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Conservation of threatened Canada-USA trans-border grizzly bears linked to comprehensive conflict reduction

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Abstract: Mortality resulting from human–wildlife conflicts affects wildlife populations globally. Since 2004, we have been researching conservation issues and implementing a comprehensive program to reduce human–bear conflicts (*Ursus* spp.; HBC) for 3 small, fragmented, and threatened grizzly bear (*U. arctos*) populations in the trans-border region of southwest Canada and northwest USA. We explored the temporal and spatial patterns of conflict mortality and found that HBC contributed significantly to the threatened status of these populations by causing decline, fragmentation, and decreased habitat effectiveness. Our program to reduce HBCs primarily included strategic private lands purchased to reduce human density in wildlife corridors, the reduction of bear attractants where human settlement and agriculture exists, and the nonlethal management of conflict bears. Attractant management strategies encompassed public education, cost-share electric fencing, bear-resistant garbage containers, and deadstock containment. We taught bear safety courses and bear spray training to increase tolerance and give people tools to avoid negative encounters with bears. We radio-collared and used nonlethal management on potential conflict bears and have a ~75% success rate in that the bear was alive and out of conflict situations over the life of the radio-collar. We identified important backcountry grizzly bear foraging habitat for motorized access control to reduce conflict and mortality and provide habitat security to reproductive females. Ongoing monitoring has demonstrated that our comprehensive HBC program has resulted in a significant reduction in human-caused mortality, increased inter-population connectivity, and improved habitat effectiveness. Several challenges remain, however, including an increase in the numbers of young grizzly bears living adjacent to agricultural areas. Herein we discuss strategies for how to integrate conservation vision into future HBC reduction programs.

Key words: conflict, connectivity, grizzly bear, human–bear conflict, human-caused mortality, trans-border, *Ursus arctos*

Human–wildlife conflicts are the proximate cause of many conservation issues around the world (Treves and Karanth 2003, Distefano 2005, Can et al. 2014). As the human footprint expands, we move deeper into what was previously wildlife habitat (Sanderson et al. 2002, Venter et al. 2016). In many areas, natural wildlife habitat now exists in a mosaic with rural human-dominated landscapes. Wildlife may benefit in the short-term from access to human-based foods, either agricultural products directly, or stored human foods (Can et al. 2014). However, these situations often result in conflicts as human livelihoods are impacted and the offending wildlife are killed. Beyond the immediacy of the conflicts themselves, long-term conflicts can impact the conservation of wildlife species, resulting in population decline, range contraction, and loss of inter-population connectivity (Distefano 2005).

We began working in an area where such a scenario was playing out; long-term human wildlife conflicts with a large carnivore had resulted in fragmented, small, and threatened grizzly bear (*Ursus arctos*) populations in the Canada-USA trans-border region of western North America. The international South Selkirk population has an estimated >83 grizzly bears (Proctor et al. 2012), and the international Cabinet-Yaak (spelled Yahk in Canada, hereafter spelled Yaak) has approximately 72 bears—48 in the Yaak and 24 in the Cabinet portions (Proctor et al. 2007, Kendall et al. 2016; Figure 1A). The South Selkirk and Cabinet portion of the Cabinet-Yaak were fully isolated to both sexes, and the Yaak has been fragmented to females (Proctor et al. 2005*a*, Kasworm et al. 2007, Proctor et al. 2012). The South Selkirk and Yaak grizzly bear populations are designated as threatened by British Columbia (www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html), the U.S. Fish and Wildlife Service (USFWS 1993), and the International Union for the Conservation of Nature Red List Authority (McLellan et al. 2017). The U.S. Cabinet population also is designated as threatened (USFWS 1993, McLellan et al. 2017) and has been the subject of an ongoing augmentation program (Kasworm et al. 2007, 2017).

All 3 grizzly bear populations are of high conservation concern. The causes of this concern have been relatively high conflict-related human-caused mortality, approximately half of which occurred in the front-country (human-settled valleys) and were mostly reported, but an equal number occurred near backcountry resource roads (Wakkinen and Kasworm 1997; Proctor et al. 2017, 2018), and some were very likely unreported (McLellan et al. 1999). Conflict-related mortality has occurred at front-country residential or agricultural properties or backcountry hunting, recreation, or work camps. Human activity and human-caused mortality have been keeping these populations suppressed for decades (McLellan 1998, Mattson and Merrill 2004, Proctor et al. 2004*a*, Kasworm et al. 2008). Population-level fragmentation also contributes to their conservation status and has been associated with fractures consisting of human settlement, human-caused mortality, and transportation corridor traffic along major valleys (Proctor et al. 2012, 2015; Lamb et al. 2017; Figure 1).

Herein, we describe a long-term effort to understand the link between these conservation issues and human conflicts with grizzly bears (human–bear conflicts, HBC) in southeast British Columbia (B.C.), northwest Montana, USA, and northern Idaho, USA. We implemented a comprehensive program to reduce conflict within 3 small, fragmented, and threatened grizzly bear populations and then measured the effect this program had on 2 indices of conservation status: human-caused mortality and inter-population connectivity.

We used over a decade of grizzly bear GPS telemetry locations to identify potential wildlife/grizzly bear population connectivity areas (Proctor et al. 2015; Figure 2). We focused conservation management on several important fractures (Figure 1B) to reduce conflict and thus mortality, simultaneously improving the population trajectory and allowing connectivity to re-establish. We also monitored the spatial and temporal patterns of human-caused mortality to inform our management activities and to assess the efficacy of those efforts. Conflict mitigation activities were carried out or instigated by our research group and a network of government and non-government organizations. Our results may have significance for solving conflict-related fragmentation in other systems across North America and the world (Distefano 2005, Locke and Francis 2012, Proctor et al. 2012, Apps et al. 2014, McLellan et al. 2017).

Study area

Our study area encompassed the Canada-USA trans-border region of the South Selkirk, Purcell, and Cabinet mountains of southeast B.C., northwest Montana, and northern Idaho (Figure 1). This mountainous area is bisected by valleys that have attracted human settlement and transportation corridors (i.e., highways and railways) that connect urban centers and often support a linear assemblage of rural landowners or communities. These linear features have previously been identified as fractures to grizzly bear populations (Proctor et al. 2012; Figure 1B). Human settlement along transportation corridors varies from stretches of private land with continuous rural settlement to stretches of public land with little development. Villages of up to 1,000 people to towns of >20,000 people occur throughout the region. Valley widths vary from <500 m to 7 km. The mountain environments are primarily conifer forest, with occasional wetlands, avalanche paths, alpine areas above tree line, and other non-forested habitats. The region supports a timber industry and sporadic mining on both sides of the border that have left an extensive network of backcountry resource roads.

Our conflict mitigation efforts were applied across many portions of our study area, but we describe 3 of the more significant population fractures that received the most effort (Figures 1B and 2). Fracture 1 extends from Creston, B.C. to Sandpoint, Idaho from the south end of Kootenay Lake along the Creston Valley to Bonners Ferry, Idaho and further south to Sandpoint, Idaho. This fracture separates the South Selkirk from the South Purcell and Cabinet Mountains (Figure 1B). The Creston Valley within B.C. is 5–7 km wide and contains the town of Creston (5,300 people) and rural settlement (~1,200 people) of farms and ranches. Approximately 40% of the valley within B.C. is the Creston Valley Wildlife Management Area (CVWMA), which is primarily managed for flood control and waterfowl and contains a rich diversity of wildlife. Within the United States, the same valley has an extensive agricultural community both north and south of the town of Bonners Ferry (~2,500 people).

Fracture 2 is the B.C. Highway 3 transportation and settlement corridor that bisects the Purcell Mountains approximately 25–40 km north of the U.S. border and connects the towns of Creston and Cranbrook, B.C. The valley containing Highway 3 is relatively narrow (0.5–1 km) and contains a discontinuous rural community with sporadic agriculture and a growing number of recreational vehicle resorts as well as significant stretches of uninhabited public land.

Fracture 3 corresponds to U.S. Highway 2 from Libby, Montana to Bonners Ferry, Idaho, running parallel to the Kootenay River and a railway and separates the southern Purcell Mountain Yaak population from the Cabinet Mountain population. In addition to Bonners Ferry, this fracture has 2 towns, Libby, Montana (2,700 people) and Troy, Montana (1,000 people) with a rural community along much of its length (Figure 1B). There are 2 8-km segments dominated by public land that have been identified as connectivity linkage areas, so efforts to acquire land or secure conservation easements have focused in these areas. The backcountry areas adjacent to this fracture receive an access management program administered by the U.S. Forest Service (USDA 2015).

Methods

Strategies to reduce HBC

Conservation easements and direct land purchases. We worked with land conservation non-government organizations (NGOs), government agencies, and private industry to protect strategic lands in high priority connectivity areas identified in Proctor et al. (2015). Using spatially-explicit ownership information, we identified key lands to inform direct purchases, securement of conservation easements, or in a few cases, land trades as opportunities arose. We developed materials to briefly explain the scientifically derived conservation story for potential sellers and funders for these conservation properties. Funds for these purchases were obtained through fund raising efforts of Nature Conservancy Canada, Yellowstone to Yukon Conservation Initiative, The Nature Trust of B.C., Vital Ground, The Nature Conservancy (USA), Trust for Public Lands, Montana Fish Wildlife and Parks, U.S. Fish and Wildlife Service, U.S. Forest Service Forest Legacy Program, and the Stimson Lumber Co.

