2023-03-22

Living Lab Program for Climate Change and Conservation - Final Report

Project title: How climate change will shape the future of human wildlife conflict in B.C.'s protected areas

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Research findings

The aim of this project was to understand how climate change is expected to shape the future of Human Wildlife Conflict (HWC) in B.C.'s protected areas throughout the next century. Using more than a decade of park visitation records, and pre-collected GPS location data on 5 species of terrestrial mammals (caribou, *Rangifer tarandus*; cougars, *Puma concolor*; elk, *Cervus elaphus*; grizzly bears, *Ursus arctos horribilis*; and mountain goats, *Oreamonos americanus*), we studied how park visitation and mammalian movement ecology responded to historical conditions and projected how they will respond under different climate change scenarios (Riahi et al. 2017). The key findings from this living lab supported research are detailed below.

Park Visitation

- Park visitation was highly correlated with weather conditions. Generally, as temperatures increased, parks had more visitors, but these relationships differed between seasons as well as between parks. A warm, wet day, for example, caused opposite attendance trends in August versus December (Fig. 1C and 1D). Attendance was usually high when August was cool and dry, while December had high attendance under relatively warm and wet conditions (Fig. 2).
- BC Parks can expect an increase in visitors over the upcoming century (Fig.2), especially during parks' respective peak and shoulder seasons (e.g., Fig. 3). We found that the exact magnitude of these changes, however, will also depend on population growth.
- Under all climate change and population growth scenarios modelled, the greatest increase in park visitors were projected under higher emissions and higher population growth scenarios.

Mammalian movement

- The effects of weather on mammal movement varied by species, but differences in temperature and precipitation alone caused the average daily distance travelled by each species to vary by as much as 10%.
- There were no clear common trends between changes in climate and animals' projected movement rates since each species' movement and the predicted changes in climate varied substantially across BC. Across all species, however, we observed little to no changes occurring in the best-case scenario (SSP 1-2.6) and the strongest changes occurring in the worst-case scenario (SSP 5-8.5). Overall, caribou, cougars, and grizzly bears are expected to increase their speed across BC by 1-2%, while elk are not expected to exhibit substantially different movement, and mountain goats are expected to move ~1% slower. While these

numbers may seem low, they represent the average change in animal movement, and do not capture changes during periods of extreme weather (e.g., heat domes or heavy rainfall events).

- As with the movement rates, the effects of climate change on habitat quality varied substantially between species. Here again, however, the trends were similar between climate scenarios, with the largest changes occurring in the worst-case scenario. For each species excluding mountain goats, our models suggest there will be areas which will become 50% to 400% less hospitable for the study species. Conservation efforts should therefore account for future habitat quality besides current habitat quality.

When taken together, the projected increases in park visitation and changes in large mammal movement and habitat use suggest that climate change over the next century will impact the frequency of HWC throughout the province. Although changes in animal movement and spatial preference are complex and spatially heterogeneous, the models developed in this project provide BC Parks with key information to assist in both near-term reactive, and long-term proactive management, by allowing for fine-scale, spatiotemporal, species-specific predictions.

Methods summary

Data sources

Park Visitation

To understand drivers of park visitation, we analyzed day-use attendance records from 2010 to 2019 from 249 BC Parks. These data were fit with a Hierarchical Generalized Additive Model (HGAM), which was then used to predict park attendance up to 2100. Attendance was predicted under two population growth scenarios (high and low growth) and four of the IPCCs "Shared Socioeconomic Pathways" climate change scenarios (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5). A summary of the workflow for this portion of the project follows:

- Monthly day-use attendance data were directly provided by BC Parks.
- BC population growth rates up to 2042 were obtained from Statistics Canada (2019), and projected out to 2100 using Generalized Linear Mixed-effect Model (GLMM) from the lme4 package (Bates et al., 2015).
- Monthly averages for temperature and precipitation from 2010 through 2020 and projections under the different SSP scenarios for 2020 through 2100 were downloaded via the climatenaR R package.
- All temperature and average monthly precipitation were converted to °C and mm, respectively.
- Monthly attendance totals were annotated with coordinates, then climate data. Coordinates were obtained by placing a pin in Google Maps in the approximate center of the park.

Mammalian Movement

Animal movement plays a vital role in determining patterns of HWC. Because animal movement depends strongly on energetics, and since an animal's energetic costs in turn depend strongly on weather (Brown et al. 2004, Noonan et al. 2014,2018), we aimed to estimate the effect of weather on mammals' movement and spatial preference within a landscape. A summary of the workflow for this portion of the project follows:

goats (*Oreamonos americanus*), were provided by collaborators and assumed to be free of outlier and erroneous locations (Fig. 4).
- Hourly temperature, precipitation, and snow depth data were downloaded from Copernicus's Atmosphere Data Store via the ecmwfr package (Hufkens, Stauffer, & Campitelli, 2019) for R (R Core Team 2022).
- Temperature, hourly precipitation, and snow depth were converted to °C, mm/hr, and mm, respectively.
- Rasters of elevation were downloaded using the elevatr (Hollister et al., 2021) package for R at a resolution of approximately 0.018 degrees (zoom level 5, see this page for more information). Rasters of percent forest cover and fresh water were downloaded from EarthEnv (Tuanmu and Jetz. 2014) with a resolution of 0.00833 degrees, and a raster of distance from the nearest raster cell containing water was calculated from the latter.
- Monthly climate projections (temperature and precipitation) for the years 2020-2100 were downloaded at the same resolution as the digital elevation model via the climatenaR package (Burnett 2022) for R. Unfortunately, no estimates of snow depth are available, so the effect of snow depth was not included in the forecasts of animal speed and habitat quality.
- Movement data were annotated with weather and resource data using the extract() function from the raster package (Hijmans 2023). Elevation, forest cover, and distance from water were assumed to be constant over time, while the weather data was extracted from the closest raster in time.

Statistical analyses

Park Visitation

- Attendance rates for each park were modeled and projected using Hierarchical Generalized Additive Models (HGAMs, see Wood 2011, Simpson 2018, and Pedersen et al. 2019) via the mgcv package (Wood 2017) for R, and validated using a range of standard model validation techniques.

Mammalian Movement

- Animal movement was modelled using continuous-time movement models via the ctmm package (Fleming et al. 2021) for R, and instantaneous speeds were estimated using the movement models with sufficiently high sampling frequency.
- The effects of hourly temperature, precipitation, and snow depth on animals' movement were estimated using HGAMs via the mgcv package.
- Animals' spatial preferences were modeled using Hierarchical Resource Selection Functions (HRSFs) fit via the mgcv package.
- Changes in habitat quality since 2020 were calculated as the ratio of the habitat quality in 2100 (under each climate change scenario) over the habitat quality in 2020, such that a value of 2 indicates a doubling in habitat quality, while a value of 0.5 indicates a halving of habitat quality. Changes in habitat quality can be assumed to impact a location's carrying capacity, although the relationship between change in habitat quality and carrying capacity may not be one to one.

The R scripts required to reproduce the park visitation analyses are openly available at https://github.com/QuantitativeEcologyLab/BCParks_Attendance, whereas the scripts required to

Key outcomes for BC Parks

Park visitation and animal movement were both affected by prevailing weather conditions. Critically though, these effects were predictable. Because these relationships were predictable, they can, and should, be factored into BC Parks' planning and decision-making processes. Key actionable outcomes are detailed below.

- Attendance predictions (Fig. 2) show that under any climate change scenario, changes in weather will result in BC Parks experiencing increased attendance. More visitors in parks could result in more disturbance of the environment and wildlife, and HWC is likely to increase. This may also lead to overcrowding and altered visitor experiences. As a more fine-scale example of the effects of climate change and population growth on park attendance, projections for Golden Ears Park (Fig. 3) show how monthly attendance is projected to increase over time, especially during peak seasons. Similar projections are available for all parks, and under all combinations of scenarios, but are not shown here due to space constraints.

- As the climate changes, animal movement and habitat use are also expected to change. The maps and projections of estimated daily movement (Figs. 5-9) can be used to estimate the risk of HWC in BC Parks, since greater daily movement implies a higher chance of human-wildlife interactions. Figures 11 through 15 show the estimated habitat quality in 2020 and 2100 for the five study species. These latter maps can be used to determine which areas should be protected to maximize the quality of protected areas in the coming century, including which areas will be of high quality at the end of the century.

