased adult survival, it is important to monitor future adult survival rate.

Recommendations

Sterilization research should continue using the existing protocol and techniques. There is evidence the pilot study is moving towards MCRIP recovery objectives, and has a reasonable likelihood of achieving the goal of 350 caribou in the Barkerville and Wells Gray North groups. However, I recommend some changes in wolf research and treatment methods, and significant changes in caribou and moose monitoring protocol and schedules.

Wolf Recommendation 1. *Continue the wolf treatment for three years.*

Wolf reproduction was depressed only after 2009, providing three years of effective treatment to base assessment of caribou responses. Since then caribou have increased, albeit not quickly, while other regional herds have declined. In short, the treatment could be working, but more slowly than expected. Small changes in adult and calf survival may take 4-5 years before there are measurable changes in caribou abundance. I recommend the project be continued for three more years to provide enough information to confidently assess caribou responses. Large-scale wolf removals have been assessed after 5-7 years of treatment in order to interpolate ungulate responses (Gasaway et al. 1983, Gasaway et al. 1990, Farnell and MacDonald 1987, Hayes et al. 2003). Continuing the sterilization project will give a total of six years of wolf treatment to test for responses in caribou abundance.

Wolf Recommendation 2. *Maintain sterilization in fertility-treated packs, and remove untreated packs*.

In March 2012, there were eight sterilized packs in the study area. Efforts should be made to maintain at least one dominant wolf in each group. In any new, small packs (3-4 wolves), dominant members should be sterilized. In large packs, efforts should be to first lethally remove all pack members. When territories are vacant, sterilize new colonizing pairs the following year, similar to methods used by Spence (1999).

Moose Recommendation 1: *Count moose in MU 15a, b, c to estimate change in abundance since 2008.*

Moose should be counted using stratified random block design (Gasaway et al. 1986) in 2015 to estimate change since 2008. Alternately, the three MUs in Quesnel Highland (15a-c) could be counted separately in 2013, 2014 and 2015.

Moose Recommendation 2: *Estimate moose harvest rate, and model the combined effect of wolf reduction and harvest on moose abundance.*

Although moose harvest was substantially increased since 2001, there was no population survey conducted until 2008. As a result, it is not possible to measure harvest rate during that period or determine if it was sustainable, because after 2009 wolves were reduced, adding a second treatment to moose overharvest. However, by counting moose in 2015 (moose recommendation 1), the combined effects of wolf reduction and harvest can be measured between 2008 and 2015.

Caribou Recommendation 1: *Radio-tag a sample of 30 cow caribou to estimate cow/calf ratios, adult survival rate, and provide sightability correction to estimate herd size.*

The absence of adult survival information is the largest deficiency in understanding caribou response to wolf treatment. By monitoring a sample of 10% adult caribou, annual survival can be generated using a Kaplan-Meier estimator. Visually locating radio-tagged cows in October and March will also provide information about the timing of calf mortalities, and a second measure to verify recruitment rate based on

caribou counts. Last, radio-tagged adults provide reliable annual sightability corrections to estimate herd size at the end of each year.

Caribou Recommendation 2: *Annually count the Quesnel Highlands caribou in March 2013, 2014, 2015.*

Continue counting caribou and estimating recruitment for three more years because it is necessary for assessing caribou response of continued wolf treatment. Counting caribou abundance and recruitment each year will also provide a second method to calculating mean adult survival using census interpolation from 2009 through 2015.

Caribou Recommendation 3: *Monitor changes in abundance and calf recruitment in comparison herds.*

Comparisons herds were useful for my analysis, because it allowed me to evaluate how the Quesnel Highland caribou behaved compared to other regional herds. It was only fortuitous that comparison herds were adequately monitored, not a result of good experimental design. The declining trends in four regional herds adds some weight to the possibility that Quesnel Highland caribou are increasing in response to wolf treatment. This is what is most different about Quesnel Highland caribou, and why I recommend the study should continue. Select two or more comparison herds (to maintain untreated replicates) and continue monitoring and ensure counts are made at least once in 2014 or 2015.

Conclusion

There is substantial effort to reverse the declining trend of threatened mountain caribou in British Columbia including maternal penning in Revelstoke area, translocation in the Kootenay, moose reduction in the Parnsip herd, reducing access and recreational disturbance in various herds (Chris Ritchie, personal communication), and this wolf sterilization study in the Quesnel Highland. There is also no evidence that any methods

are causing herds to increase. However, wolf sterilization may be stabilizing Quesnel Highland caribou, or causing a recent increase in abundance. It is important that the project continue to measure responses to recently effective wolf reductions.

Messier et al. (2004) suggested the scale of mountain recovery studies in B.C. need to be increased to include 'control' herds, and more information should be collected about the internal dynamics of mountain caribou response. My evaluation shows the value of comparison herds, and the need to understand adult and calf survival rates to better explain the nature of short-term caribou responses to wolf treatment

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