Nonlethal management of conflict grizzly bears. We implemented a nonlethal conflict management program on candidate grizzly bears in both Canada and the United States that was patterned after a program developed by Montana Fish Wildlife and Parks (MFWP, Dood et al. 2006) and the U.S. Interagency Grizzly Bear Committee (IGBC). Both programs emphasized public and property safety as the first 2 priorities to reflect the belief that the public first needs to feel safe and secure to accept coexistence with large, occasionally dangerous carnivores like grizzly bears. When those priorities were addressed, we focused on direct action to reduce bear attractants (the first action). When warranted, we considered additional management action on a case-by case basis based on several criteria, especially if it was determined a bear needed to be captured. Within Canada, this was done in cooperation with the B.C. Conservation Officer Service. If a bear's behaviour mimicked natural behavior (e.g., feeding on a livestock carcass or eating fruit from a tree), the bear was not threatening to humans or property, and the bear did not have a history of conflicts, then they were considered a candidate for nonlethal management. What this meant in practice was that we tried to intervene early in what might be a progression of bolder, more aggressive actions by the bear to obtain human-based foods (e.g., breaking into a building). We captured and immobilized these bears for radio-collaring. In Canada, our bear handling procedures were in accordance with the Canada Council on Animal Care Standards. In the United States, methods were in accordance with the University of Montana Institutional Animal Care and Use Committee (protocol identification number is 007-06CSFWB-040106; Proctor et al. 2015). We used Telonics Inc. (Mesa, Arizona, USA) Global Positioning System (GPS) Spread Spectrum radio-collars (and occasionally store-on-board collars), and in recent years Iridium-based GPS satellite collars, and remotely downloaded bear locations on a periodic basis. Collars were programmed to take locations between 1 and 4 hours during the non-denning season for 1–3 seasons, depending on the age and sex of the bear (Proctor et al. 2012). For long-term identification, we also applied ear tags, lip tattoos, and injected a small Passive Integrated Transponder (PIT tag) under the skin.

Radio-collared bears were usually kept in a barrel or culvert trap for 1–2 nights. The first night was usually the night they were captured, the second night was to allow them to fully recover from immobilization and to associate the location (proximity to human settlements) with an unpleasant experience for bears kept on site. Bears were kept dry and provided water during their second night.

Release options varied by situation, depending on the history of the bear, the nature of the conflict, the land owner, the ease of securing the attractant, and other factors. This varied from on-site release with some combination of bear dogs, bean bags, rubber bullets and cracker shells, to short movement releases (1–2 km away to get to secure habitat for the bear), to longer movements within their home range. Bears were occasionally taken beyond their estimated home range, but it was avoided if possible. Data suggested that bears moved outside their natural home range expanded their range, which increased their risk of getting into trouble elsewhere (M. Proctor, unpublished data; Milligan et al. 2018).

Cost-share electric fencing program. We implemented a cost-share electric fencing program that focused on identified connectivity linkage areas but was also applied anywhere HBCs occurred. We contacted landowners who experienced a conflict, and our program grew through word of mouth or through attendance at electric fencing workshops. In the United States, we implemented a free temporary loaner fence program and secured county sanitation collection sites throughout the area. These programs were administered by the regional conflict specialist (MWAP) with several partners including Defenders of Wildlife, Yellowstone to Yukon Conservation Initiative and Lincoln County, Montana. Both the U.S. and the Canadian programs provided experienced guidance on how to build and maintain an electric fence when necessary.

Loaner/subsidized bear-resistant garbage container program. Adequately securing garbage and other attractants before they are picked up by collectors was a challenge in rural neighborhoods. In Canada and the United States, we worked with multi-stakeholder working groups to implement bear-resistant garbage bin programs and encourage communities to adopt or improve wildlife attractant bylaws or regulations. Bear-resistant bins were loaned out temporarily, or sometimes permanently, and were often eventually purchased. The income from the sale of the bins was recycled back to purchase more bins.

Backcountry access management. To increase habitat effectiveness and reduce human-caused grizzly bear mortality in the backcountry (Proctor et al. 2018), we identified the most important food resources and their locations across the Canadian South Selkirk and Purcell Mountains. Our goal was to protect these high-value habitats with some level of motorized access control to reduce mortality risk and help secure the habitat. Recent research has shown that these high quality foraging patches support a higher relative density of female grizzly bears that also have a higher realized reproductive output (Proctor et al. 2017, 2018).

Measures of HBC program effectiveness

Mortality events and causes. We documented grizzly bear mortality in 2 ways. First, we tracked all known mortality and their causes through a long-term radio collaring effort (Table 1). These mortalities were known to our research team but not necessarily to wildlife managers or conservation officers. Within the U.S. portion of our study area, we radio-collared grizzly bears annually since 1983. Within Canada, we radio-collared grizzly bears from 1990–2017. Our sample sizes varied from 1–17 bears annually. We also tracked non-collared grizzly bear mortalities and their causes from reports to wildlife managers and conservation officers in each country. These combined records allowed us to investigate causes, trends, and spatial patterns in human-caused mortality.

Spatial patterns in human-caused mortality. First, we explored the causes of human-caused mortality in 2 different realms, front and backcountry. We defined front-country mortalities as being where a bear was attracted into a permanent residence, farm, or ranch and subsequently killed. Backcountry mortalities were away from settled areas and usually did not involve attractants (although a bear attracted to a recently killed game animal or hunting camp was considered a backcountry mortality).

Second, we modeled spatially-explicit HBC mortality risk using logistic regression methods (Proctor et al. 2015) with the addition of Akaike Information Criterion (AIC) model selection methods (Burnham and Anderson 1998). A priori models were compared using small sample size corrected AICc scores. Models with delta AICc scores >2.0 were considered to be supported by the data. Our input (predictor) variables included human disturbance variables that have been shown to influence human-caused mortality elsewhere (Nielsen et al. 2004), including road presence, road density, distance to roads, highways, and settlements (buildings), as well as several ecological variables we expected might influence mortality risk (i.e., riparian areas, elevation, canopy openness).

We compared 207 mortality events (i.e., non-hunt, non-natural that also include mortalities within 10 km of the periphery of our focal populations) to 5,170 random points within a minimum convex polygon of all mortality events (available) using ArcGIS 10.6 (ESRI, Redlands, California, USA). We estimated the parameters of the exponential resource selection function (RSF) using logistic regression (Manly et al. 2002) and transformed predictions from the RSF using the logistic function to normalize the right skewing of exponential RSF values, and then mapped predictions at a 100-m scale in ArcGIS. We performed logistic regression using the statistical software package STATA (Intercooled 9.2, College Station, Texas, USA). We only used variables correlated <0.7 in the same model during the modeling process. The relative influence of variables in our top model was determined by running the model with each variable removed separately and comparing the resulting log likelihoods (Schwartz et al. 2010). The variables with the most reduction in log-likelihoods were considered more influential.

Habitat variables. We used land-cover variables (e.g., riparian, canopy cover, elevation). We included elevation as a variable because grizzly bears in our region use high country extensively, which may be for a variety of reasons (e.g., high elevation habitat types, thinner forest cover with more edible vegetation, human avoidance).

Human disturbance variables. We used backcountry resource roads (i.e., associated with timber harvest, mining) in various forms including road presence/absence, distance to roads, and road density. Distance to the nearest road was derived within ArcGIS as was road density using a moving window and was recorded in km/km^2. We realize that traffic intensity on these roads may be a relevant variable, but road density does not lend itself to the addition of frequency of traffic. In other work (Proctor et al. 2017), we tested a human access variable (Apps et al. 2004, 2016) that combines human population centers and distance down road networks to estimate human access. Our tests show that in our study area, road density was a better predictor of habitat use, density, and fitness. For that reason, and the fact that we do not have an access variable across the U.S. portion of our study area, we used road density. We digitized highway and human developments from 1:50,000 scale topographic maps and orthophotos. We buffered highway, human developments, and backcountry roads by 500 m on either side to reflect their potential influence on grizzly bear mortality risk (Mace et al. 1996, Proctor et al. 2018). These human-use variables repeatedly have been demonstrated to correlate with habitat selection by grizzly bears (Mace et al. 1996, 1999; Nielsen et al. 2002; Apps et al. 2004).

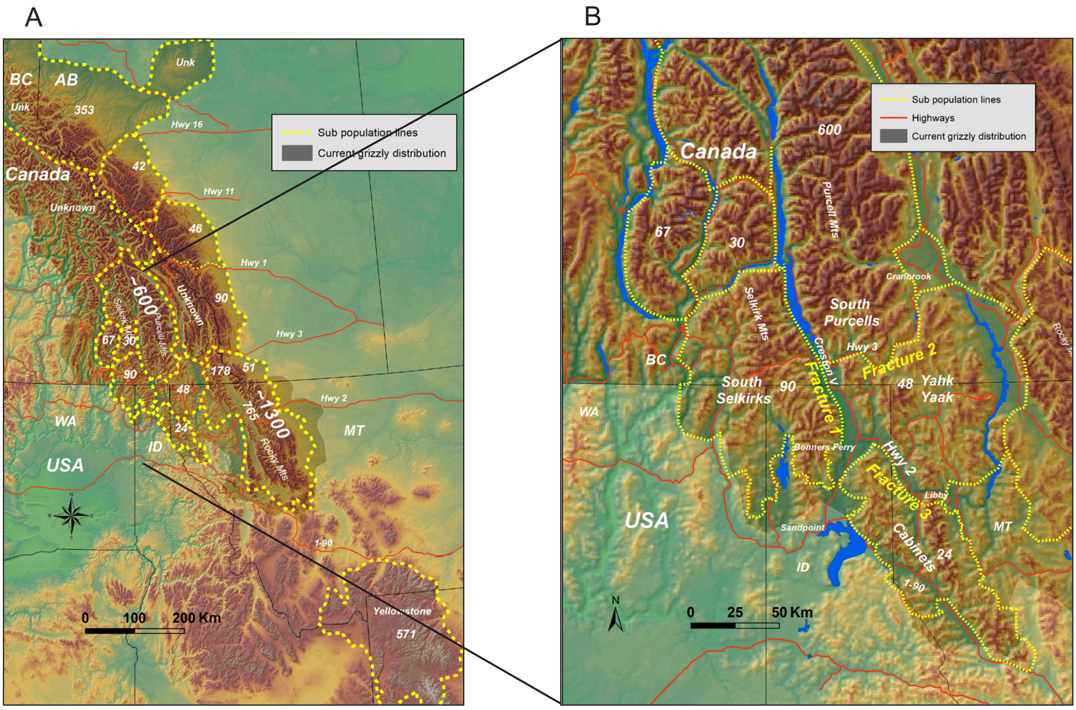

Figure 1A. Grizzly bear (*Ursus arctos*) population fragmentation within the extended Canada-USA trans-border region. Yellow dotted lines characterize fragmented sub-populations, primarily for female grizzly bears. Numbers are data-based population estimates. Shaded areas in the United States outside of yellow dotted lines represent recent population expansion (adapted from Proctor et al. 2012). **Figure 1B.** The Canada-USA trans-border study area. Fracture 1 extends north-south from the Creston Valley, B.C. to Sandpoint, Idaho, USA. Fracture 2 extends along B.C. Highway 3 in the Purcell Mountains east-west Cranbrook B.C. to Creston B.C., and Fracture 3 extends along U.S. Highway 2 east-west from Libby, Montana, USA to Bonners Ferry, Idaho.