Relevance to BC Parks management

While of the projected trends in mammalian movement and park visitation were too complex to visualize and report on here, the models developed as part of this project are openly available, and allow for fine-scale location, species, and time specific predictions. As we move through the century and approach 2100, we recommend that BC Parks management make use of these predictions to understand how animal movement patterns, habitat use, and attendance are expected to change on a park-by-park, and case-by-case basis.

As an example of what this process may look like, if a local park manager(s) has information on the expected weather for the next several weeks/months, these models can be used to predict visitor numbers and large mammal movement patterns. Park managers can then use this information to proactively hire the appropriate number of park staff during peak seasons. In addition, they can identify regions of their park that animals are likely to move into and adjust trail access to minimise HWC risk.

Although the trends were too context dependent to make general recommendations to BC Parks, there were no scenarios where we saw mammalian movement and park visitation remaining consistent with present patterns. BC Parks should actively consider change as they prepare for the next century, where the models generated as part of this report can help guide that process.

Project's challenges/opportunities

The project was completed on schedule, but several challenges impacted the pace of this work. The biggest challenges were related to data access and processing. Despite being funded by BC Parks, project's timeframe. This limited the scope of the project and potential value to BC Parks. The core data access challenges are detailed below.

Park Visitation

The park visitation data were difficult to obtain, and it appeared as if there was a lack of coordination between parks/regions on how these data were collected and stored. In addition, the files were difficult to work with and required a significant amount of effort before we could even begin our formal analyses. Improving data curation practices would help reduce the amount of effort required to work with these data. Improved accessibility would likely increase the use of these highly valuable data, and lead to more collaborations between researchers and BC Parks, and more actionable research outcomes.

The day-use attendance records used in this project were also monthly totals. Finer scale data—i.e., daily visitation rates—would allow us to account for institutional seasonality (holidays, long weekends, etc.) in the model. Although we recognise that these data would be challenging to collect, their value in understanding park visitation would be high. Related to this, Parks can only carry a limited number of visitors. Data on individual park capacity would have been useful in creating an upper limit for attendance projections or estimating the risk of overcrowding.

The park attendance projections are also contingent on available climate. While the human-use model was well-behaved and had good predictive performance, the biggest opportunity for projection refinement would be the incorporation of additional climate, park, and attendance data. Fortunately, the developed framework is flexible, and can be adapted and refined as new data become available. A valuable opportunity for future work would be to develop a self-updating model that could automatically take advantage of new attendance records and climate predictions.

Mammalian Movement

While each species used had a minimum of 2650 observed locations (grizzly bear), the minimum number of estimated statistically independent locations was substantially lower (46 independent cougar locations), and, for some individuals, the temporal range of the locations was short (minimum of 14 days). More GPS tracking data would substantially improve the model estimates, particularly if the additional data had a wider spatial range (e.g., one individual for each area of BC where the species is present), and, in the case of the mountain goats, over longer periods of time. Ideally, the dataset should also include a representative sample of the weather each study species experiences in BC. Table 1 summarizes the data used to model the effects of short-term weather on animals' movement. Because the elk dataset had so many locations, only a tenth of the telemetry data was used to fit the models due to time constraints (although the number of independent locations was kept the same by proportionally increasing each location's weight in the model, to a maximum weight of 1).

Table 1. Sample sizes for the five species modeled, specifically number of observations (n), the estimated number of independent observations (n_{indep}), number of quadrature points (i.e., unobserved locations, n_Q), and the number of quadrature points per location and independent location.

Species	Date range (days)	n	n_{indep}	n_Q	n_Q/n	n_Q/n_{indep}
C. elaphus	2,503	87,759	9340	199,092,816	2,269	21,317
O. americanus	14	1,238	243	2,379,456	1,922	9,809

R. tarandus	4,096	12,568	100	39,128,738	3,113	391,569
U. arctos horribilis	1,804	2,650	91	79,562,250	30,023	875,533

While the animal movement data used in this project are spatially, temporally, and taxonomically limited, we were unable to obtain additional data within the time frame of the project. Multiple BC Parks collaborators suggested obtaining data via the BC Telemetry Warehouse, but the time required to complete the training and read each agreement was prohibitive. We recommend that these data be made more accessible, and we are willing to expand the scope of the project if we could obtain data on additional species and ecozones within BC.

The models used to describe patterns in animal movement and habitat use are complicated, and subject to many potential sources of bias (e.g., temporal autocorrelation, small sample size bias, model misspecification, etc.). HGAMs with a Poisson distribution can be used to fit a HRSF to multiple animals, which allows analysts to estimate the average resource preferences using nonlinear, non-monotonic model terms. The data's spatiotemporal autocorrelation can be mitigated by weighting the telemetry data based on the animal's movement model and utilization distribution (fit via the ctmm package). However, due to time constraints it was not possible to perform in-depth sensitivity analyses on the final models. Sensitivity analyses will be performed prior to publication, but the results presented in this report should be approached with this limitation in mind.

Lastly, the climate change projections for BC only provided data on temperature and precipitation. There are, however, many other climate change-related variables that will undoubtedly affect park visitation. For instance, incorporating snow cover projections, wildfire/natural disaster projections, and sea level projections for select regions would increase the accuracy of the model's projections. While developing predictions for all of these factors was beyond the scope of this effort, these would improve the accuracy of our models and refine BC Parks' capacity to anticipate future conditions.

Conclusions/next steps

Our research determined that climate change over the next ca. 80 years will likely result in substantial increases in BC park attendance. In tandem with this increased attendance, animals will be moving through parks in different ways. Challengingly, no two species were expected to respond in the same way, and the different climate change scenarios all resulted in substantially different trends, even for the same species, in the same place, at the same time. Despite these nuanced, context-specific responses, our study provides informed predictions of which areas should be considered for long-term conservation, as well as which areas may decrease in value to wildlife. Collectively, our findings can help managers throughout the province make informed decisions about how human-wildlife conflict in their park(s) can be expected to change.

In terms of next steps, two manuscripts are currently being prepared based on the findings from this work, with the intention of turning them into peer-reviewed publications. Longer-term, the models generated as part of this work allow for fine-scale location, species, context, and time specific predictions. Synthesizing the findings from these models in a static report is challenging, and necessarily requires some amount of information loss. Developing these models into openly accessible software that can allow managers throughout the province to explore trends and model predictions (for instance as an RShiny webapp) would allow them to focus on the locations and times that matter most to them and improve the overall utility of this work.

