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Working Together for Grizzly Bears: A Collaborative Approach to Estimate Population Abundance in Northwest Alberta, Canada

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Grizzly bears are a threatened species in Alberta, Canada, and their conservation and management is guided by a provincial recovery plan. While empirical abundance and densities estimates have been completed for much of the province, empirical data are lacking for the northwest region of Alberta, a 2.8 million hectare area called Bear Management Area 1 (BMA 1). In part, this is due to limited staff capacity and funding to cover a vast geographic area, and a boreal landscape that is difficult to navigate. Using a collaborative approach, a multi-stakeholder working group called the Northwest Grizzly Bear Team (NGBT) was established to represent land use and grizzly bear interests across BMA 1. Collectively, we identified our project objectives using a Theory of Change approach, to articulate our interests and needs, and develop common ground to ultimately leverage human, social, financial and policy resources to implement the project. This included establishing 254 non-invasive genetic hair corral sampling sites across BMA 1, and using spatially explicit capture-recapture models to estimate grizzly bear density. Our results are two-fold: first we describe the process of developing and then operating within a collaborative, multi-stakeholder governance arrangement, and demonstrate how our approach was key to both improving relationships across stakeholders but also delivering on our grizzly bear project objectives; and, secondly we present the first-ever grizzly bear population estimate for BMA 1, including identifying 16 individual bears and estimating density at 0.70 grizzly bears/1,000 km^2-the lowest recorded density of an established grizzly bear population in Alberta. Our results are not only necessary for taking action on one of Alberta's iconic species at risk, but also demonstrate the value and power of collaboration to achieve a conservation goal.

Keywords: conservation, governance, collaboration, management, grizzly bear (*Ursus arctos*), population, theory of change, SECR

INTRODUCTION

Grizzly bears (*Ursus arctos*) are an icon of the North American wilderness and a symbol of both conservation and conflict (Proctor et al., 2018; Hughes and Nielsen, 2019; Hughes et al., 2020b). However, as with other large carnivores, human-caused mortality, including illegal killing and vehicle collisions, as well as implications from habitat alteration are the primary threats to grizzly bears (Alberta Sustainable Resource Development., 2008; Nielsen et al., 2009). While scientific research and applied management is ongoing across much of North America, data deficiencies persist in grizzly bears' more northerly range, including those in the boreal northwest region of Alberta, Canada.

Grizzly bears in Alberta were listed as threatened in 2010 due to their small population size, slow reproductive rate, limited immigration from other populations, and increased habitat alteration (Alberta Sustainable Resource Development., 2008). A recovery plan identified seven demographically-separate bear management areas (BMA) with recovery objectives including the necessity for population estimates to be conducted for each BMA, and addressing human-caused bear mortality through access and attractant management along with educational outreach (Alberta Sustainable Resource Development., 2008). From 2004 through 2010, a series of DNA-based population inventories were completed across Alberta, including testing non-invasive genetic techniques and modeling estimates by Foothills Research Institute in the boreal northwest (Alberta Sustainable Resource Development., 2008; Festa-Bianchet, 2010). Based on these data, alongside habitat modeling and expert opinion, Alberta's estimated grizzly bear population was 691, plus additional bears in portions of Banff and Jasper National Parks (Festa-Bianchet, 2010).

Estimating grizzly bear density in the northwest population unit called Bear Management Area 1 (BMA 1) has remained particularly challenging, given the large and relatively remote geographic area and wetland conditions of this landscape. This is contrasted with other BMAs, which are largely comprised of the Rocky Mountain and Foothills natural regions and increased human density, resulting in more road or trail access into grizzly bear habitat (Alberta Environment Parks, 2020). While problematic for human-caused mortality and habitat fragmentation, this increased linear footprint in other BMAs generally reduces the costs associated with efficiently inventorying bear populations.

Another challenge in BMA 1 are the differing perspectives and experiences people have across the region concerning grizzly bears, which can hinder effective conservation and management efforts. Grizzly bears are a charismatic species valued for their aesthetics as well as ecosystem function, but also a species that poses serious human safety risk and economic costs to peoples' livelihoods (Morehouse and Boyce, 2017; Proctor et al., 2018; Hughes and Nielsen, 2019; Hughes et al., 2020a; Morehouse et al., 2020). People across BMA 1 hold values and cultural identity linked to the concept of "frontiersmen," with their ancestors being hardy pioneers of this harsh boreal landscape (Hughes and Nielsen, 2019). Human-bear relationships are viewed and experienced from the perspective of subsistence lifestyles, generating income, and ensuring human safety, and today this still resonates with many people who call the northwest home (Hughes and Nielsen, 2019). That said, the cultural identity, values and practices in the northwest has conflicted with the provincial government's grizzly bear recovery policy, including how provincial direction governed industrial-scale petroleum and forestry production (Hughes and Nielsen, 2019; Alberta Environment Parks, 2020). Tension between local government and stakeholders across BMA 1 has persisted since the late 1990's (Fullerton, *pers. comms*). This may be related to a lack of trust in grizzly bear science and scientists, or inaccessibility of scientific information and lack of layperson understanding, as well as local perspectives that problem bears were simply "dumped" (i.e., re- or translocated) into BMA 1 thus contributing to human-bear conflict (Hughes and Nielsen, 2019). During this time public reporting of human-grizzly bear interactions was limited, and a "shoot, shovel, and shut up" sentiment was commonly expressed to occur across rural communities in the northwest (Hughes et al., 2020a).