Temporal trends in human-caused mortality. We explored temporal mortality trends prior to and after mortality reduction efforts were initiated. We excluded natural mortalities from this analysis. There was no legal hunting in these populations, either in the United States or Canada, during our study period. Within the United States, a bear conflict specialist was hired in northwest Montana in 2007 after which enhanced mortality reduction activities were applied. Within the Canadian portion of our study area, the Trans-border Grizzly Bear Project began enhanced mortality reduction mitigation efforts in 2004. Both programs are ongoing.

Connectivity monitoring

We tracked 2 levels of connectivity, movements of individual bears across fractures separating populations, and gene flow events, breeding with detected offspring after an inter-population movement. We monitored connectivity through radio tracking a sample of bears (described earlier) and their direct movements using genetic samples to assign population of origin or through family unit pedigrees (Proctor et al. 2012, Kasworm et al. 2017; Table 1). Grizzly bears were genetically sampled during inventory surveys done to estimate population size through the capture history of genotyped individuals (Woods et al. 1999, Proctor et al. 2007, Kendall et al. 2009, 2016), from live capture events for radio-collaring (Proctor et al. 2015, Kasworm et al. 2017), from dead bears, and opportunistically. Microsatellite genotypes were developed at Wildlife Genetics International (Nelson, B.C., Canada) using techniques that have been thoroughly described in previous work (Woods et al. 1999; Kendall et al. 2009, 2016). Briefly, DNA is extracted from the roots of hair samples. Polymerase Chain Reaction (PCR) is used to amplify that DNA, allowing the development of microsatellite-based individual genotypes (DNA fingerprints). Microsatellites are excellent markers for identifying individuals, familial relatedness (e.g., parent-offspring), determining population of origin, and limited family pedigrees as this project does (Proctor et al. 2005*a*, Kendall et al. 2009, Proctor et al. 2012,

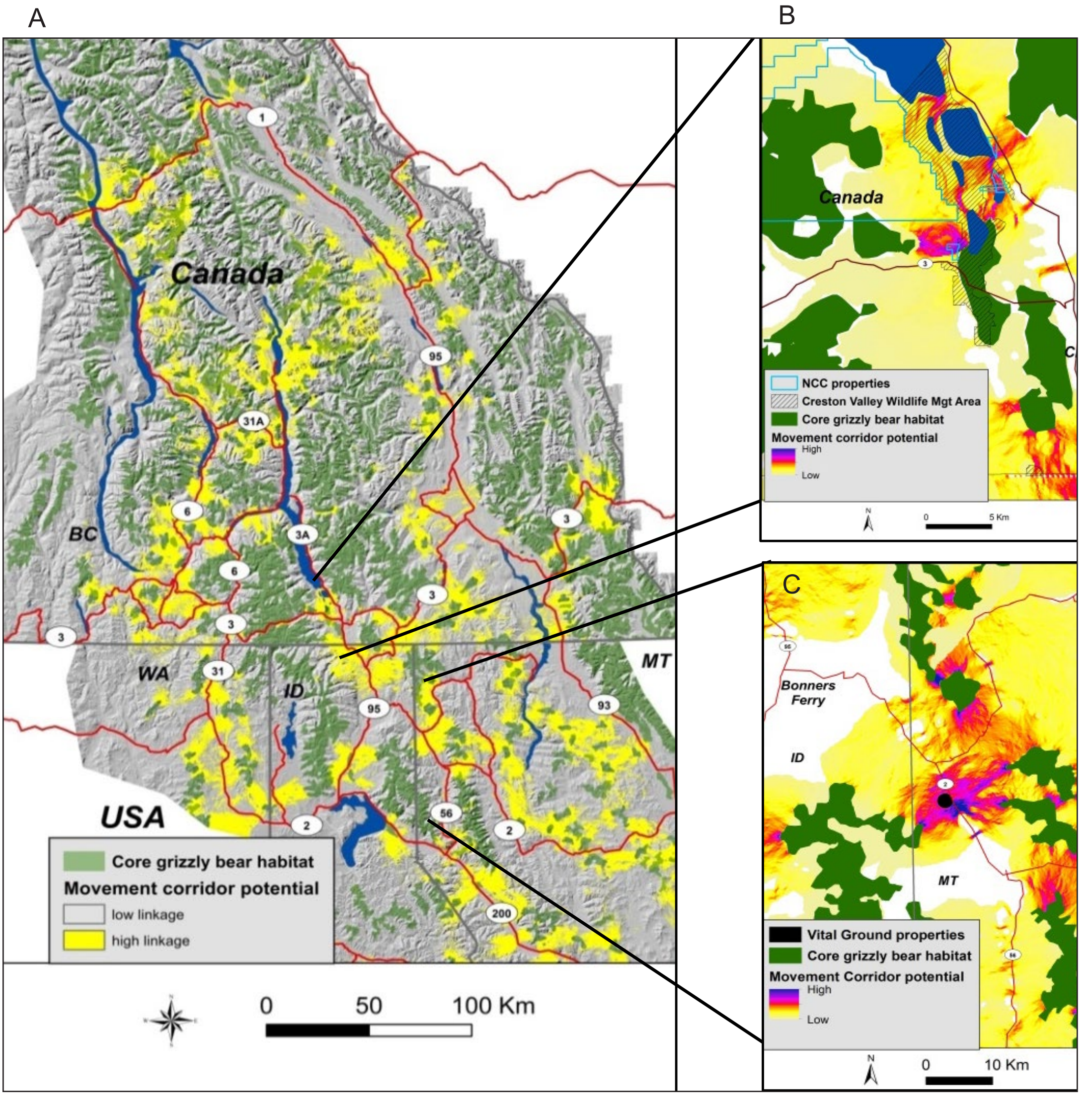

Figure 2A. Model predictions of grizzly bear (*Ursus arctos*) connectivity areas across transportation corridors and human-settled valleys in Canada-USA. trans-border region. Green polygons are core grizzly bear habitat and yellow are areas of high connectivity potential (adapted from Proctor et al. 2015). **Figure 2B.** A close-up view of Creston Valley, B.C. connectivity predictions juxtaposed with Nature Conservancy of Canada (NCC) purchased properties and the Creston Valley Wildlife Management Area. **Figure 2C.** A close-up view of Vital Ground purchased properties in the connectivity area along U.S. Highway 2 between Libby, Montana, and Bonners Ferry, Idaho, USA.

Kendall et al. 2016, Morehouse et al. 2016). All bears were genotyped to 21 loci to insure we could distinguish family groups (Kendall et al. 2016), and error checking was done in accordance with methods outlined by Paetkau (2003).

We used assignment methods identical to Proctor et al. (2005*a*, 2012). First, we used GeneClass 2.0 (Paetkau et al. 2004, Piry et al. 2004) to examine our power to distinguish true from statistical migrants, and we generated significance levels for individuals that cross assigned to a neighboring area using the simulation routine within GeneClass 2.0 software (Paetkau et al. 2004, Piry et al. 2004). We determined significance levels by comparing individual genotypes of cross assigned individuals to a simulated set of 10,000 genotypes that were generated using area-specific allele frequencies. We also used the program Structure, (Pritchard et al. 2000) that clusters individuals into groups through iterative assignments and develops probabilities of area origin for each

Table 1. Monitoring effort and methods used to track grizzly bear (*Ursus arctos*) mortality and movement with radio telemetry and to collect genetic samples in the Canada-USA trans-border region of southeast B.C., northwest Montana, and northern Idaho, 1987–2017. The South Selkirk (S. Selkirk) population has an estimated >83 grizzly bears (Proctor et al. 2012). The South Purcell (S. Purcells) population north of the Yaak and the International Cabinet-Yaak has approximately 72 bears: 48 in the Yaak and 24 in the Cabinet portions (Proctor et al. 2007, Kendall et al. 2016).

Monitoring method	S. Selkirk	S. Purcells	Yaak	Cabinets
Genetic				
Live capture	1990–2017		1986–2017	1983–2017
DNA sampling	1999, '05, '07		2002–2017	2002–2017
DNA survey		1998, '99, '02, '04, '05	2001, '04, '05, '12	2012
Telemetry				
Live capture	1990–2017	2008–2014	1986–2017	1983–2017

Table 2. Summary of A) connectivity linkage conservation land and B) connectivity linkage buffer land directly purchased or within Conservation Easements in the trans-border area of southeast B.C., northwest Montana, and northern Idaho, USA, 2004–2017.

	Population fracture	Hectares purchased	Conservation easements	Total hectares
A.	Creston-Sandpoint	160	9,922	10,082
	B.C. Hwy 3	236		236
	U.S. Hwy 2	46	10,927	10,973
				21,290
B.	Creston-Sandpoint	49,636		49,636
	B.C. Hwy 3			
	U.S. Hwy 2	57	667	725
				50,361

Table 3. Summary of the fates of grizzly bears (*Ursus arctos*) that received nonlethal management in the international South Selkirk and Cabinet-Yaak grizzly bear populations of southeast B.C., northwest Montana, and northern Idaho, USA, 2003–2017. Success was defined by a bear being alive and out of conflict for the life of their radio-collar (2–3 years).

	Collared and managed	Alive when collar off	% success
Females	18	15	83
Males	17	11	65
Total	35	26	74

individual through the cumulative results of those assignments. Individuals that repeatedly assign to a group other than that of their capture are considered putative migrants from their source area. For display purposes, we used a multidimensional Factorial Correspondence Analysis (FCA; Benzecri 1973, She et al. 1987) within the program GENETIX (Belkhir 1999). Factorial Correspondence Analysis is a special case of principal components analysis that provides an objective exploration into groupings of similar genotypes with no a priori assumptions of group membership.