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Figures

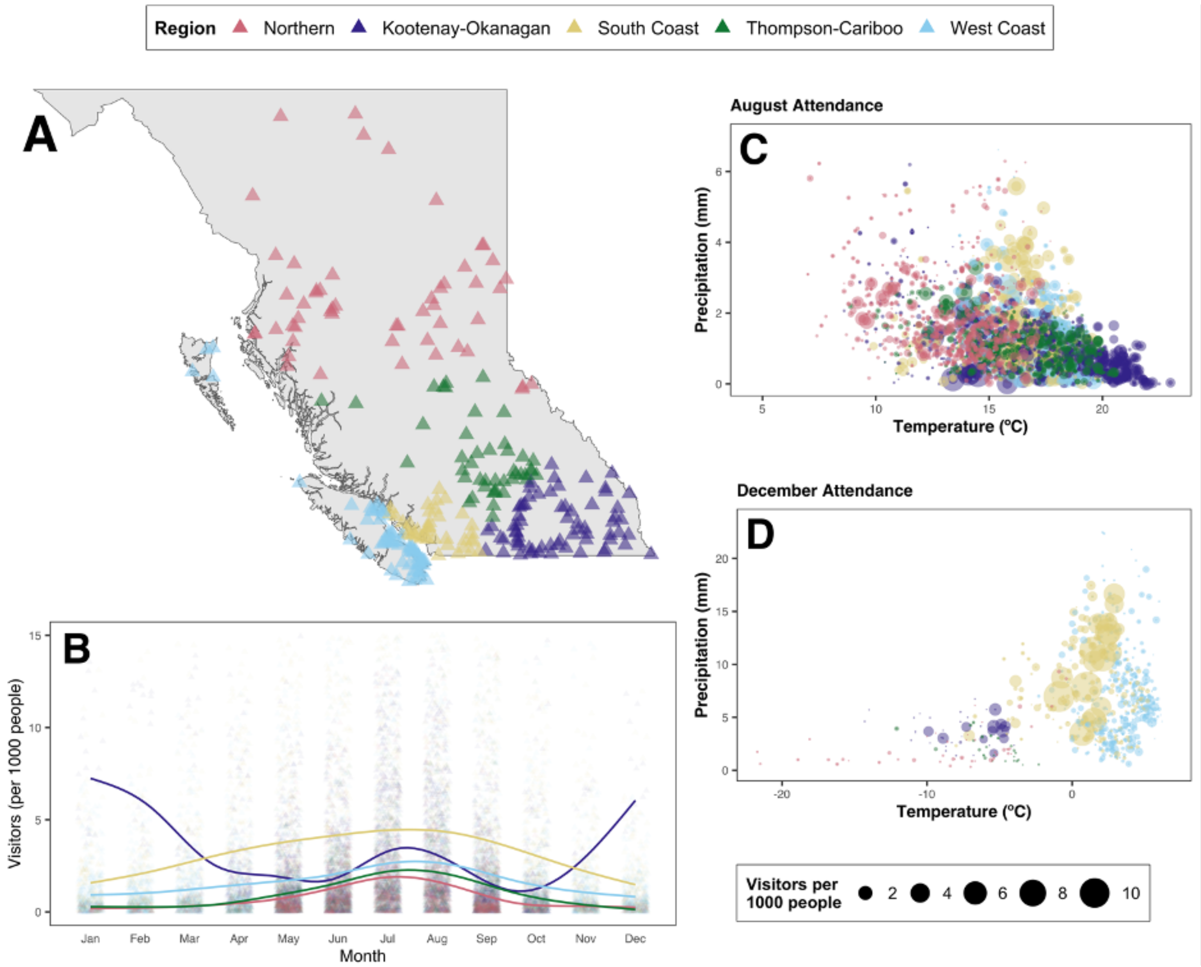

Fig 1. **Visualization of BC Parks attendance records**. (A) shows the geographic distribution of BC Parks included in this analysis (n = 249), coloured by region. (B) illustrates average seasonal trends for each region from 2010 to 2019. Points are observations, while the smooth lines represent average trends across each respective region. The relationship between attendance (represented by the size of the points) and weather for (C) August, and (D) December are also shown.

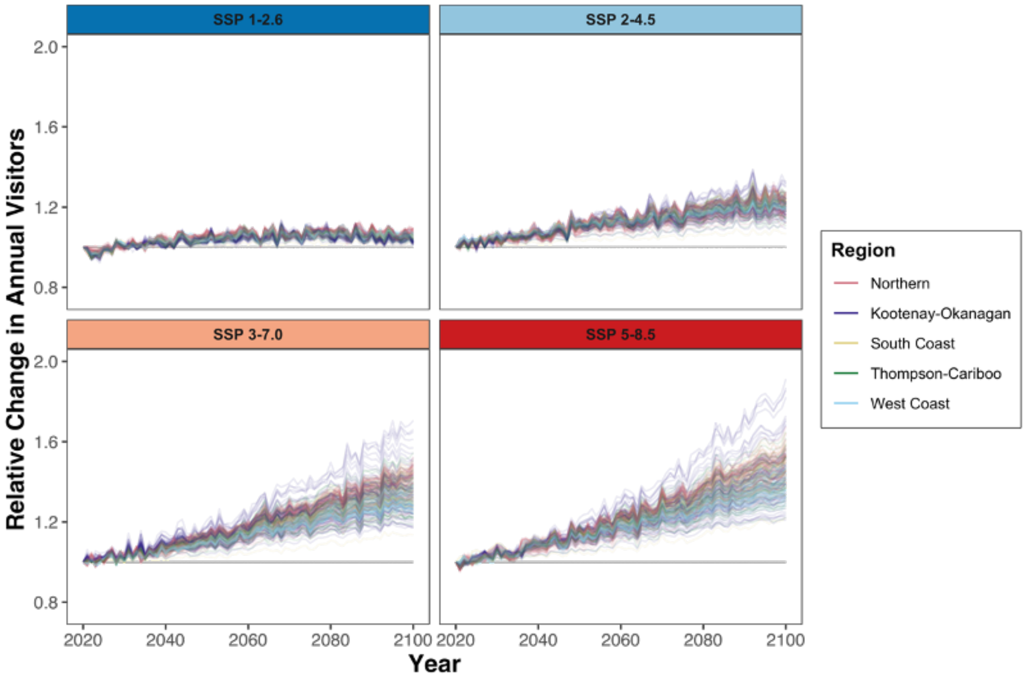

Fig 2. **Projected change in attendance for 249 BC Parks**. A single line represents one park's change in visitors relative to 2020. Projection lines are coloured by region and are separated by climate change scenarios into four panels (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5).

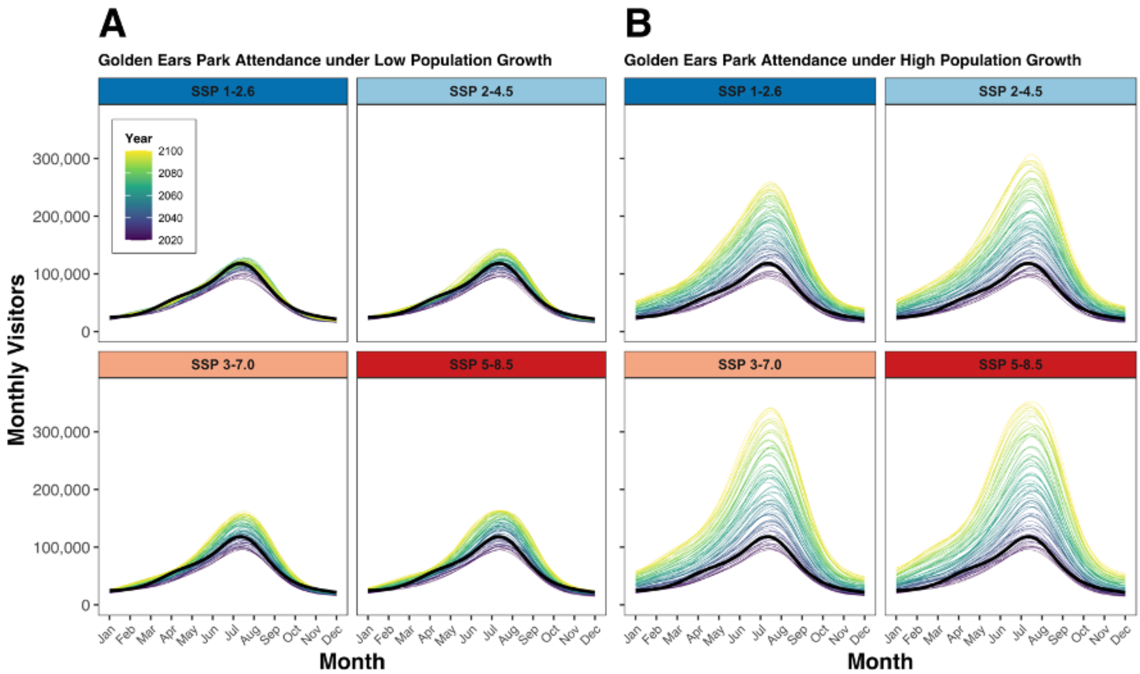

Fig 3. **Projected attendance at Golden Ears Park under different population growth and climate change scenarios**. Average historical attendance from 2010 to 2019 is represented by a thick, black line. Projections are coloured according to year, ranging from 2020 to 2100. Attendance depends on the climate change scenario — represented by panels (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5) — and population growth scenario, with low growth shown in (A), and high growth in (B).

