Indigenous-led analysis of important subsistence species response to resource extraction

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Abstract

Subsistence hunting, or "country food," is essential for Indigenous Peoples who face high food insecurity and is critical for Indigenous Food Sovereignty. For many First Nations of Canada, subsistence hunting is also inextricably linked to traditional conservation practices, as hunting is an important way of engaging with nature. In the boreal of Canada, large game such as moose (Alces alces) are a primary source of protein for many First Nations. However, resource extraction, including forestry practices and oil and gas extraction, has shifted large game distributions and affected the availability and abundance of food resources. Here, we used remote camera trap data and generalized linear models to evaluate moose habitat use and spatial-numerical response to possible stressors in north-central Alberta, including fire, harvest, oil and gas extraction, and other disturbances. We also examined the effects of human-caused stressors on habitat use by sex and age class data. The proportion of various land cover types and human land use for resource extraction were important in moose habitat use. Overall, adult moose avoided burned areas and grasslands. Notably, male, female, and young moose all used habitat differently and at different spatial scales. However, young moose (with their mothers) strongly selected natural forest disturbances such as burned areas but avoided human-created disturbances such as petroleum exploration "seismic" lines. Female moose with young attempting to maximize forage opportunities do not use human-disturbed forests in the same ways they use naturally disturbed areas. This also aligns with observations from Indigenous communities, which have linked human disturbance to declines in moose densities and displacement from traditional hunting grounds. Understanding and predicting shifts in large game distributions is critical to supporting Indigenous Food Sovereignty and identifying where industries operating on First Nations lands can better engage responsibly with First Nations.

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Conflict of Interest

The authors declare no conflicts of interest.

Author's Contributions

Kathleen Carroll: Conceptualization of Analysis, Formal Analysis, Methodology, Visualization, Writing – Original Draft Preparation; **Fabian Grey:** Conceptualization of the Methods, Data Curation, Writing – Original Draft Preparation; **Nicholas Anderso** n: Conceptualization of the surveys, Data Curation, Writing – Review & Editing; **Nelson Anderson** : Conceptualization of the surveys, Data Curation, Writing – Review & Editing; **Jason Fisher:** Conceptualization of Methods, Conceptualization of Analysis, Methodology, Supervision, Writing – Original Draft Preparation.

Data Availability Statement

All relevant data are cited in the text or are property of Whitefish Lake First Nation and other First Nations of Canada (see the CARE Principles for Indigenous Data Governance: https://www.gida-global.org/care). Please contact Whitefish Lake First Nation co-authors with further questions regarding access to these datasets.

Statement of Inclusion

Our camera trap study was conceived by members of the Whitefish Lake First Nation (WLFN), and our work brings together authors from the First Nation, where data were collected, with US and Canada-based scientists. All authors were engaged throughout the research and study design to ensure that their diverse perspectives were considered from the onset. Elders from WLFN were also consulted for their expertise and perspectives on moose ecology and changes in habitat use before and during the writing process.

Abstract

Subsistence hunting, or "country food," is essential for Indigenous Peoples who face high food insecurity and is critical for Indigenous Food Sovereignty. For many First Nations of Canada, subsistence hunting is also inextricably linked to traditional conservation practices, as hunting is an important way of engaging with nature. In the boreal of Canada, large game such as **moose (*Alces alces*)** are a primary source of protein for many First Nations. However, resource extraction, including forestry practices and oil and gas extraction, has shifted large game distributions and affected the availability and abundance of food resources. Here, we used remote camera trap data and generalized linear models to evaluate moose habitat use and spatial-numerical response to possible stressors in north-central Alberta, including fire, harvest, oil and gas extraction, and other disturbances. We also examined the effects of human-caused stressors on habitat use by sex and age class data. The proportion of various land cover types and human land use for resource extraction were important in moose habitat use. Overall, adult moose avoided burned areas and grasslands. Notably, male, female, and young moose all used habitat differently and at different spatial scales. However, young moose (with their mothers) strongly selected natural forest disturbances such as burned areas but avoided human-created disturbances such as petroleum exploration "seismic" lines. Female moose with young attempting to maximize forage opportunities do not use human-disturbed forests in the same ways they use naturally disturbed areas. This also aligns with observations from Indigenous communities, which have linked human disturbance to declines in moose densities and displacement from traditional hunting grounds. Understanding and predicting shifts in large game distributions is critical to supporting Indigenous Food Sovereignty and identifying where industries operating on First Nations lands can better engage responsibly with First Nations.

Keywords

Traditional ecological knowledge, moose, subsistence hunting, resource extraction, country food

Introduction

Indigenous communities globally have relied on subsistence hunting of local species since time immemorial. However, communities most reliant on local ecosystem services, such as subsistence hunting, are the most vulnerable to threats associated with biodiversity and species loss (Díaz et al., 2006). Subsistence hunting sometimes exacerbates the deleterious effects of human resource use on local systems and species (Luz et al., 2017), particularly in regions where hunting is non-selective, or species are already at high risk due to habitat loss, climate change, or pollution (Lindsey et al., 2013; Ripple et al., 2016; Theriault, 2011). However, the assumption that subsistence hunters solely maximizing harvest in the short-term rather than balancing foraging with conservation (i.e., considering the long-term benefits of sustainability) is incorrect (Alvard, 1994; Bodmer et al., 2020; VanStone, 1974).