To address challenges associated with a population inventory of BMA 1 grizzly bears and improve local relationships to enable progress on grizzly bear management, we implemented a collaborative approach that engaged representative stakeholders from across this multi-use working landscape (Wondolleck and Yaffee, 2000; Wilson et al., 2017; Hughes et al., 2020a). Collaborative approaches have been used around the world, including to address bear hunting in Romania (Hartel et al., 2019), conflicts with gray wolves in Montana (Wilson et al., 2017), lion conservation in Zimbabwe (Sibanda et al., 2020), and human-bear coexistence in southwestern Alberta (Morehouse et al., 2020). Collaborative approaches are considered effective at bringing different people across multiple disciplines, perspectives, and experiences together to identify and achieve defined outcomes (Yang, 2017; Hartel et al., 2019; Hughes et al., 2020a). Additionally, collaborative approaches enable participants to decentralize decision-making and share power, foster fairness, and improve credibility and trust in project or policy processes (Singleton, 1998; Wondolleck and Yaffee, 2000; Carlsson and Berkes, 2005; Mattson et al., 2006; Clement et al., 2020). Moreover, collaboration can help groups access and leverage shared resources and funding opportunities, as well as foster co-learning amongst participants.

Our paper weaves together our collaborative approach with a multi-stakeholder team to help identify and address data gaps for BMA 1 grizzly bears, the results from a qualitative evaluation of these collaborative efforts, and the results of the grizzly bear population inventory. We also provide considerations for implementing collaborative approaches elsewhere, to help address potentially contentious contexts for the conservation and management of wildlife species.

STUDY AREA

BMA 1 is within a multi-use landscape in the boreal forest of northwest Alberta, adjacent to historical grizzly bear habitat

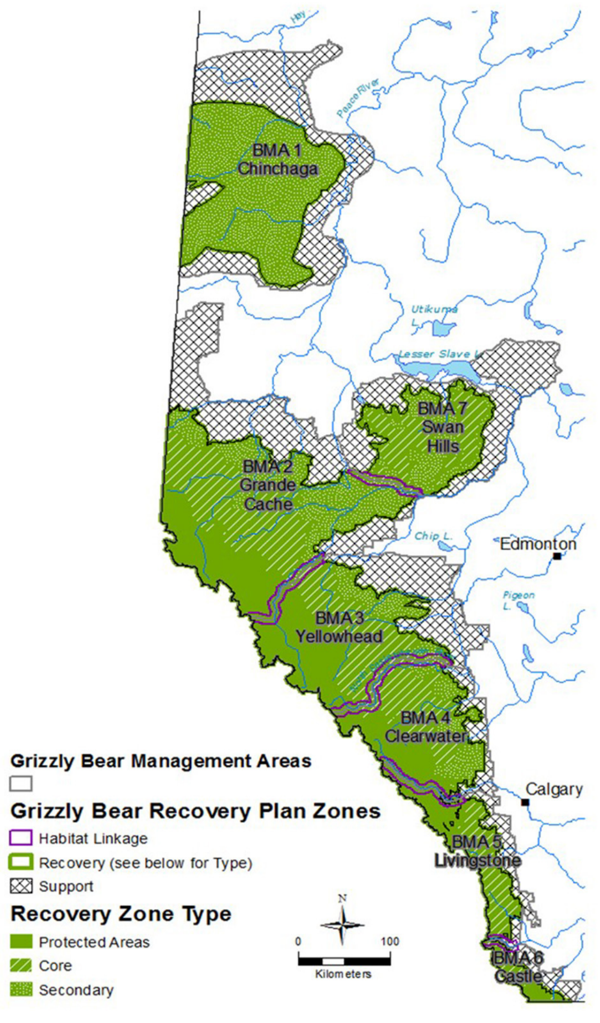

FIGURE 1 | Provincial map of Alberta with bear management areas (BMA), recovery and support recovery zones (Alberta Environment Parks, 2020).

in British Columbia, and covers ~41,000 km^2 (Poole et al., 2001; Alberta Environment Parks, 2020). It is comprised of boreal and mixed-wood natural regions with extensive wetland complexes, with only 2% of the land base protected under provincial park designation limiting motorized (vehicle) access (Alberta Environment Parks, 2020; **Figure 1**). Human use across the area includes a history of extensive petroleum developments (i.e., well-sites and pipelines), forestry harvest, electrical transmission, agricultural areas for livestock and crop production, recreational use including hunting, off-highway vehicle enthusiasts, river travel and camping, and small residential communities and farmsteads.

Grizzly bear habitat in BMA 1 is classified either Recovery or Support Zones (Alberta Environment Parks, 2020). The Recovery Zone, an area covering 23,458 km^2 delineated through habitat modeling and expert opinion on bear occurrences, is the focus of our study area (Nielsen et al., 2009). The Recovery Zone identifies where the Alberta government reasonably expects to manage the presence of grizzly bears and reduce human-caused mortality, which has been associated with open road density (Alberta Environment Parks, 2020). The Support Zone (~18,000 km^2) is intended to allow for grizzly bears to disperse, with management focusing on securing food attractants and teaching bear safety, largely with agricultural landowners and recreationalists. The Alberta BearSmart program (www.alberta.ca/alberta-bearsmart-program-overview.aspx), in existence since 2008, is the primary outreach strategy used to educate the public and address human-bear conflicts.