We also detected movements and gene flow through development of limited pedigrees to look for direct dispersers who moved to a different population than their mothers or to detect breeding in a new population by a migrant (Proctor et al. 2013, Kasworm et al. 2017). Limited pedigrees consisted of family unit triads with a mother, father, and offspring, all with a complimentary allele sharing pattern where the offspring holds an allele from each parent at all 21 loci. We used program PARENTE (Cercueil et al. 2002) for detecting family relationships. Given the low relative variability in these populations, searches for a single parent would not reliably differentiate between sibling and parent–offspring relationships, so we only used

Figure 3. Conflict male grizzly bear (*Ursus arctos*) being released on-site after radio collaring (A). An electric fence set up around a cherry orchard through our cost-share program (B). A bear safety course with bear spray training in both the Canada and the U.S. trans-border region (C and D).

family groups where we could unambiguously detect both parents and an offspring. During this process, we reran any genotypes that had 1 or 2 mismatched pairs and where PARENTE indicated $P > 0.5$ for the potential family members in case that pattern was due to a genotyping error.

The South Selkirk population previously has been reported to be completely isolated (fragmented to both sexes), evidenced by having no inter-population dispersers with adjacent populations and a significantly lower expected heterozygosity (H_E = 0.54) than adjacent populations (Proctor et al. 2012). We measured updated heterozygosity values (previously reported by Proctor et al. 2005*a*) and the number of alleles to assess any increase in gene flow that may have influenced genetic variability in that population.

Results

Strategies to reduce HBC and mortality

Conservation easements and direct land purchases. Our affiliated network of NGOs, government agencies, and private industry have protected >52,000 ha across the 3 main fracture areas through lands purchased directly or in conservation easements managed by a land conservation NGO in perpetuity (Table 2). These purchased lands and conservation easements were valued at >$58,000,000.

Nonlethal management of conflict grizzly bears. We radio-collared and used nonlethal management on 18 female bears from 2003 to 2017. Of these, 15 bears were alive and staying out of conflict when their radio-collars released (2–3 years later; Table 3). We are not aware of any of the managed female bears getting into conflict after their radio-collar released. In the same period, we radio-collared 17 males. Of these, 11 males were alive and staying out of conflict when their radio collars dropped 2–3 years later (Figure 3A; Table 3).

Cost-share electric fencing program. In Canada between 2012 and 2017, we sponsored 88 electric fence installations at a cost of ~$65,500 USD (Figure 3B). The municipality of Creston electric-fenced their landfill in 2010 as a result of our GPS telemetry data showing grizzly bear use of the landfill. In the U.S. Highway 2

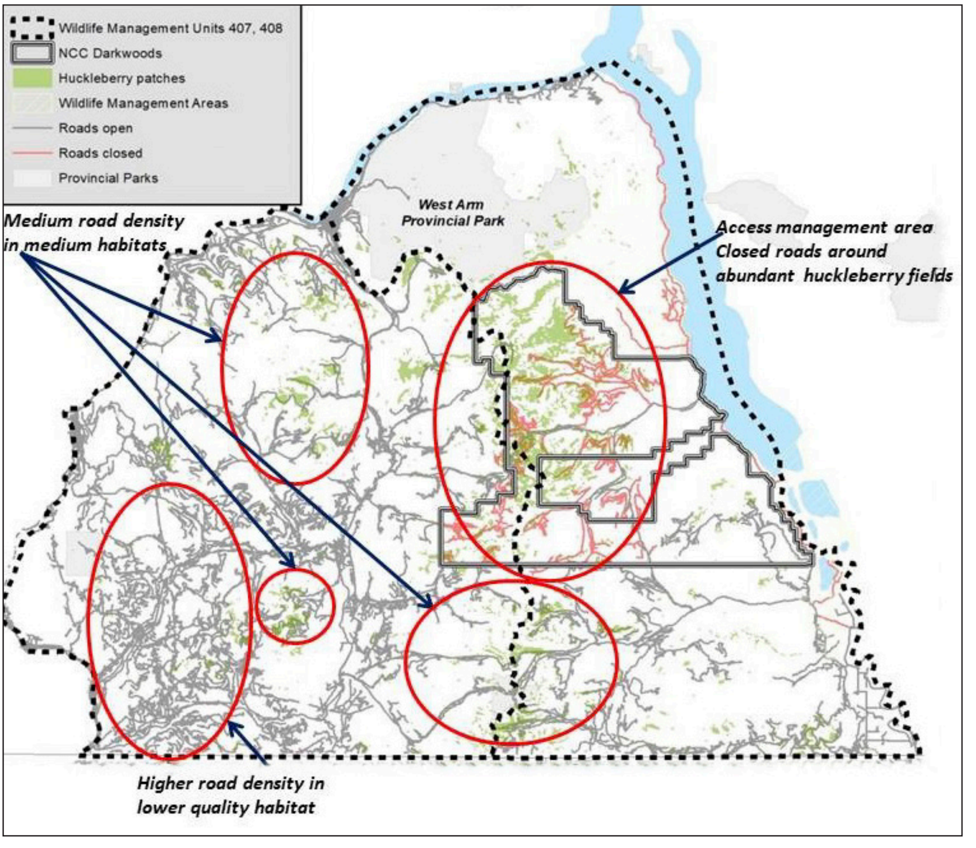

Figure 4. An example of resource road management on Nature Conservancy of Canada lands in the South Selkirk Mountains as a mitigation for backcountry mortality and to increase habitat effectiveness (adapted from Proctor et al. 2018). Public access was controlled around good huckleberry patches, and this resulted in increased female habitat use, density, and realized reproductive output (fitness; Proctor et al. 2017).

Table 4. The relative proportion of front and backcountry grizzly bear (*Ursus arctos*) mortalities recorded between 1984 and 2017 in the international South Selkirk and Cabinet-Yaak grizzly bear population ecosystems.

	Front-country	Backcountry	Total
Cabinet-Yaak	30	41	71
South Selkirk	40	30	70
Total	72	69	141
Proportion	0.51	0.49	

fracture, our network installed >118 temporary and permanent electric fences, and 10 public sanitation collection sites have been secured with electric fences.

Loaner/subsidized bear-resistant garbage container program. In Canada, since 2010, we have loaned out >100 bear-resistant garbage bins. In the United States, 18–20 bear-resistant containers were temporarily loaned out annually to people without regular pickup services.

Public education and outreach. We supported a multifaceted public education and outreach program. In Canada, we sponsored a Wildsafe B.C. (https://wildsafebc.com/) education specialist for over a decade who presented bear education information to local residents and communities in a variety of ways. We also have held "Bear Fairs" where we taught bear safety courses that included practice with bear spray for local residents and farmers and their families (Figures 3C and 3D). We gave 20–30 public presentations about bear conservation and our overall program annually. In the U.S. Highway 2 fracture, a bear specialist and a conservation officer were employed to do public outreach and education in a variety of ways, in addition to mitigating conflicts. They met regularly with local and regional government officials, industry, schools, and the public, overall attending 15–30

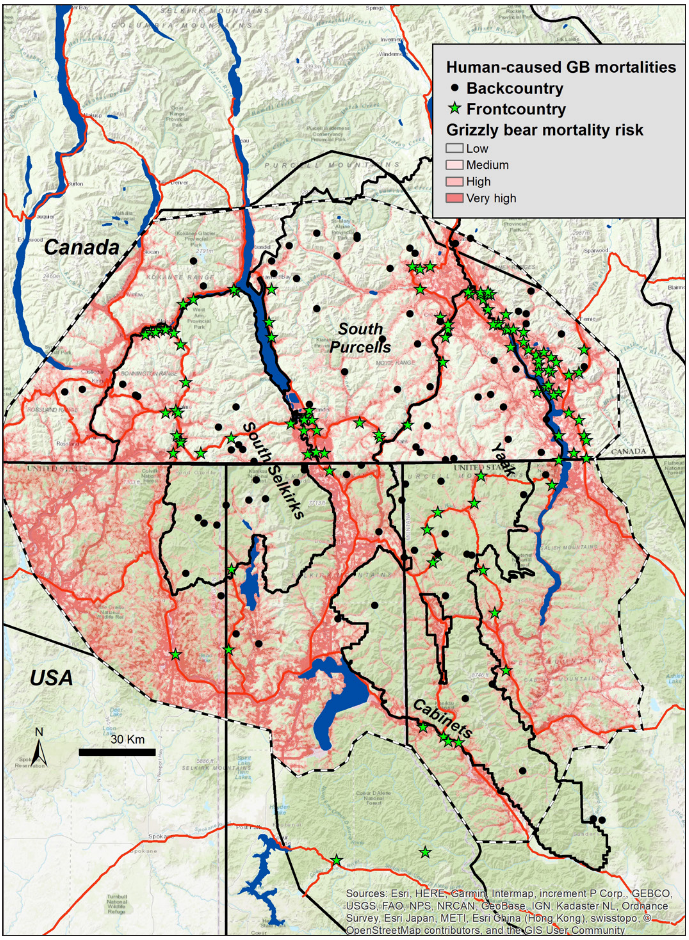

Figure 5. Modelled grizzly bear (*Ursus arctos*) mortality risk across the international South Selkirk and Cabinet-Yaak ecosystems. Patterns were derived from 207 human-caused (non-hunting) mortality events between 1984 and 2017.

public outreach events annually.

Backcountry access management. The Nature Conservancy of Canada (NCC) owns and manages a 550-km^2 conservation property in the east-central part of the South Selkirk Mountains in Canada. The NCC has controlled public access on a significant number of backcountry resource roads for protection of the high quality grizzly bear habitats we identified (Proctor et al. 2018; Figure 4). They reduced the average road density within these lands to 0.24 km/km^2 while the road density within this unit outside of the Darkwoods property is 1.2 km/km^2. The reduced human access has reduced human-caused grizzly bear mortality in this portion of the backcountry, thereby increasing habitat effectiveness, particularly for females (Proctor et al. 2017, 2018). The bulk of B.C. Provincial lands within our study area have minimal access control outside of several protected areas. Within the U.S. South Selkirk and Cabinet-Yaak grizzly bear recovery zones, the U.S. Forest Service administers a motorized access control program for the benefit of many wildlife species (road density = ~0.6 km/km^2 within recovery zones and ~1.6 km/km^2 outside of recovery zones). This program has been in effect since 1999 and works to reduce mortality risk and displacement through applications of management standards for open motorized routes and total motorized routes on National Forests (USDA 2015).