In North America, subsistence hunting (also referred to as "country food") is closely linked with Indigenous conservation practices (Feit, 1973; Gottesfeld, 1994). These conservation practices range from limits on the number of individuals harvested to seasonal rotations of hunting grounds. In many parts of North America, ethical subsistence hunting (as determined by local Indigenous communities) is essential for food security (Theriault, 2011), supports Indigenous Food Sovereignty (Cidro et al., 2015), and has additional social, cultural, and spiritual importance (Van Oostdam et al., 2005). Across much of North America, Indigenous harvesting is declining despite the importance of subsistence hunting for Indigenous communities (Gilbert et al., 2021; Shafiee et al., 2022), in part due to cost (i.e., permits, equipment) and concerns about environmental contaminants in hunted food (Skinner et al., 2013), including cadmium, lead, arsenic, mercury, methylmercury, and other persistent organic pollutants (Chan et al., 2021). Many Indigenous communities have expressed resignation at the continued loss of their subsistence landbase (Westman & Joly, 2019).

Industrial resource extraction has resulted in rapid changes in the densities, distributions, and communities of traditionally hunted species across Canada. Energy development, specifically oil and gas extraction, is one of the primary causes of the decline of woodland caribou (*Rangifer tarandus; atihk* in Cree*)* across western Canada, (Hebblewhite, 2017). Some species, such as wolves and bears, benefit from and consistently use anthropogenically-created landscape features in Western Canada (Dickie et al., 2020; Dickie et al., 2017), increasing hunting efficiency (McKenzie et al., 2012). However, not all species benefit from these features, and many more actively avoid them (Fisher & Burton, 2018). Increases in predator population size due to landscape development (Latham et al., 2011) and the high prey-kill rates associated with anthropogenic features (Boucher et al., 2022) impact traditionally hunted species across Canada, leading to additional pressures on country food.

Moose (*Alces alces; moswa in Cree*) are an important, but declining, subsistence resource for the First Nations of Canada (Kuzyk et al., 2018; Natcher et al., 2021; Priadka et al., 2022; Ross & Mason, 2020), and there is widespread recognition that resource extraction impacts moose population dynamics, distributions, and predation rates in Alberta (Lamy & Finnegan, 2019; Neilson & Boutin, 2017). In the boreal, moose select for habitat that provides security when predator abundance is high (Ethier et al., 2024), and have lower occurrence in areas with pipelines, seismic lines, 3D seismic lines, unpaved roads, and new cutblocks (Dickie et al., 2022; Finnegan et al., 2023; Fisher, Grey, Anderson, Sawan, Anderson, Chai, Nolan, Underwood, Maddison, et al., 2021; McKay & Finnegan, 2023; McKay & Finnegan, 2022), which are often used by predators. This suggests that perceived predation risk is a strong driver of habitat selection, especially in areas with high human use. There are some potential benefits of human land use for moose, as forest cutblocks offer increased moose forage (Francis et al., 2021; Johnson & Rea, 2023). However, the effects of herbicide treatment and predation risks in these cutblocks might outweigh the benefits, as moose in high herbicide-use areas consume fewer forbs (Koetke et al., 2023). Finally, resource roads and trails associated with forestry and petroleum open access to previously remote areas, facilitating poaching, as has been observed by First Nation communities. Overall, the degree to which moose abundance and habitat use have shifted across traditional territories with increasing human land use is unclear, partly due to the challenges of monitoring moose populations in traditional hunting areas.

There are many inherent challenges in assessing moose abundance and distribution changes, primarily those associated with animal detection. While aerial surveys are often used in moose monitoring (Moll et al., 2022), these methods are challenging for Indigenous communities to employ (e.g., cost, time, and human safety risks associated with helicopters (Jones IV et al., 2006; Watts et al., 2010). Instead, remote cameras (also known as "camera traps" or "trail cameras") offer an effective means of sampling mammal populations when appropriately employed (Burton et al., 2015). Furthermore, camera trap studies are an effective approach for the coproduction of knowledge and Indigenous-led or co-created research (Fisher et al., 2021).

We sought to quantify the effects of human disturbance, fire, and land cover on moose relative abundance and spatial distribution using remote camera data to inform First Nation subsistence hunting. Specifically, our goal was to determine the relative impacts of forest harvest, linear features (e.g., roads and pipelines), oil and gas extraction sites, forest cover types, and age of burned areas on moose distribution. We also sought to compare the relative effects of these features by age and sex, as male and female moose (with and without young) may select different features at different scales when balancing predation risk with forage availability. We generally expected moose with higher nutritional needs (e.g., females with young) might use "riskier" (open) habitat when high-quality forage is available and that all moose would be strongly associated with aquatic features due to their dietary needs (Fraser et al., 1984). We also expected differences in habitat use by sex and age, primarily between young moose (young of the year and young of last year) and males due to different dietary and safety needs. We also expected that the spatial scales at which landscape features explain moose distribution (Holland & Yang, 2016) might differ by sex and age, as male moose may use broader areas, balancing foraging and seeking mates. In contrast, cows with young moose would likely be driven by the need for high-quality forage to support nursing young and offspring growth.