MATERIALS AND METHODS

Collaborative Planning: the Northwest Grizzly Bear Team

In 2011 government staff, led by the regional manager, coordinated a meeting between local petroleum industry and forestry representatives to identify research and management needs for grizzly bears in BMA 1. This first meeting was an integral step in fostering a collaborative working group in the area. The main topic discussed was how to best address the persistent data gaps on the local grizzly bear population, which is required to meet recovery objectives, as well as discussions on how these data would assist in land use planning, including guiding forest management. However, efforts at the time were hampered by a lack of funding and staffing, coupled with public skepticism, limited local understanding of current scientific information, and lack of trust in government agencies and scientific methods. As a result, a pilot project was initiated between 2012 and 2014 to test the efficacy of bear hair collection procedures and open communication between government and stakeholders. This work helped to share information, seek participation from academic and other scientists, identify funding opportunities, and cooperate with local landowners and industry personnel, specifically to identify bear use areas and rub objects (i.e., trees and power poles that bears rub on as a form of communication) in BMA 1 (Morehouse et al., 2021). These efforts were an important step forward in rebuilding trust and generating enthusiasm across different groups of people in BMA 1. In turn, this became the impetus for formalizing a collaborative multi-stakeholder working group in 2015, called the Northwest Grizzly Bear Team (NGBT; **Table 1**; Wondolleck and Yaffee, 2000; Ansell and Gash, 2008).

Invitations for those interested in voluntarily participating in the newly formed NGBT reflected the suite of different land users and stakeholders across BMA 1. Invited representation included local petroleum industry and forestry representatives, those from the electrical utility sector, government staff, academic and research scientists, agricultural landowners, municipal government representatives, and Indigenous community representatives. Given the types of land use overlapping the grizzly bear recovery zone in BMA 1, participation in the NGBT largely reflected industrial scale natural resource production, with agricultural landowners, municipal government and Indigenous communities declining future participation for various reasons (i.e., perceived relevancy, time commitment,

TABLE 1 | Northwest Grizzly Bear Team composition.

Stakeholder sector	Number of representatives
Forestry	6
Electric company	1
Petroleum	2
Non-profit organizations	3
Government	9
Public at large	1
Total	22

Co-chairs were represented by one Alberta Environment and Parks staff, given the mandate for grizzly bear recovery, and one forest company staff by nomination from other stakeholders.

subject matter expertise) and reasons unknown (i.e., no response to participate despite repeated requests).

In order to ensure common understanding around scope of work, particularly related to legislative and recovery policy requirements, the NGBT developed a terms of reference (TOR). This included expectations set out for member conduct, interpersonal conflict management, and consensus-based decision-making, along with identifying a shared vision, objectives and strategies to achieve objectives, and limitations. To develop the TOR, our discussions followed principles adapted from interactive group decision-making processes, to identify consensus and develop a prioritized list of actions that would resonate with the NGBT (Emerson and Nabatchi, 2015; Huge and Mukherjee, 2017; Mukherjee et al., 2017). Generally this included: (1) defining the management or research questions about BMA 1 grizzly bears; (2) brainstorming on how to address these questions; (3) clarifying and consolidating ideas; and, (4) agreeing upon the top priorities (Huge and Mukherjee, 2017). Based on these discussions, a theory of change (TOC) model was developed to assist in project planning, grant writing, and project evaluation (**Figure 2**; Margoluis et al., 2013; Morehouse et al., 2020).

Theory of Change models have increasingly been used in different conservation contexts to help plan, implement and evaluate projects, given their utility to conceptually illustrate different connections between activities and outcomes (Biggs et al., 2016; Balfour et al., 2019; Sibanda et al., 2020; van Eden et al., 2021). Particularly critical to successfully acquiring substantial funding for this project was collaboratively co-authoring a compelling grant proposal for benefactors, which articulated how investing in our applied project would directly address current political challenges and be valuable for government, industry, the public and grizzly bears.

Lastly, we conducted a summative evaluation of our collaborative governance arrangement to determine the efficacy of this approach and provide recommendations for future efforts (Emerson and Nabatchi, 2015; Robinson et al., 2020). We used a qualitative semi-structured questionnaire asking the NGBT to reflect on and explain their motivations for joining the NGBT, benefits, challenges, outcomes, and future recommendations (**Supplementary Material A**). The questionnaire was developed by the government co-chair with input and review by three members from the NGBT, and shared with the membership for completion. Given the small group size ($n = 22$), we sought to ensure respondent confidentiality and anonymity by using a numerical code for each respondent and clarified how data would be stored and used (Kaiser, 2009; Creswell and Poth, 2017). Using the questions as guiding codes, we identified common themes across the dataset (Guest et al., 2014; Creswell and Poth, 2017). Results were shared back with the NGBT for verification and validation (Creswell and Poth, 2017).