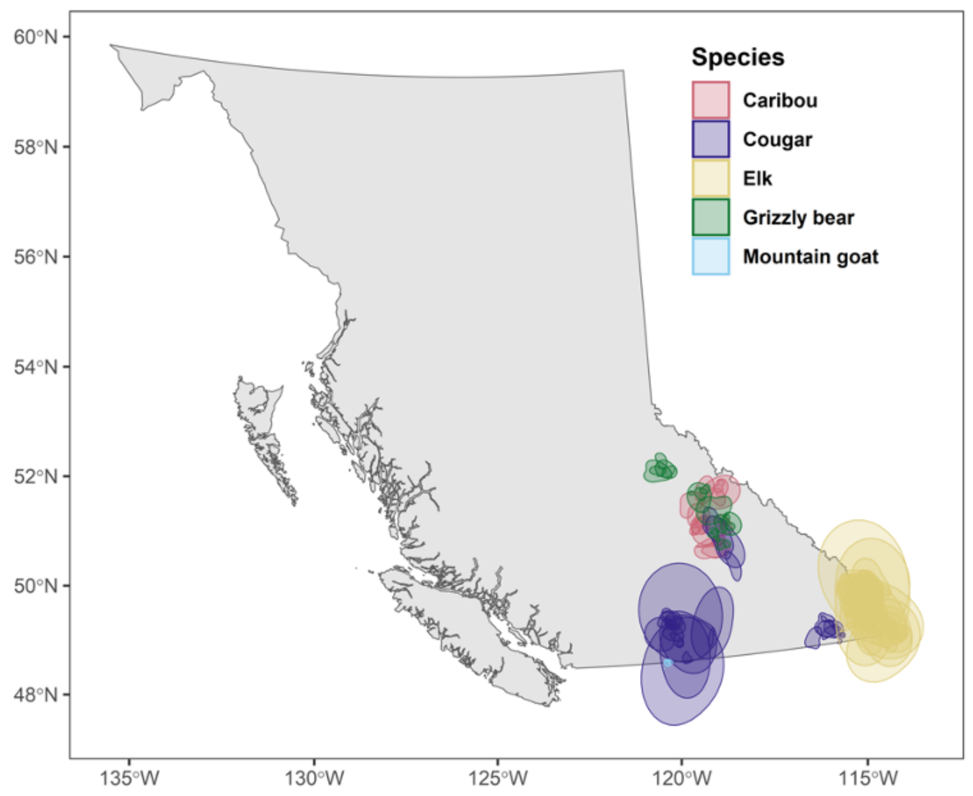

Fig 4. **Estimated 95% home ranges of each of the animals included in the analyses.**

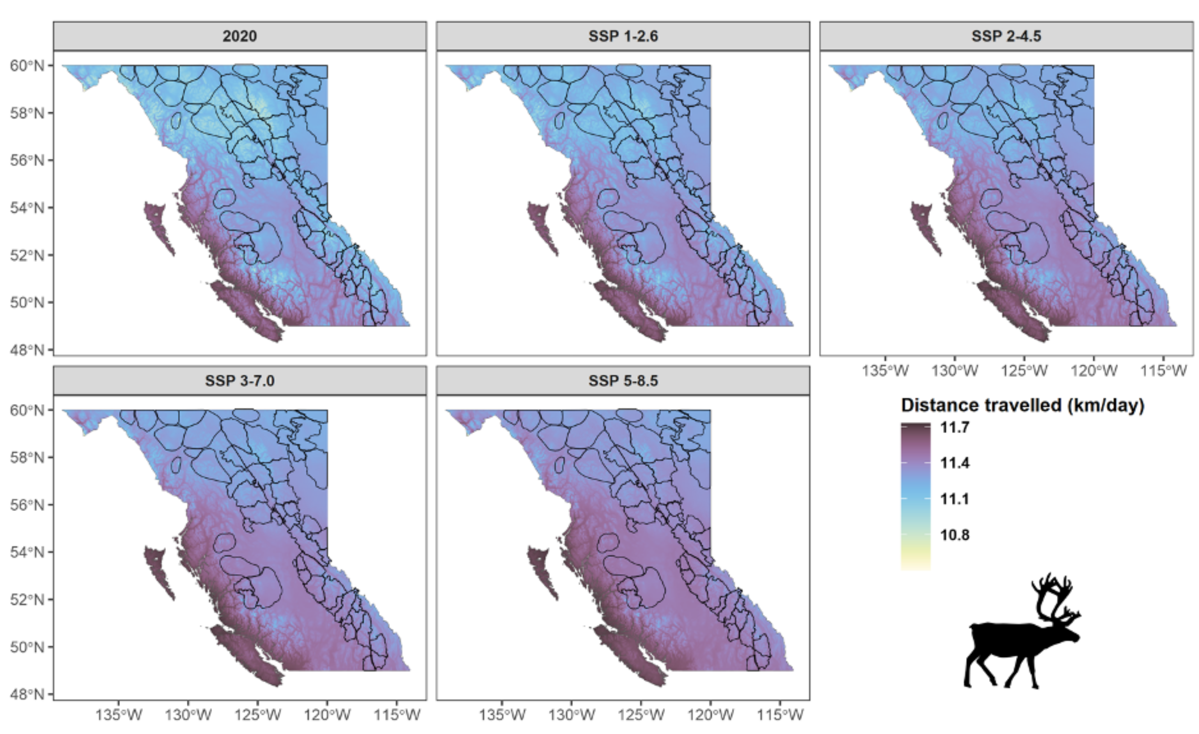

Fig 5. **Estimated average daily speeds for caribou in 2020 and 2100, under different climate change scenarios.** Estimates are based on monthly average temperature and precipitation from historical weather data for 2020 and climate projections for 2100. The black polygons depict caribou herd boundaries.

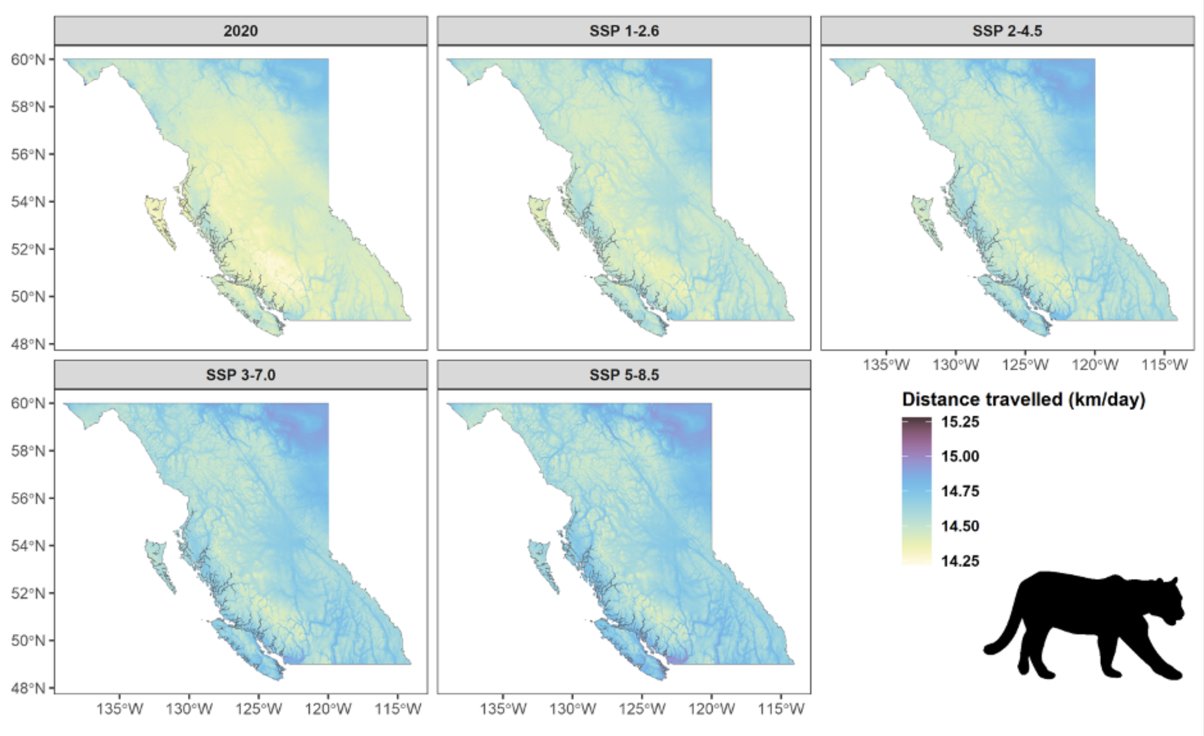

Fig 6. **Estimated average daily speeds for cougars in 2020 and 2100, under different climate change scenarios.** Estimates are based on monthly average temperature and precipitation from historical weather data for 2020 and climate projections for 2100.