Methods

Study area

Our study area encompassed the Whitefish Lake First Nation (WLFN) traditional territory, a Treaty 8 Territory (Fumoleau, 2004) in north-central Alberta, Canada (Figure 1), characterized by expansive central mixedwood forests interspersed with many small lakes, bogs, wetlands, fescue grasslands, both open and closed conifer stands, and closed shrublands (AMBI 2020). The Indigenous co-authors have been living on this land for millennia, relying on its resources to survive in this cold and relatively nutrient-poor boreal landscape. Recent industrial modification in the form of forestry and oil and gas extraction – which we refer to as "anthropogenic landscape features" and "anthropogenic disturbance" – differs vastly from traditional stewardship techniques and is abundant across the landscape (Figure 1). The area has experienced forest harvest for a few decades. Harvested conifer stands are typically replanted and treated with glyphosate (N-(phosphonomethyl) glycine) via helicopter, resulting in notable changes to plant communities and resources used by the First Nation. Widespread petroleum extraction is a more recent and even more widespread and diverse disturbance (Pickell et al. 2013, Pickell et al. 2014, Pickell et al. 2015). WLFN Elders note that the drastic human-induced landscape changes on their Territory have resulted in precipitous declines of many important mammal and plant species. They also note that, like many other parts of Canada, increasing fire frequency is 'extreme' (Gaboriau et al. 2022), with new burn records being set in recent years (CIFFC, 2023; Canadian National Fire Database, 2023; but see Chavardès et al. 2022).

Camera Trapping

WLFN co-authors designed the research study, sampling sites were assigned based on a constrained random stratified design. The landscape was divided into four strata based on dominant canopy cover and hydrological conditions, and sites were randomly selected from these strata, with some constraints based on the logistics of access. Community members deployed 130 Reconyx$^{\text{TM}}$ Hyperfire 2 (Holmen, WI, USA) cameras between 2018 and 2023 (Figure 1). Of these cameras, 75 were deployed and active from December 2018 to April/May 2019, 25 more were added in March, and all 100 were active between March and November 2019. WLFN deployed an additional 30 cameras, which were active from June 2022 to July 2023. Cameras were placed *ca.* 1.5 m above ground at sampling sites. Sampling sites were active wildlife trails and camera sensors were set to "high sensitivity" to record one image with each heat-in-motion detection, with no programmed delays between photographs, adopting techniques used in Fisher and Burton (2018)**. WLFN staff and volunteers classified images to species by using TimeLapse2 Image Analysis software (** Greenberg et al., 2019)**. Of the deployed cameras, timelapse data and images were retrievable from 121 cameras (96 of the original 100 and 21 of the subsequent 30). Images were grouped across sampling periods for our analysis to ensure naïve occupancy was sufficiently large for meaningful results. Images were also categorized as**

male, female, young of the year (YOY), or young of last year (YLY) whenever possible.

Predictor Variables

We identified 30 predictor variables that were either previously linked to moose ecology or of interest to WLFN (Table 1). These variables fell into three broad categories: land cover, human features (or footprint), and burn area. Various land cover and human feature categories were combined based on their similar impacts (e.g., oil wells, gas wells, and other types of wells were all binned under "well") or structures/functions (e.g., bogs and wetlands). We z-scaled all predictors (mean=0, s.d. = 1) before checking for spatial autocorrelation (Zuur et al., 2010**). We then calculated the area covered by each predictor within different buffer sizes surrounding camera locations from 250 to 5000m radii, sensu** Fisher et al. (2011)

Habitat Model

To control for repeated captures of animals (e.g., a single moose being photographed repeatedly), we first binned moose detections daily, where each site was assigned a positive detection if any moose were captured that day or a negative detection (absence) if no moose were detected that day. We then binned data monthly to estimate moose site use, controlling for the number of days each camera was functional. The number of days moose were present and absent at each site was combined to generate the response variable. In this approach, we assumed that if a moose was not detected at a site within the years of sampling, we could reliably state it did not occur there – rather than assuming false absence as in an occupancy framework (MacKenzie et al., 2003**).**

Moose habitat use was examined using binomial family generalized linear models (GLM). Our predictor variables for each model included the 30 land cover, human features, and burn area variables detailed above. We summarize the area of each response variable by generating twenty buffers for each camera site, ranging from 250 m to 5000 m in diameter at 250-m intervals. Our GLM models were run across all sites using bidirectional stepAIC model selection (Zhang, 2016**). A top model and scale were then determined for all data and for each age or sex category examined. After determining a top model, we examined predictor variance inflation factors (VIFs; ensuring each was < 4), component plus residual plots (to check for missing polynomial relationships(** Fox et al., 2012**)), and residual versus leverage plots for top models. The estimate and standard error were then assessed for each variable in each model.**

Habitat Use by Age and Sex

After running the overall model with all moose data, we ran separate models for male, female (including those with and without calves), and young moose (YOY and YLY). We initially planned to analyze YOY and YLY separately, but these were grouped based on data limitations. Each age or sex model followed the same framework, used the same buffer sizes, and included the same variables as the overall moose model. These models were assessed using the same methods as the overall model.

Results

Moose Detections

WLFN's cameras provided over 8,000 moose images. When controlling for trapping days, the age and sex of moose detected varied across years (Figure 2). Female moose had the highest overall number of detections and were detected more in 2019 and 2023 than were males or young. Males had slightly more detections in 2018, and much higher detection than females in 2022. However, there were also many adults of unknown sex detected in 2022. The detections of young were highly variable across years, with many YOY detected in 2019, but none in 2018. Very few YLY were detected in any year, but 2023 had the high detection rates of YLY.