DNA Field Methods

We designed a non-invasive DNA-based (i.e., grizzly bear hair) population inventory to estimate grizzly bear density and abundance using spatially explicit capture-recapture (SECR; **Supplementary Material B**; Boulanger et al., 2004, 2018; Efford and Fewster, 2013; Rovang et al., 2015; Morehouse and Boyce, 2016). We used simulation modeling with the *secrdesign* package (version 2.4.0., Efford, 2016) in R (R version 3.2.5) to design the study area configuration and guide sampling efforts. We used our simulation modeling results to inform our hair trap density and spacing. Results from our simulations indicated that the optimal size of the required sampling grid was dependent on the size of the estimated bear population. To ensure the highest probability of program success, which included in-depth discussions with NGBT members on required staffing and financial resources, we ultimately chose to use a sampling grid of 10 km^2.

In addition to sampling stations across BMA 1, we collaborated with the government of British Columbia's (B.C.) Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) to include 32 sampling stations in the adjacent Taiga Grizzly Bear population unit in British Columbia. We anticipated this would provide important additional sampling effort which would help reduce model uncertainty. Any data collected by B.C. government staff was sent to our team for analysis and reporting.

We selected sampling stations based on habitat features, accessibility, and soliciting expert knowledge from the NGBT members. In total, we installed 222 barbed wire hair snare corrals and 32 rub object stations to non-invasively collect grizzly bear hair samples. Each wire corral was set at ∼4 m in width by stretching four-pronged barbed wire taut around the outside of trees or stakes, at a height of ∼60 cm (Kendall and McKelvey, 2008; Kendall et al., 2009). The same barbed wire was wrapped at ∼6 ft in height around the different rub objects in the sampling grid (Morehouse and Boyce, 2016). Liquid lure made of rancid cow blood and fluids from rotten fish was poured in the center of each wire corral, or splashed on rub objects, and loosely covered with woody debris to protect it from rainfall and drying. All corral and rub object site information was shared with the NGBT so that members could communicate with their field staff to better ensure safety during operations. We also asked petroleum and forest industry staff, as well as agricultural landowners, to report any grizzly bear sightings online or directly to government project staff if and when they occurred, including location information.

To improve model performance, provide variability in spacing between accessible wire corral stations, and increase the total

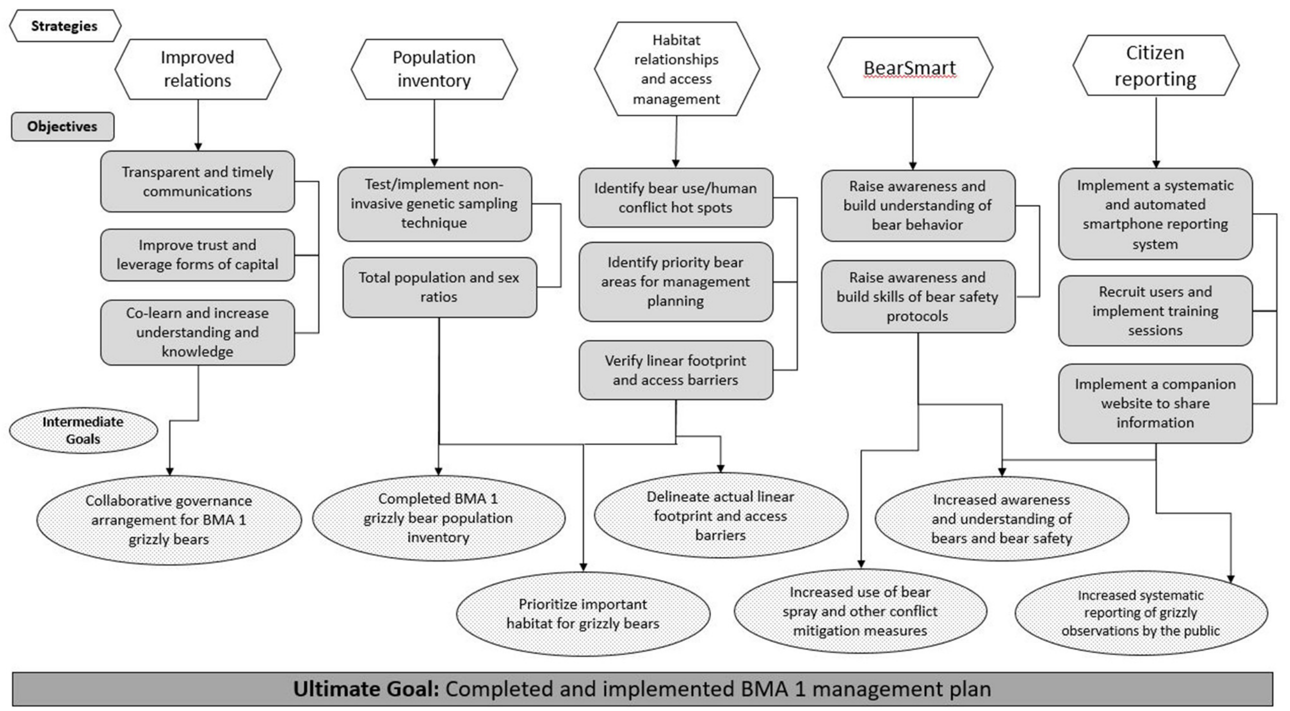

FIGURE 2 | Northwest Grizzly Bear Team's Theory of Change conceptual model.

number of sampling stations without significantly decreasing field crew efficiency, we opportunistically added additional wire corral stations to the grid along existing travel routes (i.e., roads). These stations were predominately focused in the ground-accessible portions of the grid, which may have introduced a slight sampling bias in areas of higher road density.