Measures of the HBC program effectiveness

Mortality events and causes. One hundred forty-one recorded grizzly bear mortalities within the international South Selkirk and Cabinet-Yaak ecosystems were divided almost equally between the front and backcountry (Table 4; Figure 5). The differences in the 2 spatial arenas were notable in their causes. Front-country mortalities were primarily caused by human-sourced bear attractants such as garbage, fruit trees, livestock and their feed, and highways and trains. Backcountry mortalities were predominantly poaching/illegal kills, self-defence, and mistaken identity by black bear hunters.

Spatial patterns in human-caused mortality. The covariates that best explained spatial mortality risk from our top model were proximity to highways, low elevation, road density, road presence, riparian habitats, and open habitats in order of influence (Table 5; Figure 5). The top model was the only model with a delta AIC score <2.0. Models with only human disturbance (road density, road presence and highways) or only habitat (riparian, elevation, and canopy closure) variables were not supported well by the data (Table 5), suggesting a combination of human disturbance and habitat factors best explained mortality patterns. As our mortality

Table 5. Small sample size corrected AICc model selection for mortality risk of grizzly bears (*Ursus arctos*) in the Canada-USA trans-border region. Roadden is road density, road is the presence of a road, rip is riparian habitat, hwy is major highway, dem is elevation, and cc is forest canopy closure. Models with DAICc values <2.0 were considered supported by the data.

Model	LL	n	K	corr	AICc	DAICc	wdenom	AICw
roadden road rip hwy dem cc	-796.5	207	7	0.381	1606.9	0.0	1	0.638
roadden road rip hwy dem	-798.5	207	6	0.285	1609.0	2.1	0.358	0.228
roadden road hwy dem cc	-799.7	207	6	0.285	1611.5	4.6	0.102	0.065
roadden rip hwy dem cc	-800.2	207	6	0.285	1612.4	5.5	0.063	0.040
roadden road hwy dem	-802.4	207	5	0.203	1614.8	7.9	0.020	0.012
road rip hwy dem cc	-801.7	207	6	0.285	1615.4	8.5	0.014	0.009
roadden road rip hwy cc	-802.2	207	6	0.285	1616.4	9.5	0.009	0.006
roadden road rip hwy	-804.4	207	5	0.203	1618.8	12.0	0.003	0.002
roadden road rip dem cc	-805.2	207	6	0.285	1622.3	15.4	0.0004	0.0003
roadden road rip dem	-807.8	207	5	0.203	1625.5	18.6	<0.0001	<0.0001
roadden road hwy cc	-808.0	207	5	0.203	1626.0	19.1	<0.0001	<0.0001
roadden road dem cc	-808.2	207	5	0.203	1626.3	19.4	<0.0001	<0.0001
roadden road hwy	-811.1	207	4	0.135	1630.2	23.3	<0.0001	<0.0001
rip dem cc	-827.4	207	4	0.135	1662.8	55.9	<0.0001	<0.0001

risk surface shows, human-settled valleys with accompanying highways carry the most mortality risk. Backcountry areas with higher road densities also carry greater risk. The U.S. grizzly bear recovery zones (outlined in black in Figure 5) that have had comprehensive access management programs have seen better recovery of grizzly bears than areas outside of these zones (Kasworm et al. 2017). Within Canada, human-settled valleys are where many bears died in conflicts, but backcountry habitats with roads also contributed to overall mortality.

Temporal trends in human-caused mortality. We present mortality graphs using a 3-year running average to better capture the overall trend, as conflict mortalities vary widely by year due to their link with undulant natural food supplies. We present regression values for trends using the raw mortality data.

A reversing of morality trend is detectable when the running 3-year average of non-hunt human-caused grizzly bear mortality within the northwest Montana portion of the Cabinet-Yaak ecosystem is compared pre- and post-hiring of a grizzly bear conflict specialist. The trend was increasing (non-significantly, $P = 0.14$) prior to 2009, and a significant decrease was detected after 2009 regressing the raw data ($P < 0.02$; Figures 6A and 6B). These recent trends in reduced mortality were accompanied by a recent increase in the grizzly bear population (2013–2017) that reversed a decade-long decline (2000–2012; Kasworm et al. 2017).

When the running 3-year average mortality was considered for the international South Selkirk grizzly bear population prior to enhanced mortality reduction efforts by the Trans-border Grizzly Bear Project (TBGBP), a near significant increase in human-caused mortality was apparent over a 20-year period between 1984 and 2003 when regressing the raw data ($P = 0.07$; Figure 6C). In the years after the TBGBP began implementing mortality reduction activities, the 3-year running average mortality trend decreased (2004–2017; Figure 6D). A regression of the raw data showed a non-significant decrease ($P = 0.6$). These patterns in mortality were during a period when the population experienced a gradual increase (~1.8% annually; Kasworm et al. 2017).

The majority of grizzly bears in the international South Selkirk population occur within Canada (Proctor et al. 2012) where substantial efforts have been initiated to reduce mortality. Consequently, we compared the South Selkirk mortality trend to that of the adjacent grizzly bear population to the east with a human-settled valley (i.e., B.C. Highway 3 between Cranbrook, B.C. and the Alberta

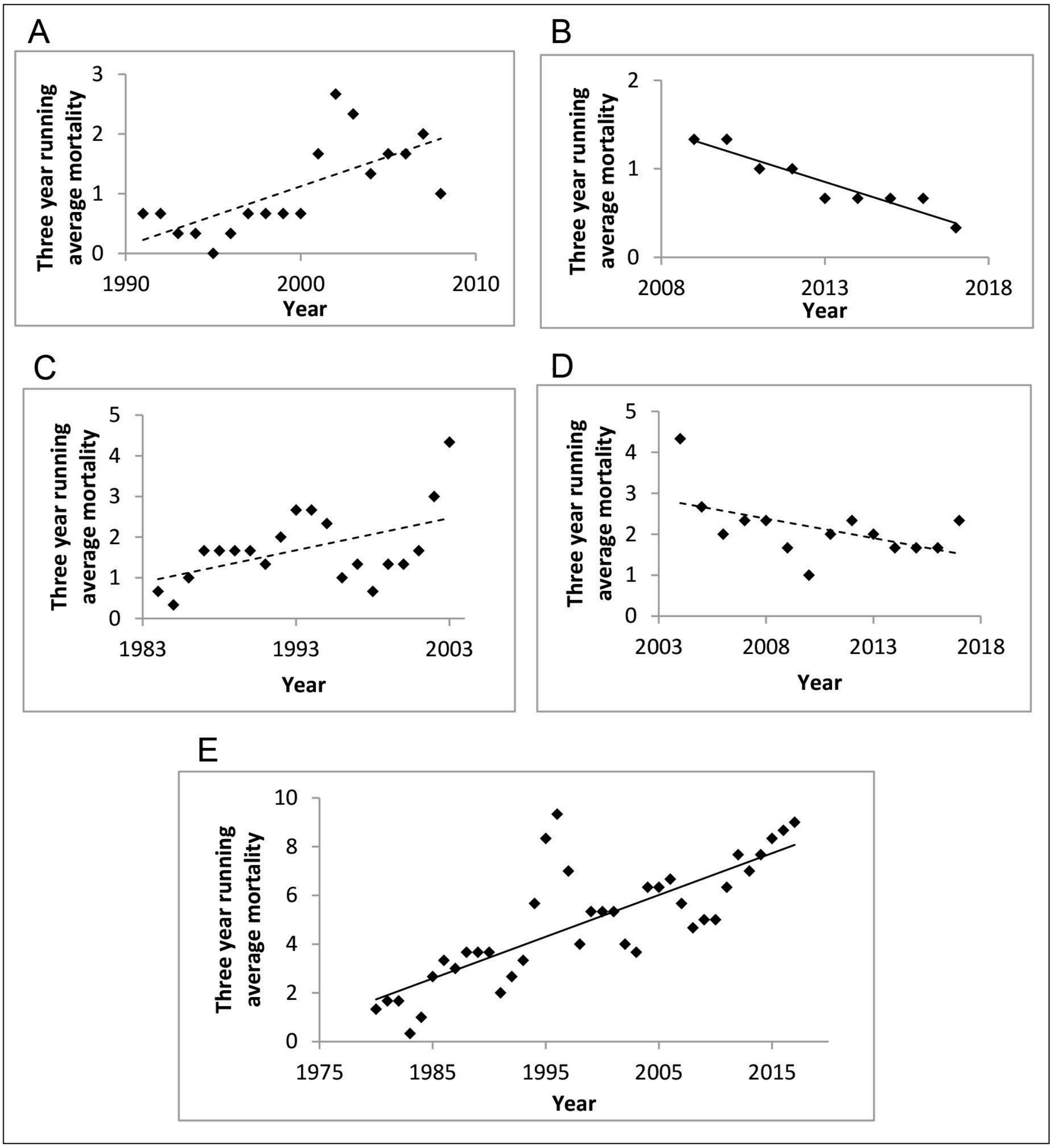

Figure 6. The 3-year running average of human-caused grizzly bear (*Ursus arctos*) mortality data prior to and after enhanced conflict reduction measures were applied in each system from the A) northwest Montana, USA portion of the Cabinet-Yaak ecosystem, 1991–2008, (raw data regression $P = 0.14$); B) northwest Montana after hiring a conflict specialist, 2009–2017, (raw data regression $P = 0.02$; Annis 2017); C) the international South Selkirk population, 1984–2003 (raw data regression, $P = 0.07$); D) the South Selkirk, 2004–2017 (raw data regression, $P = 0.6$); and E) the control population that received no enhanced conflict management, B.C. South Rocky population, 1980–2017 (raw data regression, $P = 0.007$). Solid trend lines are significant and dashed lines are not significant relationships.