Habitat Model

Overall moose habitat use (including male, female, unknown adult, and young) was best explained by 22 variables, 13 (nearly 60%) of which were human footprint features, 5 of which were related to area burned, and the remaining 4 were land cover predictors (Figures 3, 4). Area burned (including areas burnt 0-5, 6-10,11-15,16-20, and 26-30 years ago) and fescue grasslands had negative associations with moose habitat use. Thus, all human features, including harvest, pipeline, wells, trails, roads, recreation, borrowpits, cultivation, facilities, mines, vegetated road edges, seismic, and transmission lines, all had positive (albeit often small) β estimates.

Models by Sex and Age

Male, female, and young moose selected different habitat features at different scales. Male moose selected habitat at the broadest scale of the three groups, with a best-fitting spatial scale of 4750 m radius, followed by females at 2500 m, and then young at 1500 m. We did not distinguish between females with and without calves in the female, as the habitat used by females with calves was captured in modelling young.

Nine of the fourteen predictors that best explained male moose habitat use were human footprint variables: recreation, residential, cultivation, clearings, borrowpits, facilities, mines, seismic lines, and wells (Figures 3, 4). Male moose were the only group with no burn area predictors in the top model. Instead, the remaining five predictors were land cover types: water, closed mixed or deciduous forests, bogs and wetlands, closed shrublands, and open conifer stands. Of all predictors, recreation areas had the largest β estimate and wells had the smallest. Only closed shrublands, mines, and open conifer stands had negative associations with male moose habitat use, whereas all other variables had positive associations (Figures 3, 4).

Female moose were the most detected (Figure 2) and selected habitat slightly differently than males (Figures 3, 4). Area burned (including areas burnt 11-15 and 16-20 years ago) was the strongest predictor of female moose, with strong negative effect sizes. Female moose avoided nearly all burned areas but had positive habitat associations with harvest, pipelines, and many other human features. Unlike males, females had positive associations with closed shrubland and mines.

Young moose, which had the lowest detection rate (Figure 2), had the strongest effect sizes of model predictors and the largest number of predictors that differed from the other groups (Figures 3, 4). Five of the 12 variables that predicted young moose habitat were human footprint variables. Young moose were the only group to have positive associations with burned areas (including areas burnt 11-15 and 16-20 years ago). Like female moose, young moose had positive associations with closed shrublands. However, there were two predictors not in the top female moose models where young moose differed from male moose, including facilities and seismic lines. Young moose strongly avoided both features, despite their very slight positive association with adult male moose use (Figures 3, 4).

Discussion

Industrial resource extraction has altered moose relative abundance and distribution across the nearly 10,000 km^2 of the Whitefish Lake First Nation territory, just as observed by elders and community members. Human footprint metrics explained variance in moose detections in all models, though often with very small effect sizes. However, the young moose model, where we expected to see strong selection for high-quality forage areas in open spaces, had the strongest negative relationship with anthropogenic landscape features (Figures 3, 4). The strong negative relationship between young moose and petroleum exploration “seismic” lines (Dabros et al., 2018) and industrial processing facilities (Fisher & Burton, 2018) supports the observations of Indigenous community members and reiterates the importance of both broad and local-scale impacts of human land use on boreal species important to Indigenous communities. Importantly, young moose strongly selected for slightly older burned areas, suggesting that early-seral forage generated by natural disturbance is important, but that human-caused disturbance (which also has ample early-seral forage vegetation (Routh & Nielsen, 2021)) is not equivalent to the young, open-canopy patches created by fire. Fire (or here, burned area) has a large and important role in boreal environments, but is rapidly shifting in size and severity across

Canada, impacting wildlife species (DeMars et al., 2019; Palm et al., 2022). The roles of both fire and human land use as strong drivers in moose habitat selection are well-known (DeMars et al., 2019; Dickie et al., 2020; Ethier et al., 2024; Fisher & Burton, 2018; Fisher & Wilkinson, 2005; Johnson & Rea, 2023), but we highlight the important distinction between open areas caused by fire, versus those caused by resource extraction, for young moose seeking high-quality forage. For traditional territories highly impacted by development, such as WLFN's territory, this has substantial consequences for food sovereignty.

Moose and Whitefish Lake First Nation

Empirical data show young moose strongly avoid seismic and facilities, which may in part explain WLFN community members' observations about declining moose populations in historic hunting grounds. Traditionally, WFLN has always hunted within the local area (ranging about 5-10 km) to harvest moose. Now, it takes 6 or 7 days of searching, and members must go further into the bush to harvest moose since the moose population is down and moose are using the landscape differently. Hunts taking longer and requiring further travel takes members away from their land, further eroding one of the key reasons members hunted. Extended travel times result in WLFN members spending large amounts of money on gas and food to go hunting and often must drive more than five hours. One of the consequences of this change, which WLFN is concerned about, is the loss of harvesting practices of the past. Traditionally, cows weren't harvested, but those practices aren't followed these days because members must take what they can when the opportunity comes (harvest when seen). Members recognize that taking a cow takes out all its future offspring. Thus, WLFN members feel they must bear the responsibility of relearning how and where to hunt anew. Another consequence is the loss of cultural knowledge for younger generations. Elders note that the younger generation is choosing not to hunt because the changing moose availability changes how it is used as a staple. This results in younger members not only missing out on learning how to hunt but also missing out on other important knowledge like how to track moose and how to look for moose forage and other animal signs.