Each station was visited every 2 weeks (14-day intervals) between May 15 and July 19, 2017, to ensure the integrity and genetic viability of samples present/collected (Stetz et al., 2015; Lamb et al., 2016). All hair on a single barb was considered an independent sample upon each visit, and once collected was stored in a numbered envelope with corresponding site data. The barbed wire corral was then burned with a torch to minimize the possibility of any remaining genetic material contaminating future sampling, and re-lured (Kendall et al., 2009). All hair samples were stored in a dry environment away from sunlight until DNA analysis.

Analysis Methods

We sent all hair samples to Wildlife Genetics International (WGI) in Nelson, B.C. to identify the species (i.e., grizzly bear vs. black bear), sex, and individual identity through an analysis of nuclear DNA which they extracted from the hair follicle (Paetkau, 2003, 2004). Selection and analysis of hair samples for grizzly bears was done using a randomized sub-selection strategy, which included a tiered approach based on hair quality and quantity of guard and underfur hairs (**Supplementary Material C**). In the first tier of sub-sampling, high quality samples with more than one guard hair and 20 or more underfur hairs were selected. If there were not enough high-quality samples to meet these sub-selection rules, marginal samples with one guard hair and 5–19 underfur hairs were selected. Any samples with less hair than the aforementioned thresholds were treated as "inadequate" and were not selected for analysis. One exception was in 36 collection events where all available samples were classified as "inadequate." As a result, the best available sample from each of these collection events was included in analysis at the discretion of WGI. Hair samples were genotyped to eight markers (seven microsatellites plus an additional marker for sex differentiation) using QIAGEN DNeasy Blood and Tissue kits (2021), which enabled reliable differentiation between individuals (Paetkau, 2003, 2004).

We estimated grizzly bear density and abundance using the *secr* package (version 3.1.5, Efford, 2018) in the program R. We used a half-normal detection function and defined the area of integration as a 30 km buffer around the outermost hair snare stations. We did not impose a habitat mask because there were few known non-habitat areas within the study area. Due to limited detection events, density (*D*) was modeled as a uniform parameter across the study area. Sex-specific models were not possible for similar data limitations. We allowed detection probability (g0) and the spatial scale parameter (σ) to vary as a function of sampling site type (i.e., lured corral or rub object). We compared model performance using Akaike's Information Criterion corrected for small sample sizes (AIC_c) (Burnham and Anderson, 2004). Using our most parsimonious model, we derived grizzly bear abundance for the BMA 1 Recovery Zone.

The NGBT was kept apprised of decisions made and steps taken throughout all stages of analysis, and their input was solicited and questions answered where and as needed. This step helped alleviate concerns or confusion around analytic methods and prepared members for the forthcoming discussion on project results.

RESULTS

Evaluation of the Northwest Grizzly Bear Team

Fourteen of twenty two questionnaires were completed, including six from forestry representatives, six from government, one from the energy sector, and one from the public member at large. Thirteen of fourteen members indicated their primary motivation to join and participate in the NBGT was a requirement of their employment/position, demonstrating their organization's interest and commitment to grizzly bear recovery, with one respondent indicating it was their personal interest. Over half ($n = 8$) indicated they spent between 5 and 10 h monthly on this project, which was reported to be a reasonable investment of their time, whereas the co-chairs and project science lead indicated spending more than 15 h weekly. This included organizing, coordinating, facilitating and participating in over 15 different meetings, substantial financial administration, numerous different forms of reporting, and field work. Furthermore, the NGBT commissioned the production of an online video called "*Working Together for Grizzly Bears*"[1], through additional fundraising, to broadly and publicly communicate the important collaborative work of this team.

All respondents indicated they had no hesitations in joining this team and reported their curiosity about how this collaborative arrangement would function. Upon reflection, all felt that their participation was meaningful, with comments stating that the teams' professionalism, respectful conduct, cooperative spirit, and knowledge and information exchange were beneficial. When asked if they were satisfied with the outcomes, all but one respondent said yes, with this individual indicating their disappointment in the lack of implementing a BMA 1 plan post-project.

More specifically, the positive outcomes respondents noted included the benefits of collaboration and interactions, trust-building and information exchange (71.4%); the grizzly bear population estimate and verification of BMA 1 linear footprint through industry participation (42.8%); acknowledgment of the importance of the agricultural interface area and related relationship building (14.3%); leveraging funding to achieve project results (14.3%); and, the near perfect safety record (i.e., no major human safety incidences despite risks of remote work in bear country; 7.14%). Further, NGBT members indicated that despite the challenges of collaboration, collectively working together helped them build an understanding of the scientific methods used in grizzly bear population monitoring and the importance and use of scientific data in decision-making (92.8%).

[1]Uploaded by Let's Go Outdoors, 9 April 2019; https://www.youtube.com/watch?v=Gn-bQXUcN6candt=304s.

Reported negative outcomes and concerns included criticism of the lack of senior government officials' commitment to the project, including financially (21.4%); limited participation from the local energy sector, particularly given their influence on the landscape (e.g., linear footprint, bear mortality) as well as lack of engagement by Indigenous or municipal government representatives (21.4%); limited formal recognition of the importance of the NGBT as a model for collaborative governance coupled with concerns regarding support for future BMA1 planning and implementation and ensuring ongoing and active participation in the NGBT (21.4%). One respondent indicated negative outcomes was personally wanting more time to be able to participate in the NGBT.