Table 6. The number of genotyped and radio-collared grizzly bears (*Ursus arctos*) in each of the study area populations as well as the South Purcell population north of the Yaak for tracking inter-population connectivity, 1987-2017.

Sample sizes	South Selkirk	South Purcell	Yaak	Cabinet	Total
Genotyped bears	161	118	92	40	411
Radio collared bears	94	17	62	33	206

border) and where similar mortality mitigation efforts did not occur. There, the running 3-year average of human-caused, non-hunt mortality between 1980 and 2017 increased steadily. A regression of the increasing trend using the raw data was significant ($P < 0.003$; Figure 6E).

Connectivity monitoring. Between 1983 and 2017, we genetically sampled and developed multi-locus genotypes (21 loci in most cases) for 411 grizzly bears and radio-collared and tracked the movements of 206 grizzly bears (Tables 1 and 6) within the study area and the South Purcell Mountains to the north of the B.C. Yaak population (Figure 1). The previously isolated South Selkirk population (Proctor et al. 2005*a*, 2012) experienced increased movement (immigration) and gene flow (immigration accompanied by breeding; Tables 7A and 7B), and also had increased indices of genetic diversity, heterozygosity, and the number of alleles. The expected heterozygosity (H_E) increased from Proctor et al.'s (2005*a*) 0.54 to 0.57, suggesting that immigration from the Purcell Mountains and subsequent breeding have increased the genetic variability of this population. Thirteen of 15 loci tested (the same loci as used in Proctor et al. 2005*a*) increased in H_E while 2 decreased (1 tailed, paired sample *t*-test, $P = 0.07$). Furthermore, 13 of 15 loci had an increased number of alleles, while 1 declined and another stayed the same (1 tailed paired sample *t*-test, $P < 0.001$). Both the international Yaak and the South Purcell populations north of Highway 3 in southern B.C. had more alleles than the South Selkirk population (South Selkirk = 88, Yaak = 101, South Purcells = 99). South Selkirk bears had 5.9 alleles per locus on average, while the South Purcell has 6.6 and the Yaak 6.7. Yaak bears had 9 of 15 and South Purcell bears had 5 loci with more alleles than South Selkirk bears.

The number of cross assignments of genetic samples increased in the period between 2006 and 2017 after our mortality mitigations were initiated (Figure 7) and inter-population movement and gene flow across our 3 focal fractures increased after 2006 in contrast to before 2006 (Table 7). Movement of individual grizzly bears between ecosystems were up substantially between the South Selkirk and South Purcell Mountains (Table 7A). We also detected 2 male movements between the South Selkirk and Cabinet Mountains and 2 male movements between the Yaak and Cabinet Mountains, all in the post-2006 period. Movement across B.C. Highway 3 and U.S. Highway 2 only increased marginally post 2006 (Table 7A). Gene flow into the South Selkirk population went from 0 to 10 recorded events between the 2 time periods while it decreased slightly across B.C. Highway 3 and remained at 0 across U.S. Highway 2 (Table 7B; Figure 8).

There were 4 instances where our family triad pedigrees revealed inter-population movements followed by breeding in the new population (Figures 8 and 9), 3 of which were from the South Purcell to the South Selkirk mountains and 1 of which was from the South Purcell across B.C. Highway 3 into the Yaak. All dispersers were male.

Discussion

Management and conservation enhancement

The results presented here summarize the last major component of >20 years of research and management efforts to identify the factors limiting 3 grizzly bear populations in the trans-border region of southeast B.C., northwest Montana, and northern Idaho, and provide effective solutions to improve their conservation status. First, we identified that these populations were small and isolated, and with a number of factors contributing to excessive mortality and lack of effective habitat (Proctor et al. 2005*a*, 2005*b*, 2007, 2008, 2012; MacHutchon and Proctor 2016). Second, we identified and implemented a number of mitigation strategies and management actions to address these limiting factors (Proctor et al. 2008, 2015; MacHutchon and Proctor 2016). Because perfect management cannot be applied across an entire landscape, we used the results of our connectivity mapping exercise that identified the best options for re-establishing grizzly bear connectivity (Proctor et al. 2015) overlaid with our mortality risk modeling (Figures 2 and 5). We further focussed our efforts on the 3 most important fractures we considered would give us the most conservation benefit from the use of our limited resources, along B.C. Highway 3 in the Purcell Mountains, the Creston Valley in southeast B.C., and along U.S. Highway 2 between Bonners Ferry, Idaho and Libby Montana. Here we report on the results of our multi-faceted HBC management

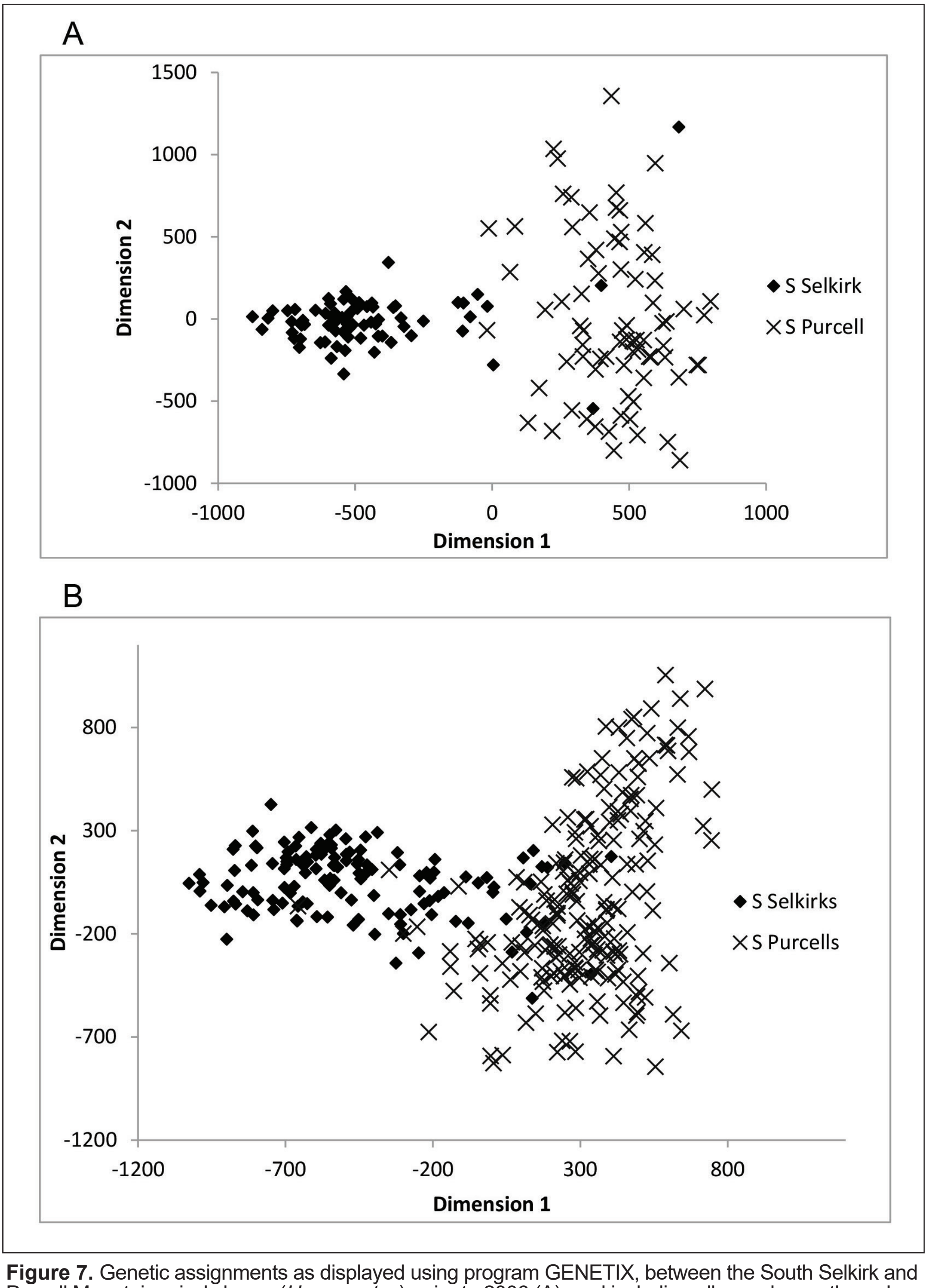

Figure 7. Genetic assignments as displayed using program GENETIX, between the South Selkirk and Purcell Mountain grizzly bears (*Ursus arctos*), prior to 2006 (A), and including all samples up through 2017 (B) where there is an increase in the number of cross assignments and the clusters of each population are not as separated in the trans-border region of southeast B.C., northwest Montana, and northern Idaho, USA. Dispersers appear in the main part of the opposite population's samples.

program and measures indicating where it has been successful and where there is room for improvement.

There was compelling evidence that our multi-faceted program has resulted in a significant decrease in human-caused mortality, an increase in inter-population movement and gene flow, and increased backcountry habitat effectiveness. This has substantially improved the conservation status of our small, fragmented,

Table 7. Summary of grizzly bear (*Ursus arctos*) movement (A), and gene flow (i.e., breeding events after inter-ecosystem movements; B) across 3 fracture zones before and after initiation of conflict management in the Canada-USA trans-border area of southeast B.C., northwest Montana, and northern Idaho, USA 1987–2017.

	Movement	Creston-Sandpoint (Selkirk-Purcell)	B.C. Hwy 3 (South Purcell-Yaak)	U.S. Hwy 2 (Cabinet-Yaak)	Total
A.	Pre 2006	2	6	0	8
	Post 2006	12	8	2	22
	Gene flow	Creston-Sandpoint (Selkirk-Purcell)	B.C. Hwy 3 (South Purcell-Yaak)	U.S. Hwy 2 (Cabinet-Yaak)	Total
B.	Pre 2006	1	2	0	3
	Post 2006	11	1	0	12

and threatened grizzly bear populations, the South Selkirk population improving more than the Yaak and Cabinet populations.