The cultural practice of hunting is not the only loss from changing moose habitat. Members of WLFN note that moose are a very important source of food and are deeply tied to the health of the land, water, and plants. They note that if the overall environment is healthy, so is the moose, and so is WLFN. WLFN members view eating moose regularly as critical for community members to get naturally occurring minerals since moose eat many medicinal plants. As they see a decline in important plants due to post-harvest herbicide use, they recognize that lower-quality medicinal plants result in lower-quality moose. This issue is much broader than moose, though; warming lakes have resulted in more algae, removing plants that WLFN uses and moose eat. WLFN community members also have limited fishing due to mercury, and there are growing concerns over waterfowl health – all issues that contribute to less and less connection to the land and more reliance on Western staples.

Broader Implications for Indigenous Food Sovereignty

Identifying how industrial land-use impacts subsistence species is only one component of the much larger issues facing Indigenous communities and Indigenous Food Sovereignty efforts (Batal et al., 2021). The rising costs of hunting and food contamination concern Indigenous communities reliant on country food (Chan et al., 2021; Shafiee et al., 2022). These issues are only exacerbated by species declines and changes in how species occupy and use landscapes as human pressures and fires increase. Concerns over access to high protein sources, specifically moose for WLFN, are evident. Community members note the challenges associated with finding moose, a lack of wildlife tracks, and evidence of browsing in harvested areas despite the possibility that regenerating stands result in increased forage (see Koetke et al. (2023). Without access to subsistence species like moose, Indigenous Food Sovereignty is increasingly out of reach for Indigenous Peoples in these systems. Thus, it is critical for Indigenous Peoples to gain additional knowledge of how these human features are impacting species habitat use, which WLFN has done using surveys and remote cameras, and to be able to harvest moose when found. Supporting these efforts through the co-production of research based on data collection and questions led by WLFN is one critical component of supporting Indigenous Food Sovereignty.

The Importance of Coproduction of Research

The co-production of science between Indigenous communities and Western scientists, based on clear expectations and relationships with knowledge-holders (Adams et al., 2023; Huntington, 2000), can provide insights and ecological understandings that might otherwise be missed and facilitate cultural continuity (Skroblin et al., 2021; Thompson et al., 2020). However, there are still many barriers to weaving together Indigenous and Western ways of knowing that can hamper collaborations (Smith, 2021), such as biases that lead to a sense of the hierarchization of knowledge (Brook & McLachlan, 2005). These barriers are slowly being surmounted as converging and diverging perspectives and values are addressed through Indigenous-Western science partnerships (Bélisle et al., 2022). Excitingly, there is growing recognition that Indigenous-centered knowledge and Indigenous-led research are essential for conservation on traditional territories and across ecosystems more broadly (FIsher et al., 2021; Rayne et al., 2020). However, much must be done to build relationships with knowledge-holders and meaningful collaborations between those practicing Western science and Indigenous Peoples. Here, we have worked together to co-create a research program based on Indigenous knowledge of the land and changes to wildlife communities and add to a slowly growing body of like research. Finally, we urge industries operating on First Nations lands to better engage responsibly with First Nations and for Indigenous conservation and stewardship to be upheld in policy.

Acknowledgments

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Tables

Table 1. Predictor variables used in model development for moose camera data.

Category	Variable	Description
Land Cover	Exposed	Exposed soil
	Closed deciduous & mixed forest	Closed aspen/balsam poplar/birch and closed mixedwood
	Grassland	Fescue grassland
	Water	All water bodies
	Bogs and wetlands	Graminoid wetlands, shrubby wetlands, undifferentiated wetlands, an
	Open conifer forest	Open undifferentiated coniferous forests
	Closed shrubland	Closed upland shrub
	Closed conifer forest	Close pine, closed Engelmann/white spruce, and closed undifferentiat
Human Features	Transmission lines	Cleared corridors designated for the location of power transmission li
	Borrowpits	Excavation outside of the road right-of-way is made solely to remove
	Clearing	Human footprint features related to various industrial activities.
	Cultivation	Lands where the forest and/or shrubs have been removed to plant cr
	Facilities	Human footprint features related to various industrial activities.
	Mines	Human footprint features directly related to mining activities.
	Trails	Cleared corridors surfaced with dirt or low vegetation for human/veh
	Vegetated edges	Disturbed vegetation alongside road edges, railway edges including di
	Wells	Ground cleared for an oil/gas well pad where at least one well is curr
	Harvest	Areas where forestry operations have occurred (clear-cut, selective ha
	Recreation	Human footprint related to vegetated facilities and recreation.
	Residential	Residential developments with buildings for human inhabitance.
	Seismic	Cleared corridors created during hydrocarbon exploration.
	Seismic 3D	Cleared corridors created during hydrocarbon exploration.
	Pipeline	A line of underground and overground pipes, of substantial length an

Category	Variable	Description
	Roads	Non-vegetated, impermeable surfaces used for motorized vehicle or ai
Fire	Area burned (0-5 years)	Area burned between 2019 and 2023.
	Area burned (6-10 years)	Area burned between 2014 and 2018.
	Area burned (11-15 years)	Area burned between 2009 and 2013.
	Area burned (16-20 years)	Area burned between 2004 and 2008.
	Area burned (21-25 years)	Area burned between 1999 and 2003.
	Area burned (26 years to 29)	Area burned between 1995 and 1998. The shorter interval was based