Respondents also suggested considerations for future efforts, including increasing the NGBT meeting frequency (from bi-monthly scheduling), broader communication to the public about our work, pursuing official government policy direction and support to complete and implement a BMA 1 plan, and increasing engagement with Indigenous communities, agricultural landowners, and municipal government.

Grizzly Bear Density Estimation

We collected a total of 4,208 hair samples during the four sampling periods of our field season. We had 23 detections of 14 unique grizzly bears (12 males, 2 females). This included nine re-detections of grizzly bears from the pilot study, and six movements of individual bears between hair corral sites (**Figure 3**). Of the 23 total detections, 14 occurred at hair corral sites, nine occurred at rub objects (i.e., trees), and all occurred within Alberta. Also of note is that we had 852 detections of 585 individual black bears (333 males, 259 females), with 50 occurring at rub objects and 802 occurring at corral sites.

The top performing model estimated a grizzly bear density in the Recovery Zone of 0.70 grizzly bears/1,000 km^2 [Realized Standard Error (RSE) = 0.349, 95% Confidence interval (CI): 0.36–1.35]. The expected grizzly bear abundance within the BMA 1 Recovery Zone was 16.3 grizzly bears (RSE 0.349, 95% CI: 8.4–31.8).

An additional outcome, and benefit to the project, was the ability to efficiently leverage human and financial capital, including establishing field teams to collect bear hair from the sampling stations, through the NGBT collaboration. Moreover, these field teams also helped foster positive relationships with petroleum industry staff, forestry personnel, and agricultural and other landowners across the study area through informal conversations detailing our project scope and activities. These unanticipated educational opportunities represented an important time for clarifying the logistics and protocols of non-invasive genetic field methods and data uses in applied management, which in turn increased our study's transparency, sparked curiosity in grizzly bear science, and ultimately helped improve government-stakeholder-public relations.

DISCUSSION

We used a collaborative governance approach, including jointly developing Theory of Change (TOC) to guide and evaluate our

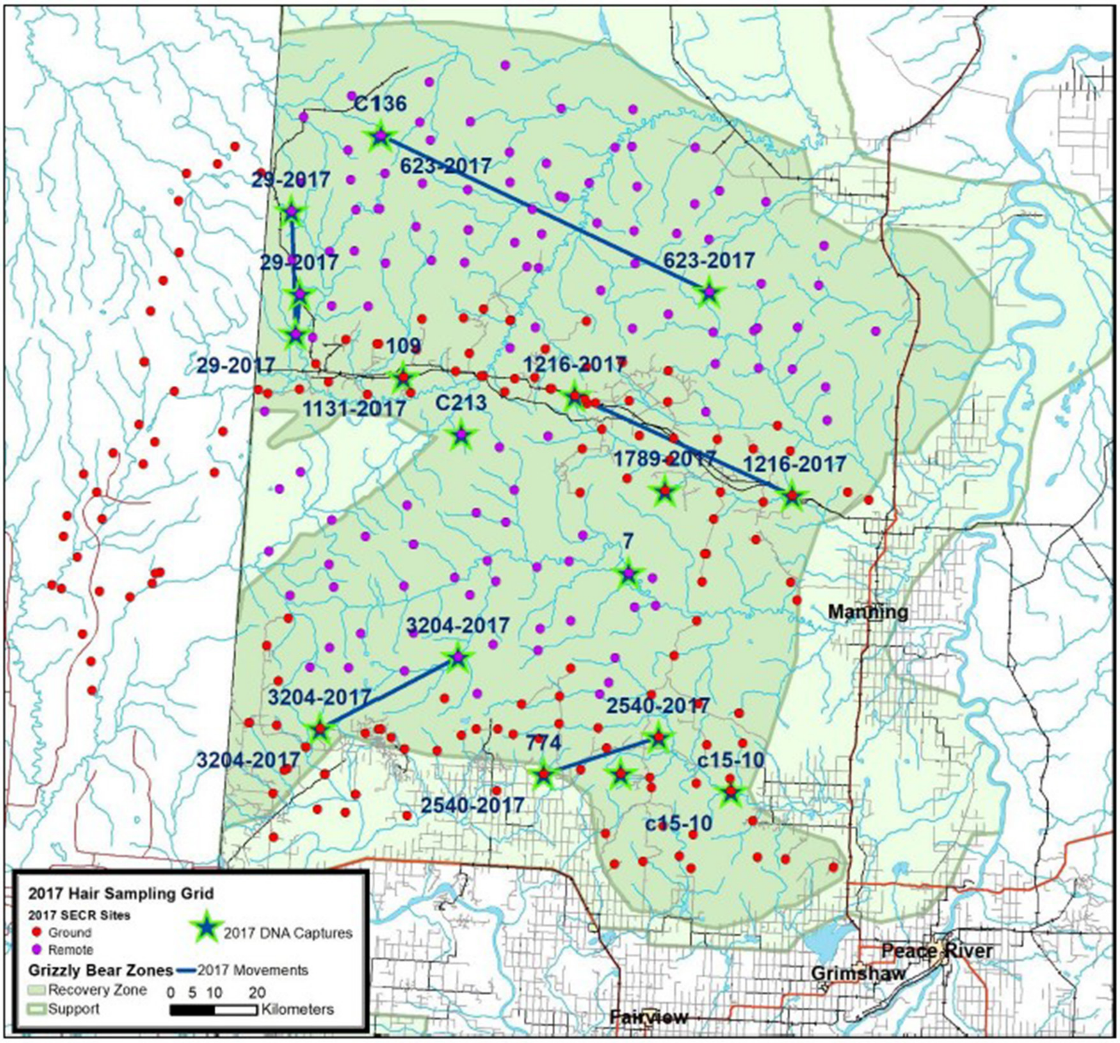

FIGURE 3 | Spatial configuration of the hair snare sampling grid and grizzly bear detections across BMA 1 Recovery Zone and along the British Columbia border. Labels indicate the ID number of detected grizzly bear individuals and associated movements between hair snare sites.