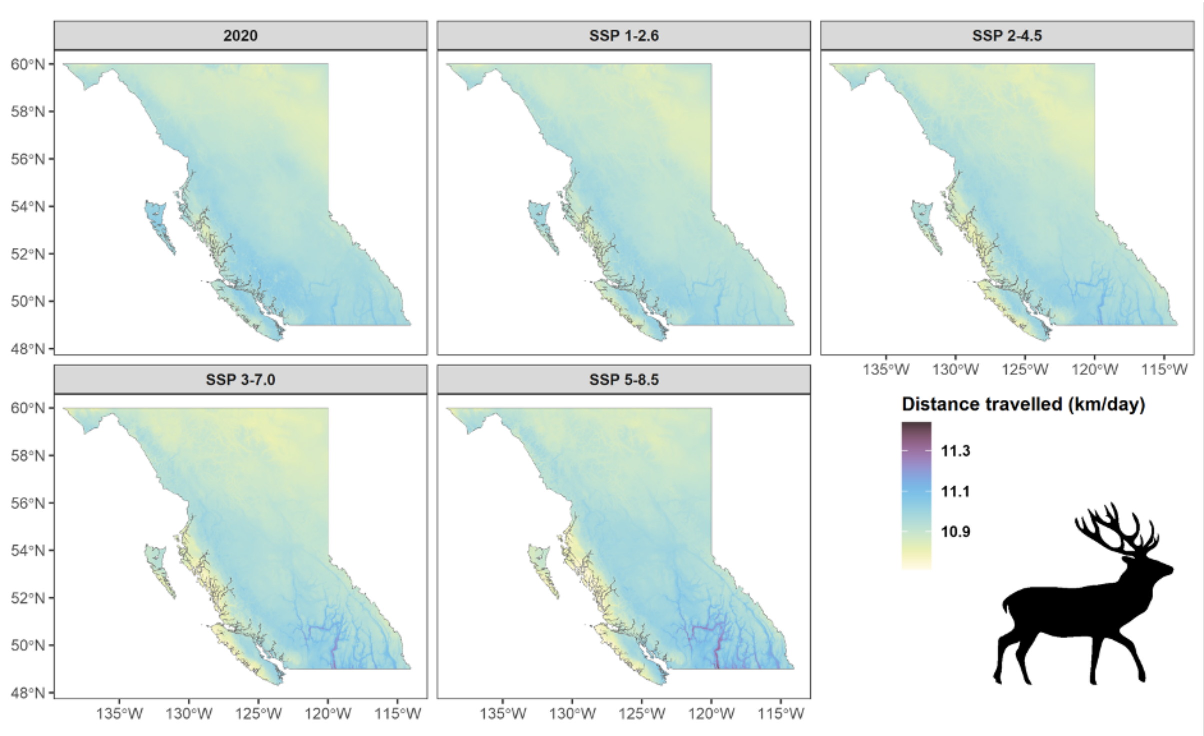

Fig 7. **Estimated average daily speeds for elk in 2020 and 2100, under different climate change scenarios.** Estimates are based on monthly average temperature and precipitation from historical weather data for 2020 and climate projections for 2100.

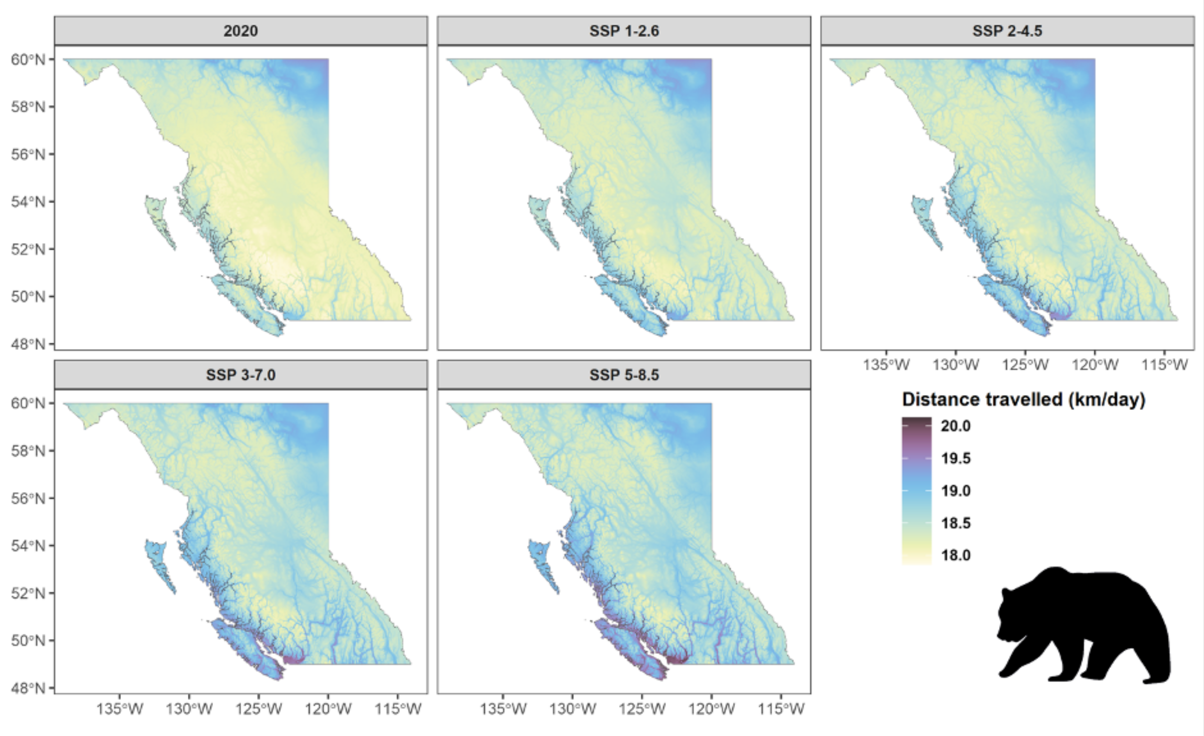

Fig 8. **Estimated average daily speeds for grizzly bears in 2020 and 2100, under different climate change scenarios.** Estimates are based on monthly average temperature and precipitation from historical weather data for 2020 and climate projections for 2100.