Figures

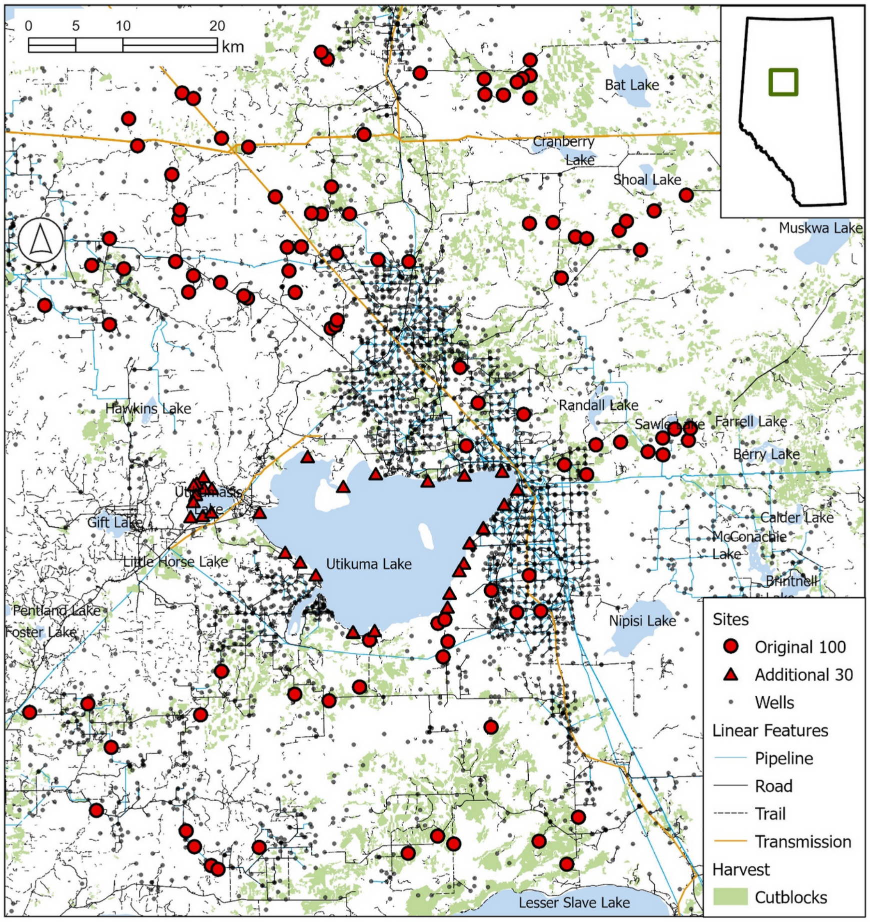


Figure 1. The study area, showing camera locations, well sites, and other human disturbances.

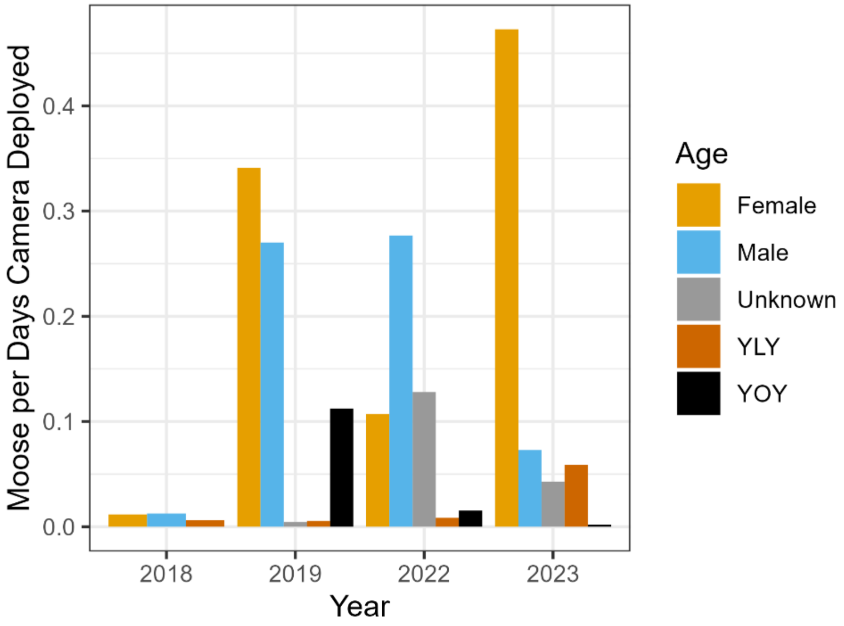


Figure 2. The count of adult male(s), adult female(s), adults of unknown sex, young of last year (YLY), and young of this year (YOY) identified each year from the camera array controlling for the number of trapping days cameras were deployed each year (total days for all cameras each year).