efforts, alongside employing a non-invasive genetic sampling project coupled with spatially explicit capture-recapture models to estimate grizzly bear density (0.70/1,000 km^2) and abundance (16.3 grizzly bears) in the Recovery Zone of BMA 1 in northwest Alberta.

While collaborative governance is a common term used across public administration literature, how it is defined and applied remains vague (Emerson and Nabatchi, 2015). Our study adopted the principle and spirit of a collaborative governance as suggested by Emerson and Nabatchi (2015), which included decision-making processes that constructively engaged people across their different sectors, perspectives, knowledge, experiences and interests to identify the values, needs and objectives for BMA 1 grizzly bear recovery. Our collaborative approach built and nurtured relationships across otherwise disconnected stakeholders and leveraged human and financial capital to conduct the first-ever population estimate for BMA 1 grizzly bears. A major strength in our approach was collectively and iteratively developing the TOR and the TOC, and learning from our collaborative arrangement by evaluating participants' experiences (Emerson and Nabatchi, 2015; Huge and Mukherjee, 2017). Through this, we learned that collaboration provides for opportunities to develop and improve relationships through active participation in discussions, decision-making and, as in our case, supporting data collection and analysis. This is a cornerstone of collaborative governance literature, where the importance of stakeholder engagement in scientific and decision-making processes is increasingly recognized (Redpath et al., 2017). However, we also learned that greater efforts must be taken in future to engage other stakeholders in grizzly bear science and applied management, and that a BMA 1 management plan

TABLE 2 | Grizzly bear density model results, with density modeled as a homogeneous surface in both models.

Model	Density (/1,000 km^2)	RSE	g_0 (e^{-3})	σ	Expected *N*	Δ AICc
$g_0 \sim$ TrapType	0.70 (0.36–1.35)	0.349	6.7 (2.6–17.2)	22,503 (14,776–34,273)	16.3 (8.4–31.8)	0
$g_0 \sim$ TrapType, $\sigma \sim$ TrapType	0.69 (0.36–1.35)	0.348	4.8 (1.5–15.1)	27,026 (15,057–48,059)	16.3 (8.4–31.6)	13.8

Detection parameters are for models parametrized using meters. Figures presented in brackets represent 95% confidence intervals. Expected population estimates are specific to the BMA 1 Recovery Zone. See DNA Field Methods and Analysis Methods for additional information.

utilizing population estimates and linear footprint results is strongly desired.

Overall, we suggest our efforts to build a strong, collaborative governance structure ultimately helped move grizzly bear conservation and management forward in northwest Alberta (Ansell and Gash, 2008; Stern and Coleman, 2015). By employing a collaborative process that shared the investment of time, money and collective actions, we were able to use the best available scientific techniques to deliver a grizzly bear population estimate for BMA 1. Indeed, the formalization of the NGBT created an open, respectful, and constructive space that made sense for the context in which we were working in and ultimately take steps toward achieving grizzly bear recovery in a multi-use landscape (Redpath et al., 2017).

Specific to grizzly bear population estimation, we found that BMA 1 contains a low density of grizzly bears and is currently the lowest recorded density of an established grizzly bear population in Alberta. Elsewhere in Alberta, grizzly bear density estimates range from 5.25 to 20.4 /1,000 km^2 (Alberta Environment Parks, 2020). We note, however, that our detection probability (g0) for grizzly bears was remarkably low and was substantially lower than the parameters we included within our simulation exercise (**Table 2**, **Supplementary Material B**). Further, our estimates of sigma (i.e., the spatial area over which a grizzly bear can be detected) were very large (**Table 2**). Given this, it is likely that we would need to substantially increase our sampling effort in order to achieve a more reliable (i.e., coefficient of variation <0.2) density estimate. However, increased sampling would be expensive and logistically challenging given the characteristics of this landscape.

We did attempt to increase grizzly bear detections by adding sampling sites opportunistically along existing travel routes (i.e., roads) and including sampling stations in British Columbia. However, our low number of detections precludes us from further examining the influence of these decisions on our density estimates. Indeed, we assumed a uniform density in our SECR models, which is an oversimplification because it is likely that grizzly bear density varies as a function of habitat and proximity to roads (Boulanger and Stenhouse, 2014).