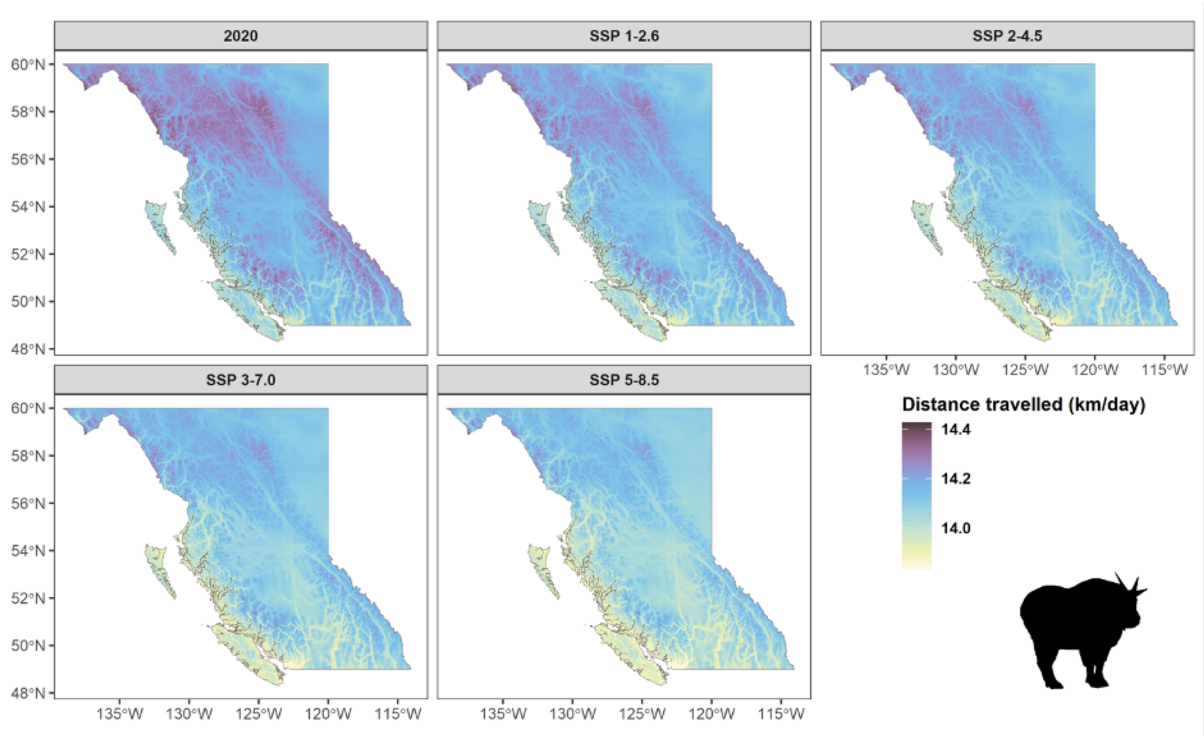

Fig 9. **Estimated average daily speeds for mountain goats in 2020 and 2100, under different climate change scenarios.** Estimates are based on monthly average temperature and precipitation from historical weather data for 2020 and climate projections for 2100. Goat silhouette used with permission by Sarah E. Haworth (CC-BY 3.0).

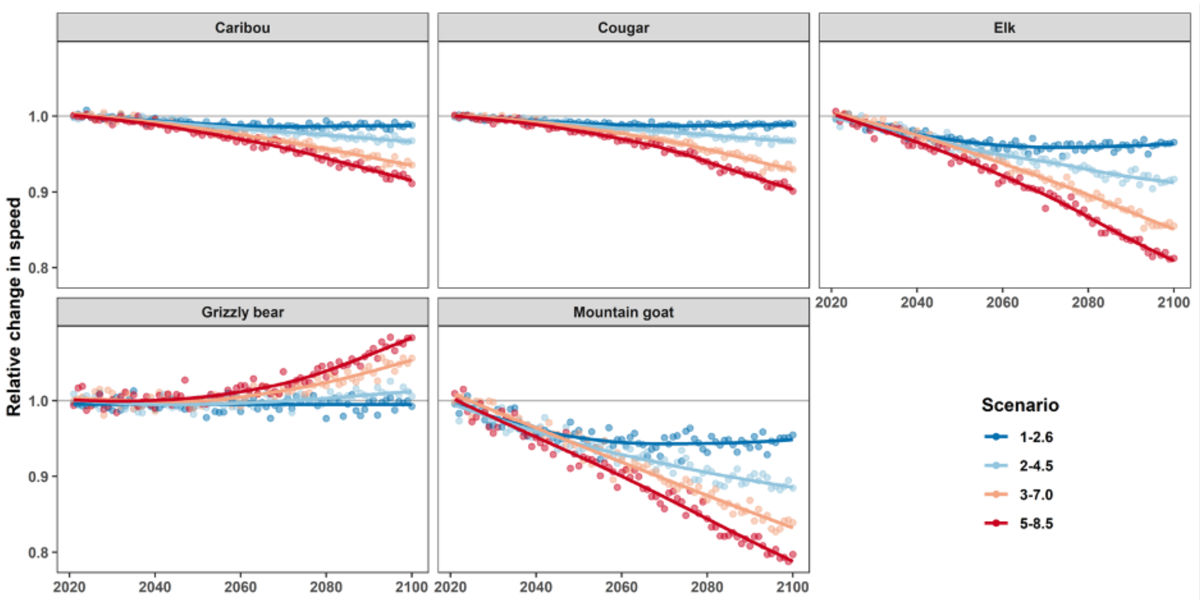

Fig 10. **Relative change in speed in the coming century for the average location of each of the study species.** Values less than 1 indicate a decrease in speed, while values above 1 indicate an increase in speed. For example, 0.9 indicates the average speed is 90% the speed it was in 2020.

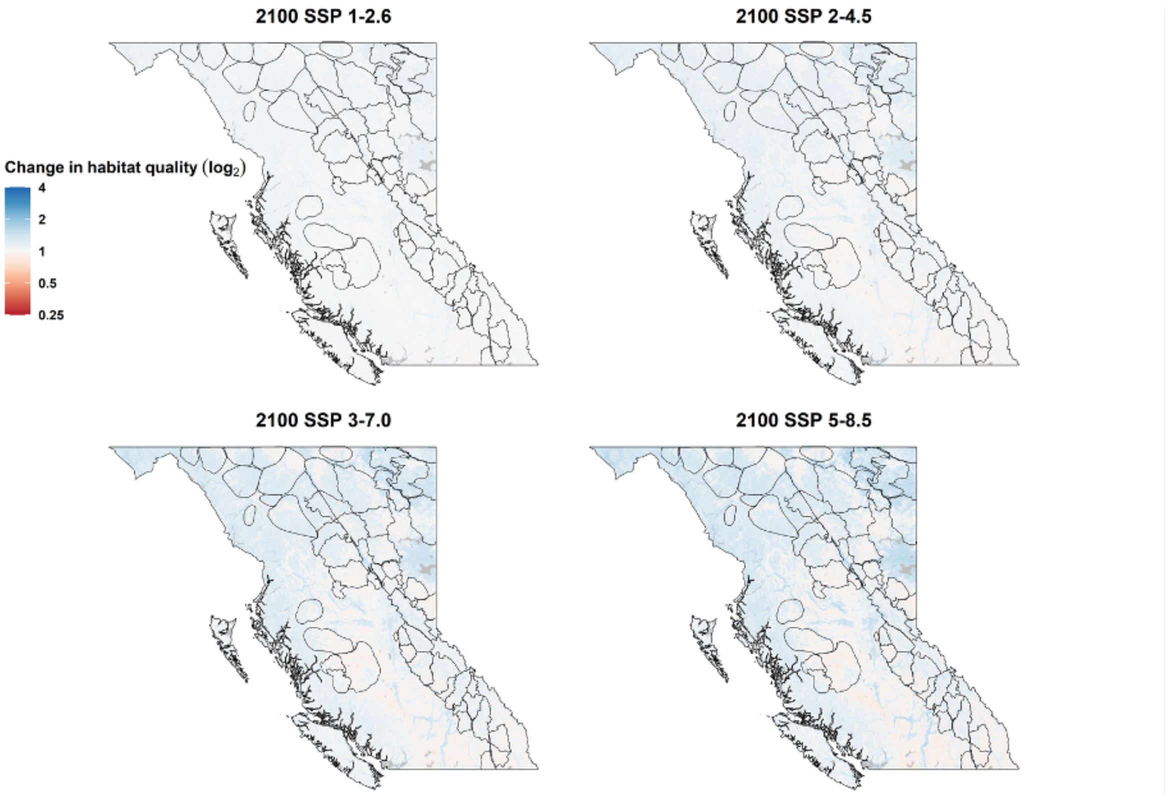

Fig 11. **Estimated change in habitat quality for caribou between 2020 and 2100, under different climate change scenarios.** Values less than 1 indicate a loss in habitat quality, while values above 1 indicate a gain in habitat quality. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve map readability and avoid excessively high predictions.