Although it is difficult to conclusively prove that our HBC program was directly responsible for these conservation benefits, our comparison with the adjacent human-settled valley in the South Rockies of B.C. suggests a strong connection between our management program and the improvements in our populations. The Elk Valley along B.C. Highway 3 has had a WildSafe B.C. education specialist for many years, but there has not been the same level of effort using electric fencing, bear-resistant bin availability, or nonlethal management of conflict grizzly bears as in our study area. Consequently, we conclude that education coupled with programs that directly help the public implement and finance conflict reduction activities will yield better concrete conservation improvements than education alone.

Genetic connectivity

We detected many males moving into the South Selkirk Mountains, a few prior to 2006, but most since then during a period of enhanced mitigation management. We have solid evidence of breeding post-movement: 11 offspring from several migrant parents and only a few that were mortalities. This combination of movement and breeding is most likely responsible for the increased heterozygosity and number of alleles in the South Selkirk population since our 2005 estimate (Proctor et al. 2005*a*). In 2005, the population had a depressed expected heterozygosity relative to neighboring populations (Proctor et al. 2005*a*). While the genetic diversity of the South Selkirk population is increasing, it is has not "equalized" with adjacent populations. Heterozygosity is still below that of the adjacent South Purcell and Yaak populations, as are the number of alleles per locus. Managing for immigration and connectivity to increase these indices of genetic variability was a goal of the USFWS recovery plan (USFWS 1993) for the South Selkirk population. We are well on the way to meeting that goal. The Yaak population was not isolated to both sexes (Proctor et al. 2005*a*) so did not experience a depressed heterozygosity that required recovery. The Cabinet mountain population is being rebuilt with an augmentation program (Kasworm et al. 2007, 2017) that has been successful, the details of which are beyond the scope of this reporting.

Demographic connectivity

Functional grizzly bear connectivity that facilitates demographic rescue of small, isolated, and threatened population requires female immigration that results in successful reproduction (Proctor et al. 2012). Previous research suggests that female natal dispersal in this region is short (~10 km, McLellan and Hovey 2001; ~14 km, Proctor et al. 2004*b*) and gradual over several years (McLellan and Hovey 2001). Therefore, we expect that the development of female connectivity between 2 populations will likely require that females live for some time in the intervening linkage areas that connect populations. This scenario has developed within the Creston Valley in southeast B.C. that separates the South Purcell and South Selkirk Mountains. While we have evidence of limited female movement from the South Purcell to the South Selkirk, we do not yet have evidence of post-movement breeding for females, our ultimate measure of demographic connectivity.

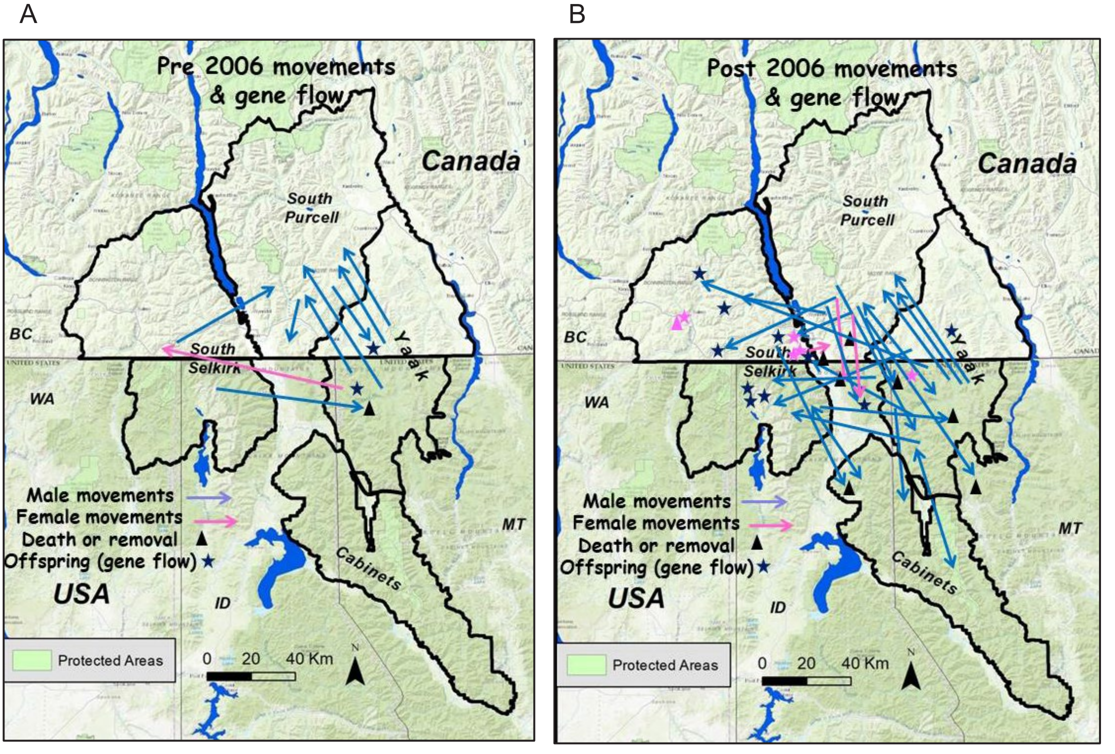

Figure 8. Cumulative evidence of inter-population grizzly bear (*Ursus arctos*) movements and gene flow (breeding events after movements) before (A) and after (B) mortality reduction management was applied in the Canada-USA trans-border region of southeast B.C., northwest Montana, and northern Idaho, USA.

Females (some which are offspring of male dispersers), are now surviving and reproducing in the Creston Valley, so we expect soon we will have female dispersers that reproduce and demographically connect the South Purcell to the South Selkirk population.

The B.C. Conservation Officer who has been working in the Creston Valley since 1993 reported that grizzly bear sightings in the valley were relatively rare in the 1990s and early 2000s. Currently (2017–2018), sightings come in at a rate of several per week (J. Barber, B.C. Conservation Officer Service, personal communication). Since 2008, we have radio-collared 7 female grizzly bears that spent the majority of their time in the Creston Valley. Our first female was collared in 2008 after an extensive multi-year effort. Between 2013 and 2016, captures dramatically increased. We suspect that these results, and improvements in inter-population movements across B.C. Highway 3 and U.S. Highway 2, are a result of our multi-faceted HBC management program. Previous to this program, at least in Canada, conflict grizzly bears were usually removed (i.e., long distance translocation out of the population or they were killed by wildlife managers).

We detected 2 female movements across B.C. Highway 3 from the South Purcell into the Yaak population, with 1 abruptly ending in mortality, and the other presumably still alive, but we have no evidence of post-movement breeding to date. We have detected no movements of females into the Cabinet Mountains. However recent male movements into the Cabinet population represent a dramatic turn-around from complete isolation and near extirpation (Kasworm et al. 2017).

Pedigrees

Pedigrees and family relationships are a powerful tool and provide direct evidence of movement and, more importantly, allowed us to detect functional connectivity, breeding after movement. They are difficult to build in large populations because sampling both parents can be challenging when there are many bears. However we had 2 advantages: we were working with relatively small populations (<100 individuals) and we had repeated sampling across many years (Table 1) that allowed us to sample many complete family triads.

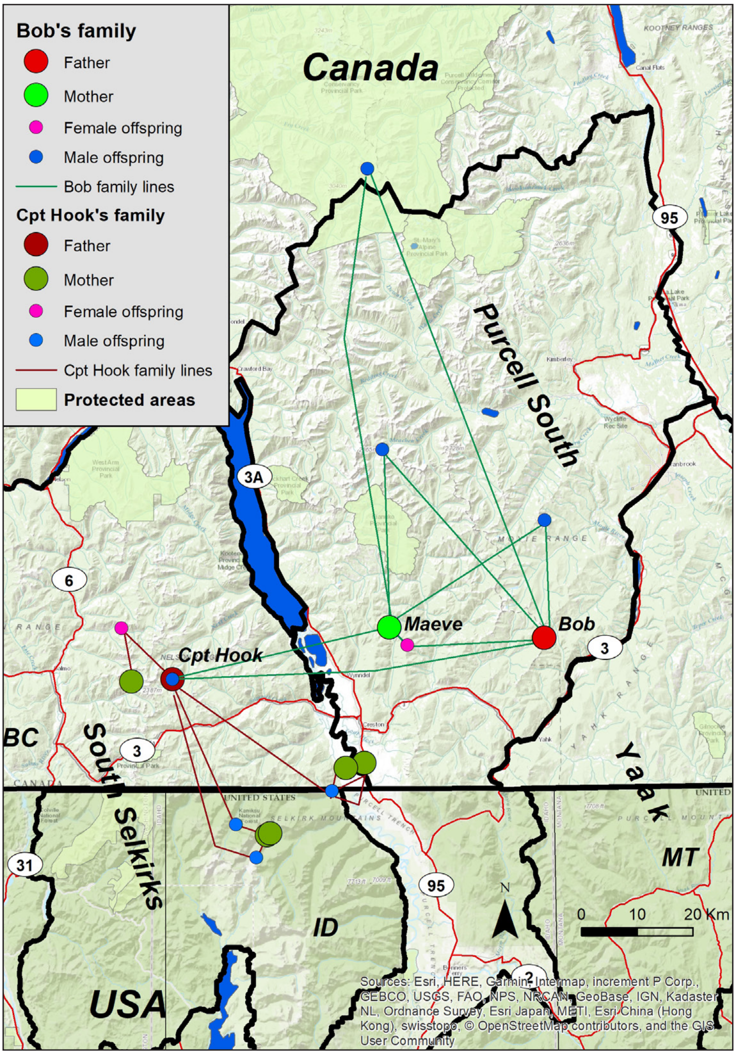

Figure 9. Evidence of grizzly bear (*Ursus arctos*) movement and gene flow across the Creston Valley from the South Purcell Mountains to the previously isolated South Selkirk population in the Canada-USA trans-border region. Evidence is a limited family pedigree where offspring all share 1 allele from each parent across 21 loci. Lines connect offspring to their parents. Dot locations represent each bear's capture or sample location. In this extended family, Bob and Maeve begat Cpt. Hook who moved from the South Purcell into the South Selkirk Mountains where he mated with 5 separate females yielding 6 offspring (1 of the blue dots for male offspring represents 2 offspring sampled at the same location).