We detected only two female grizzly bears and note that sex-specific demographic forces may be driving a male-skewed sex ratio. It is unclear if this ratio is a true component of this population or an unexplained sampling artifact. Lured rub objects represented only 13% of the sampling sites but provided 39% of grizzly bear detections, with 8 of 20 male detections and 1 of 3 female detections occurring at rub objects. Generally, male grizzly bears rub more frequently than female grizzly bears, though this difference dissipates as the season progresses (Lamb et al., 2016; Morehouse and Boyce, 2016). One factor that may have influenced bear detections and rubbing behavior is that we used lured rub objects, whereas most previously published studies used natural rub objects. It is also possible that more female bears occur outside of the Recovery Zone and therefore did not encounter our traps. One potential explanation for this is that the Recovery Zone represents higher quality habitat and is thus used by the more dominant male bears, with females being excluded or seeking alterative habitat (i.e., dominance hypothesis, Elfstrom et al., 2012; Stewart et al., 2013). This theory remains to be tested and is considered a low probability scenario given the large spatial scale over which this process would be occurring. Regardless, our detected female scarcity elevates the importance of minimizing human-caused grizzly bear mortality and further emphasizes the importance of maintaining female survival in BMA 1 (Alberta Environment Parks, 2020). Educational outreach and access management strategies should therefore continue to be implemented across BMA 1 to mitigate human-bear conflict and the potential for female mortality.

Our project also attempted to measure the transboundary population between Alberta and British Columbia, but no grizzly bears were detected in this portion of our study grid. However, this lack of detections is difficult to link to differences in bear density and should be interpreted with caution (Environmental Reporting BC, 2020). And finally, while we detected few grizzly bears, a large portion of our collected hair samples were black bears, suggesting that our sampling methods were appropriate for detecting bear species. Grizzly and black bears have different life histories, where northwest Alberta's boreal landscape is likely more suitable black bear habitat than grizzly bear habitat (e.g., Bonin et al., 2020).

Despite these challenges, our abundance estimate represents the first empirical estimate for BMA 1 and is a baseline against which future BMA 1 monitoring and management actions can be measured. This includes setting objectives to address the limiting factors (i.e., human-caused mortality) for grizzly bears, implementing local management policy co-designed by the NGBT, exploring opportunities for creative and innovative strategies to implement for this landscape, and assisting in evaluating the efficacy of grizzly bear and human behavior management as well as land use and forestry practices.

Importantly, we also provide a starting point from which to evaluate the achievements and impacts of a complex collaborative governance arrangement for an at-risk species and demonstrate success despite the challenges encountered. Going forward, priority actions the NBGT has considered for local planning includes collectively mapping actual linear footprint and taking coordinated action on motorized (i.e., on-highway vehicle) access and associated impacts (i.e., reduction and restoration of existing linear features, evaluating open road densities and access barriers). Additionally, the NGBT agrees that locally relevant educational outreach, using Alberta BearSmart principles and materials, must be delivered across BMA 1. This includes engagement with petroleum and forest industry, landowners, recreationalists, and community residents to teach and encourage proactive bear safety and conflict mitigation strategies (e.g., electric fencing). Lastly, the NGBT members recognize the need for their organizations' staff and the broader public to contribute to grizzly bear observations, and as such, supports the use of the smartphone-based reporting application GrizzTracker (www.grizztracker.ca) as an effective reporting method.

CONCLUSION

This study represents the first attempt to empirically estimate the grizzly bear density and abundance across Alberta's northern BMA 1, through a multi-stakeholder collaborative arrangement called the Northwest Grizzly Baer Team (NGBT). Collaboration was at the core of our success, which went beyond simply acknowledging the need to collaborate, to enabling proactive participation by NGBT members in project design, implementation and evaluation. In turn, the relationships we fostered enabled us to leverage financial, human, social, and policy resources, and helped to build trust, reciprocity and exchange across stakeholders and the broader public through open and transparent communications (Ostrom, 1990; Pretty and Smith, 2004; Ansell and Gash, 2008; Kallis et al., 2009). Additionally, our collaborative arrangement provided extensive opportunities to co-learn, share, and engage across the broad membership of the Northwest Grizzly Bear Team.

Our summative evaluation was an important step in understanding the efficacy of our collaborative arrangement, helping to provide evidence to inform future decisions on alternative governance structures. Indeed, this team has agreed to continue to build and strengthen relationships, facilitate constructive dialogue, and share data and knowledge going forward, to develop a locally relevant BMA 1 plan. In addition to our collaborative outcomes, our efforts provide a robust grizzly bear population dataset to help fulfill Alberta's recovery policy objectives and can contribute to future performance evaluations of integrated land management. Future collaborative governance arrangements would be well-suited to look to our project as a guideline for establishing multi-sectoral teams that applied various social and natural science methodologies to define and work toward resolving a complex, real-world, species at risk problem. Overall, the relationships, funding, datasets, and commitment to future efforts would not have been possible without coming together in the spirit and practice of collaboration.

DATA AVAILABILITY STATEMENT

The data supporting the conclusions of this article will be made available by the authors upon request.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Ethical review and approval was not required for the animal study because Animals were not handled. Non-invasive genetic sampling (hair samples) was explicitly used.

AUTHOR CONTRIBUTIONS

CH, LF, LV, and NM conceived of the project. CH and LV directed the project. LF led fieldwork logistics, with participation by NM, CH, and LV and project partners. LV completed the secr analysis, with AM and RS reviewing. CH completed the questionnaire analysis with review by project partners and led the manuscript writing process, with all other authors contributing content and revisions. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2021.719044/full#supplementary-material

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Conflict of Interest: JW was employed by Mercer Peace River Pulp Ltd. at the time of this study.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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