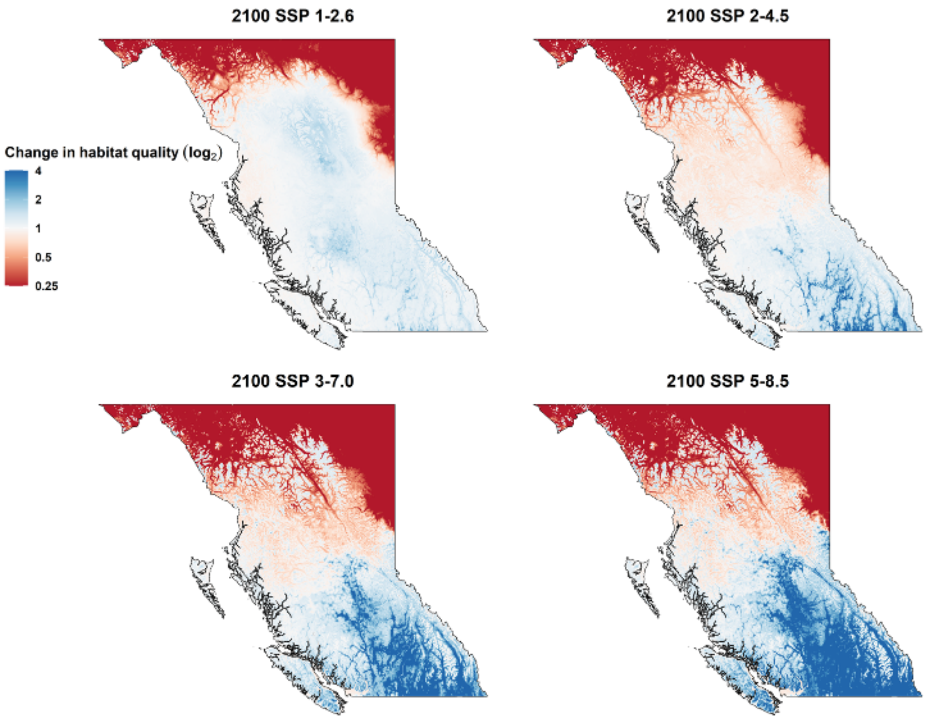

Fig 12. **Estimated change in habitat quality for cougars between 2020 and 2100, under different climate change scenarios.** Values less than 1 indicate a loss in habitat quality, while values above 1 indicate a gain in habitat quality. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve map readability and avoid excessively high predictions.

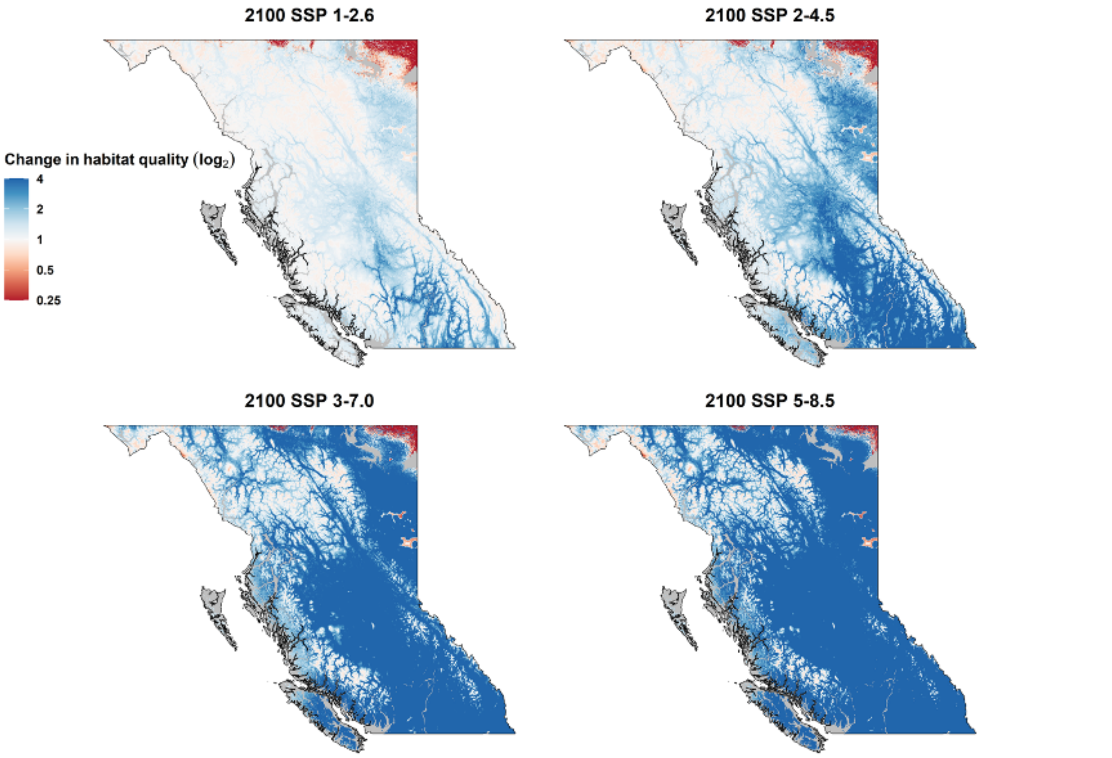

Fig 13. **Estimated change in habitat quality for elk between 2020 and 2100, under different climate change scenarios.** Values less than 1 indicate a loss in habitat quality, while values above 1 indicate a gain in habitat quality. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve map readability and avoid excessively high predictions.

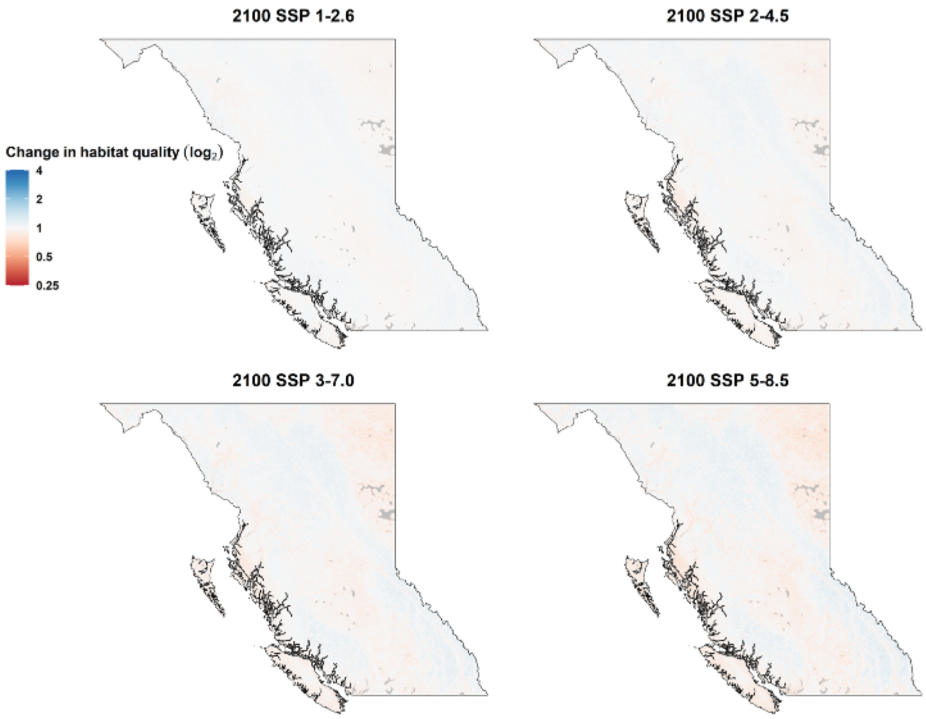

Fig 14. **Estimated change in habitat quality for grizzly bears between 2020 and 2100, under different climate change scenarios.** Values less than 1 indicate a loss in habitat quality, while values above 1 indicate a gain in habitat quality. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve map readability and avoid excessively high predictions.