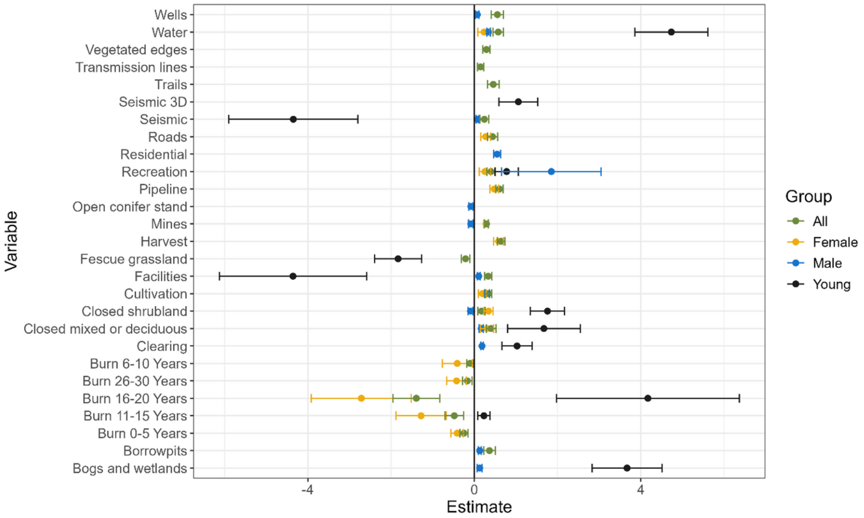


Figure 3. The effect size and direction of predictor variables on moose for all moose (including unknown adults; green) and for male (blue), female (yellow), and young (black) moose separately. Error bars are based on GLM model standard errors.

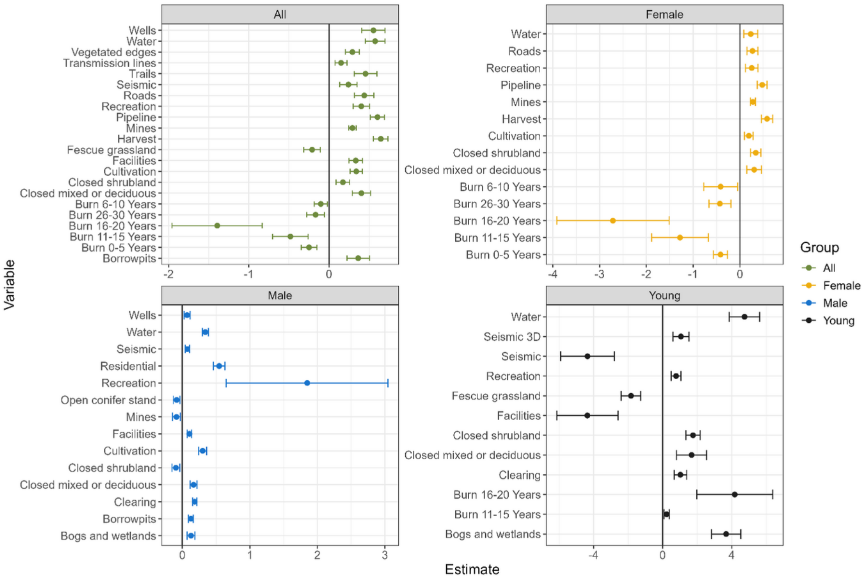


Figure 4. The effect size and direction of predictor variables with free axes on x for all moose (including unknown adults; green) and for male (blue), female (yellow), and young (black) moose separately. Error bars are based on GLM model standard errors.

References

Adams, M. S., Tulloch, V. J., Hemphill, J., Penn, B., Anderson, L. T., Davis, K., Avery-Gomm, S., Harris, A., & Martin, T. G. (2023). Inclusive approaches for cumulative effects assessments. *People and Nature* , *5* (2), 431-445.

Alvard, M. S. (1994). Conservation by native peoples: prey choice in a depleted habitat. *Human nature* , *5* , 127-154.

Batal, M., Chan, H. M., Fediuk, K., Ing, A., Berti, P. R., Mercille, G., Sadik, T., & Johnson-Down, L. (2021). First Nations households living on-reserve experience food insecurity: prevalence and predictors among ninety-two First Nations communities across Canada. *Canadian Journal of Public Health* , *112* (Suppl 1), 52-63.

Bélisle, A. C., Gauthier, S., & Asselin, H. (2022). Integrating Indigenous and scientific perspectives on environmental changes: Insights from boreal landscapes. *People and Nature* , *4* (6), 1513-1535.

Bodmer, R., Mayor, P., Antunez, M., Fang, T., Chota, K., Yuyarima, T. A., Flores, S., Cosgrove, B., López, N., & Pizuri, O. (2020). Wild meat species, climate change, and indigenous Amazonians. *Journal of Ethnobiology* , *40* (2), 218-233.

Boucher, N. P., Anderson, M., Ladle, A., Procter, C., Marshall, S., Kuzyk, G., Starzomski, B. M., & Fisher, J. T. (2022). Cumulative effects of widespread landscape change alter predator–prey dynamics.*Scientific Reports* , *12* (1), 11692. https://doi.org/10.1038/s41598-022-15001-3

Brook, R. K., & McLachlan, S. M. (2005). On using expert-based science to "test" local ecological knowledge. *Ecology and Society* ,*10* (2).

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Bayne, E., & Boutin, S. (2015). Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology* , *52* (3), 675-685.

Chan, H. M., Singh, K., Batal, M., Marushka, L., Tikhonov, C., Sadik, T., Schwartz, H., Ing, A., & Fediuk, K. (2021). Levels of metals and persistent organic pollutants in traditional foods consumed by First Nations living on-reserve in Canada. *Canadian Journal of Public Health* , *112* (Suppl 1), 81-96.

Cidro, J., Adekunle, B., Peters, E., & Martens, T. (2015). Beyond food security: Understanding access to cultural food for urban Indigenous people in Winnipeg as Indigenous food sovereignty. *Canadian Journal of Urban Research* , *24* (1), 24-43.