Data limitations

We suspect we may have overestimated the number of inter-population dispersers in the post-2006 period (Figure 8B) to some degree because we have imperfect information on when the bears actually moved. Monitoring is never perfect, but several of our initiatives lend support to our results. We have maintained a somewhat continuous sampling effort, telemetry and genetic, over several decades (Table 1). We carried out several thorough genetic sample surveys within the Canadian portion of our study area in the period before we initiated our HBC program that represented our sample base for detecting subsequent movement and gene flow. For example, during a 2005 DNA survey in the B.C. portion of the South Selkirk population, we sampled 30 individual grizzly bears, and our population estimate for that area was 33 bears; therefore, our methods allowed us to sample a high proportion of the population. These DNA survey samples were also augmented by live captures that began in the 1990s. We have not yet replicated the thoroughness of our 2005 effort, so our detection of an increase in movement and gene flow is in spite of the fact that our best sampling effort was prior to our management activities.

Gene flow events are offspring of dispersers, and their birth and survival is what matters most to establishing genetic and demographic connectivity. Our management efforts have helped their survival, both in the front and backcountry. Therefore, we feel it is relevant to have included them in the post-2006 period when they were detected, even if occasionally their parents moved in the pre-2006 period.

We are certain that we have not detected all mortalities. There is always a portion of unreported mortalities that go undetected or unreported (McLellan et al. 1999). We compensated somewhat for this through our radio-collared bear sample that allowed us to detect a portion of what otherwise might have been unreported mortality.

Front and backcountry management

We believe that any HBC or conservation management program should consider and address the full spectrum of issues facing a species or system rather than just 1 or 2 issues. This was confirmed by our spatial mortality patterns, which underpinned our decision to put management efforts into both the front and backcountry. Because our study area populations were small, both geographically and numerically, many bears spent time, and died, in both realms. It was important for bears to be able to survive inter-population movement through human-dominated valleys, but also for them and their offspring to be able to survive and reproduce in their backcountry habitat.

Backcountry. Researchers in Alberta also found that human access, among other topographic and ecological factors, influenced mortality risk (Nielsen et al. 2004). Our backcountry management effort was inconsistent spatially. The United States initiated a backcountry access management program in the 1990s that was implemented over several years. Therefore, a portion of the backcountry mortalities (Figure 5) occurred when road densities were higher than they are currently. In Canada, there were only backcountry forestry road controls in the Darkwoods Forest (now Nature Conservancy Canada land) within the South Selkirk population and a few scattered seasonal access management areas in the Yaak and South Purcell populations (MacHutchon and Proctor 2016). Access management in the NCC Darkwoods area has had a positive influence on grizzly bear density and reproductive success in the South Selkirk population (Proctor et al. 2017). The B.C. portion of the Yaak has a high road density (1.6 km/km^2; MacHutchon and Proctor 2016) and, while we have no direct evidence, this high road density may be 1 reason we have not detected more surviving movement or gene flow events. Grizzly bear survival (particularly female) has been demonstrated to be negatively associated with road density in western North America (Schwartz et al. 2010; Boulanger and Stenhouse 2014; Lamb et al. 2017; Proctor et al. 2017, 2018). To further improve survival of bears that provide connectivity and gene flow to and within the Canadian Yaak, we recommend that access controls be applied, especially in high-value habitats we have identified (Proctor et al. 2017, 2018). In addition to access management being the cornerstone of recovery of threatened U.S. grizzly bear populations, Alberta is also implementing this tool to recover their threatened populations across the western portion of their province (Alberta Environment and Parks 2016).

Our focus here on access management does not diminish the importance of habitat quality on grizzly bear conservation status. For example, habitat capability (quality) is higher in the South Selkirk population than the Canadian portion of the Yaak due to the presence of extensive huckleberry patches (important soft mast food resource; Proctor et al. 2017). In the South Selkirk population, the access management program was applied over the best of those patches (Figure 4), providing a synergistic benefit to the females in that population (Proctor et al. 2017, 2018).

Front-country. While some level of enhanced front-country management occurred throughout our entire study area, focal areas of concentrated management were the Creston Valley in southern B.C. since 2005 and the U.S. Highway 2 corridor where a bear conflict specialist has been active since 2007. The Creston Valley was targeted to reconnect the isolated South Selkirk grizzly bear population to the larger South Purcell Mountain population north of B.C. Highway 3 (Proctor et al. 2012, 2015). The U.S. Highway 2 area received extra attention to help reconnect the fragmented Cabinet and Yaak populations. Management to try and reconnect the South Selkirk to the Cabinet mountain populations have been initiated, and the results of this analysis will inform those efforts.

Cost-sharing was an essential component to the success of our electric-fencing program, and we promoted it in several ways. First, because electric fences need regular maintenance, investments by the landowner helps ensure they will better maintain the fence. Second, this system reflects the idea that a broad spectrum of society helps contribute to the financial burden of living with large carnivores as these animals benefit that broader society. This helps remove any consideration of charity or accepting undeserved financial assistance among rural landowners, who are generally an independent group of people. Third, through an initial shared investment, landowners can reduce conflicts with grizzly bears, physical risk (real or perceived), and repeated financial losses (through property damage or loss of crops, feed, or livestock). The electric-fencing program has grown in popularity, primarily through intra-community word of mouth, and maintained fences have eliminated or dramatically reduced wildlife conflicts for program participants. Funding the program has been an ongoing challenge and requires annual fundraising. Our long-term goal is that society recognizes the benefit of this program and invests in it so it becomes self-sustaining.

Our nonlethal program for early conflict bears has kept a number of female (and male) grizzly bears alive to contribute to the breeding population. Our protocols were pioneered by, and largely copied from, programs run by bear conflict specialists within Montana Fish, Wildlife and Parks since the 1990s.

One outcome of our apparent HBC program success in reducing mortality, increasing local grizzly bear populations, and improving inter-population connectivity is that there are now a number of female grizzly bears spending much of their active season in the Creston Valley in close proximity to residences, farms, and ranches. The effect of this is that every year there is a new crop of offspring that learn how to forage from their mothers, and sometimes they learn to feed on agricultural products or other anthropogenic foods (Morehouse et al. 2016, Morehouse and Boyce 2017). We anticipated this issue and consequently focused our electric-fencing, bear-resistant bin, and bear safety education programs in this valley. However, these efforts will need to continue and likely intensify to try and maintain area residents' tolerance and acceptance of grizzly bears. There was a non-fatal, defensive grizzly bear attack by a female bear to an early morning hiker in the valley in the summer of 2018. This did not appear to increase local residents' negative attitudes toward grizzly bears, but there is a concern for personal safety (J. Barber, B.C. Conservation Officer, personal communication). Consequently, we will try to channel that concern into being knowledgeable about bear safety and the use of bear spray by continuing to host safety courses.

Broader applicability

The threatened Northern Continental Divide Ecosystem (NCDE; Interagency Grizzly Bear Committee 2018) in northwest Montana and previously threatened Yellowstone (YE; Interagency Grizzly Bear Committee 2016) grizzly populations in the United States have received significant conservation management attention over the past 40 years and are now, by and large, recovered (Schwartz et al. 2006, Kendall et al. 2009, Mace et al. 2012; https://www.federalregister.gov/documents/2018/04/30/2018-09095/endangered-and-threatened-wildlife-and-plants-review-of-2017-final-rule-greater-yellowstone). There were 2 important differences relative to the populations discussed here. The NCDE and YE were much larger spatially and in number of bears and a larger proportion of those ecosystems are protected (e.g., National Park, Wilderness designation). However, our results may have relevance for developing inter-population connectivity between the YE and the NCDE, and the NCDE and the Cabinet-Yaak populations, and eventually between a re-established Bitterroot population.

Our conservation management program has been science-driven and might be considered a blueprint for recovering small, fragmented grizzly bear populations elsewhere in B.C., Alberta, and western North America. For example, the Yellowstone to Yukon Conservation Initiative works to improve wildlife and ecosystem connectivity north to south along the Rocky Mountains from the lower 48 United States into Yukon, Canada (Locke and Francis 2012). Grizzly bears are one of their focal species (playing an umbrella function). Our study area is within that landscape, and our results may be useful in others regions within that larger initiative (Hauer et al. 2016).

Our results may also have some utility for other threatened and isolated bear populations around the world (McLellan et al. 2017). However, while we suspect that general principles may apply, particular activities will likely vary country-to-country and culture-to-culture. In a broader context, these results may also provide insight and inspiration to other connectivity efforts around the world within the IUCN Connectivity Conservation Specialist Group (https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/connectivity-conservation).

Management implications

Our HBC program will need to continue within our study area, and some facets of the program will need to be improved to ensure continued conservation benefits. We are currently developing a Creston Valley Grizzly Bear Management Plan that outlines a community vision and related management strategies on how to coexist with grizzly bears safely and securely, and also how to allow for these ecological processes on the larger landscape (connectivity). In practice we envision that will entail an even more intensive attractant management program on the human side, and from the bears' perspective, leaving some portion of the reproductive females in the valley and removing some, either through translocation or killing.

We will work to make the management programs an integral part of the way our society functions, an ongoing challenge. We anticipate more progress at a time when we have functional female connectivity between the Cabinet, Yaak, and South Selkirk populations, as well as with other neighboring populations. Human–bear conflicts will never be eliminated, but we hope to minimize them with self-sustaining programs to allow a functioning metapopulation of sorts, which should give the region's grizzly bears a good chance of adapting to climate change and surviving well into the future.

Acknowledgments

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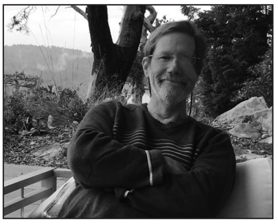

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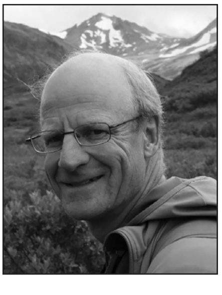

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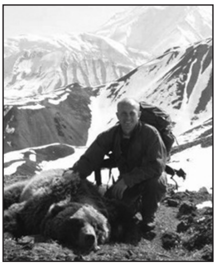

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