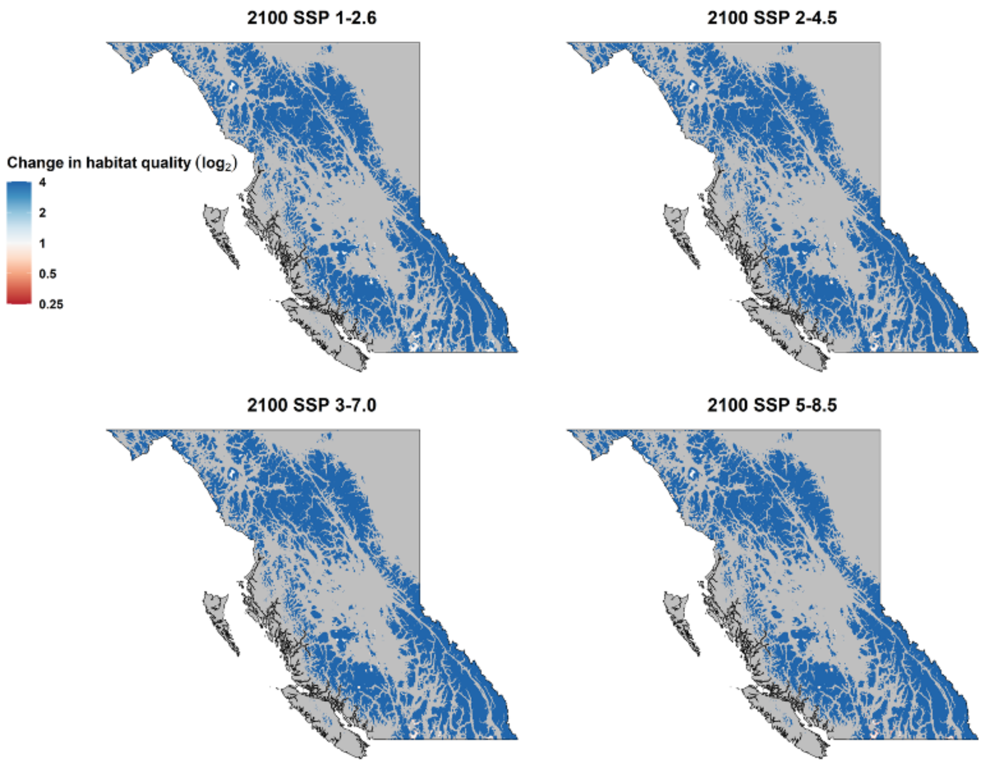

Fig 15. **Estimated change in habitat quality for mountain goats between 2020 and 2100, under different climate change scenarios.** Values less than 1 indicate a loss in habitat quality, while values above 1 indicate a gain in habitat quality. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve map readability and avoid excessively high predictions.

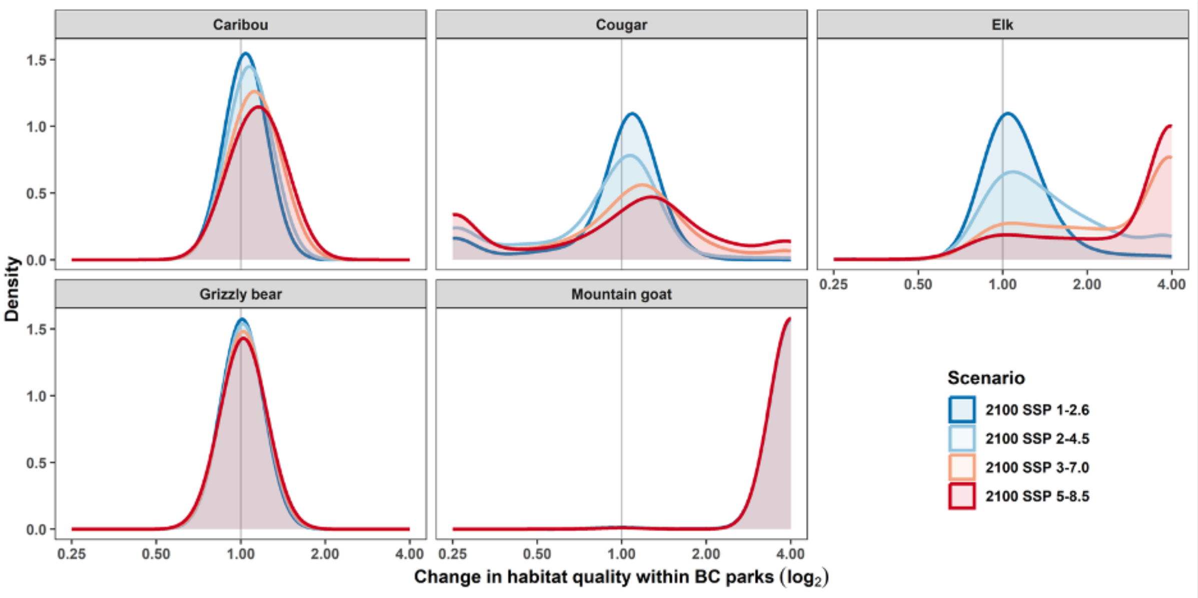

Fig 16. **Estimated change in habitat quality within BC parks and protected areas relative to 2020, under different climate change scenarios.** Values less than 1 indicate poor habitats, while values above 1 indicate good habitats. Values have been capped at a minimum of 0.25 and a maximum of 4 to improve readability and avoid excessively high predictions.

NCE / NON-NCE
STATEMENT OF ACCOUNT

Family Name, given name and Initial(s) of Grantee	**Program Name**	**Intern**	**Date**	**Year ending**
Noonan, Michael			**March 22, 2023**	**February 28, 2023**
Institution	**Project Title**		**University Account No.**	**Grant NO.**
University of British Columbia	**How climate change will shape the future of human wildlife conflict in B.C.'s protected areas**		**PQII GR023998 BCMENCCS 2022 Noonan**	

FUNDS AVAILABLE FOR CURRENT YEAR				
Balance of grant at close of previous year				$ -
Current Year Grant				$ 7,000.00
Federal Granting Agency authorized transfers				$ -
Total funds available for current year			**A**	**$ 7,000.00**
EXPENDITURES INCURRED FOR CURRENT YEAR				
1) Salaries to students (including benefits)	Canadian and Permanent Residents	Foreign		
a) Bachelor's	$ -	$ -	-	
b) Master's	$ 17,651.89	$ -	17,651.89	
c) Doctorate	$ -	$ -	-	
2) Salaries to non-students (including benefits)				
a) Postdoctoral	$ -	$ -	-	
b) Other	$ -		-	
3) Salary and benefits of Intern			-	
4) Professional and technical services/contracts			-	
5) Equipment (including power vehicles)				
6) Materials, supplies and other expenditures			368.91	
7) Not applicable (do not enter value)				
8) Travel			2,931.55	
9) Research time stipend (SSHRC Grantees only) -				
10) GRF, GGSF, SIG and ASU expenditures only -				
11) Other expenditures (eg., NCE administration costs) -			1,047.65	
Total expenditures incurred for current year			**B**	**$ 22,000.00**
Balance (A-B)				**$ (15,000.00)**
UNSPENT BALANCE				
Outstanding commitments at close of year			$ -	
SIGNATURES				

I hereby certify that the above statement is correct; that the expenditures conform to the general conditions and regulations governing grants as outlined in the Federal Granting Agency guide, and were for the purpose for which the grant was made.

Principal Investigator

23/03/2023

Date

I hereby certify that the expenditures summarized above were incurred and paid wholly on behalf of the grantee, and that the vouchers are available for monitoring purposes.

Financial Officer

March 23, 2023

Date

THE UNIVERSITY OF BRITISH COLUMBIA

Sponsor Invoice

Bill To:
British Columbia Ministry of Environment & Climate Change Strategy Attention:

Date:	03/23/2023
Invoice Number:	CI-0000168884
UBC Reference #:	AWD-021940/GR023998
Prime Award #:	TP23JHQ001
Subaward #:	
Payment Due:	04/22/2023

Project Title: How climate change will shape the future of human wildlife conflict in B.C.'s protected areas

Principal Investigator: Michael Noonan - CC00845 Biology I Biology I Provost and VP Academic - Faculties - UBCO

How climate change will shape the future of human wildlife conflict in B.C.'s protected areas	$15,000.00
CAD	$15,000.00

To pay by cheque, please attach the advice below and mail the cheque to the address stated.

Should you need to pay **by wire** or **EFT**, please email us at AR@finance.ubc.ca for wire transfer instructions. Ensure you include your Customer ID and/or invoice number as part of this transaction.

THE UNIVERSITY OF BRITISH COLUMBIA

INVOICE

Invoice No.:	CI-0000168884
Customer ID:	SPN-01365
Amount Due:	$15,000.00

Accounts Receivable
Finance Operations I Okanagan Campus
1157 Alumni Avenue
Kelowna, BC
V1V 1V7

Direct queries to: Deanna Dolhanty

Email:deanna.dolhanty@ubc.ca

Please make all cheques payable to “The University of British Columbia"

Late payment may be subject to interest charges