Dabros, A., Pyper, M., & Castilla, G. (2018). Seismic lines in the boreal and arctic ecosystems of North America: environmental impacts, challenges, and opportunities. *Environmental Reviews* ,*26* (2), 214-229.

DeMars, C. A., Serrouya, R., Mumma, M. A., Gillingham, M. P., McNay, R. S., & Boutin, S. (2019). Moose, caribou, and fire: have we got it right yet? *Canadian Journal of Zoology* , *97* (10), 866-879.

Díaz, S., Fargione, J., Chapin III, F. S., & Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS biology* , *4* (8), e277.

Dickie, M., McNay, S. R., Sutherland, G. D., Cody, M., & Avgar, T. (2020). Corridors or risk? Movement along, and use of, linear features varies predictably among large mammal predator and prey species. *Journal of Animal Ecology* ,*89* (2), 623-634.

Dickie, M., Serrouya, R., McNay, R. S., & Boutin, S. (2017). Faster and farther: wolf movement on linear features and implications for hunting behaviour. *Journal of Applied Ecology* , *54* (1), 253-263.

Dickie, M., Sherman, G. G., Sutherland, G. D., McNay, R. S., & Cody, M. (2022). Evaluating the impact of caribou habitat restoration on predator and prey movement.*Conservation Biology* , *37* (2), e14004. https://doi.org/https://doi.org/10.1111/cobi.14004

Ethier, C. A., Barnas, A. F., Boucher, N. P., Baillie-David, K., & Fisher, J. T. (2024). Lethal wolf control elicits change in moose habitat selection in unexpected ways.*The Journal of Wildlife Management* , e22620.

Feit, H. A. (1973). The ethno-ecology of the Waswanipi Cree: Or how hunters can manage their resources. In. McClelland and Stewart.

Finnegan, L., Hebblewhite, M., & Pigeon, K. E. (2023). Whose line is it anyway? Moose (Alces alces) response to linear features. *Ecosphere* , *14* (8), e4636. https://doi.org/https://doi.org/10.1002/ecs2.4636

Fisher, J. T., & Burton, A. C. (2018). Wildlife winners and losers in an oil sands landscape.*Frontiers in Ecology and the Environment* , *16* (6), 323-328.

Fisher, J. T., & Wilkinson, L. (2005). The response of mammals to forest fire and timber harvest in the North American boreal forest. *Mammal Review* , *35* (1).

Fisher, J. T., Anholt, B., & Volpe, J. P. (2011). Body mass explains characteristic scales of habitat selection in terrestrial mammals. *Ecology and Evolution* ,*1* (4), 517-528. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3287334/pdf/ece30001-0517.pdf

Fisher, J. T., Grey, F., Anderson, N., Sawan, J., Anderson, N., Chai, S.-L., Nolan, L., Underwood, A., Maddison, J. A., Fuller, H. W., Frey, S., & Mallory, M. (2021). Indigenous-led camera-trap research on traditional territories informs conservation decisions for resource extraction. *FACETS* , *6* , 1266-1284. https://doi.org/10.1139/facets-2020-0087

Fox, J., Weisberg, S., Adler, D., Bates, D., Baud-Bovy, G., Ellison, S., Firth, D., Friendly, M., Gorjanc, G., & Graves, S. (2012). Package ‘car’. *Vienna: R Foundation for Statistical Computing* , *16* (332), 333.

Francis, A. L., Procter, C., Kuzyk, G., & Fisher, J. T. (2021). Female moose prioritize forage over mortality risk in harvested landscapes. *The Journal of Wildlife Management* , *85* (1), 156-168.

Fraser, D., Chavez, E., & Palohelmo, J. (1984). Aquatic feeding by moose: selection of plant species and feeding areas in relation to plant chemical composition and characteristics of lakes. *Canadian Journal of Zoology* ,*62* (1), 80-87.

Fumoleau, R. (2004). *As long as this land shall last: A history of Treaty 8 and Treaty 11, 1870-1939* . University of Calgary Press.

Gilbert, S. Z., Walsh, D. E., Levy, S. N., Maksagak, B., Milton, M. I., Ford, J. D., Hawley, N. L., & Dubrow, R. (2021). Determinants, effects, and coping strategies for low-yield periods of harvest: a qualitative study in two communities in Nunavut, Canada. *Food Security* , *13* , 157-179.

Gottesfeld, L. M. J. (1994). Conservation, territory, and traditional beliefs: An analysis of Gitksan and Wet'suwet'en subsistence, Northwest British Columbia, Canada.*Human Ecology* , *22* , 443-465.

Greenberg, S., Godin, T., & Whittington, J. (2019). Design patterns for wildlife-related camera trap image analysis. *Ecology and Evolution* , *9* (24), 13706-13730.

Hebblewhite, M. (2017). Billion dollar boreal woodland caribou and the biodiversity impacts of the global oil and gas industry.*Biological Conservation* , *206* , 102-111.

Holland, J. D., & Yang, S. (2016). Multi-scale studies and the ecological neighborhood. *Current Landscape Ecology Reports* , *1* (4), 135-145.

Huntington, H. P. (2000). Using traditional ecological knowledge in science: methods and applications.*Ecological applications* , *10* (5), 1270-1274.

Johnson, C. J., & Rea, R. V. (2023). Response of moose to forest harvest and management: a literature review.*Canadian Journal of Forest Research* , *54* (4), 366-388.

Jones IV, G. P., Pearlstine, L. G., & Percival, H. F. (2006). An assessment of small unmanned aerial vehicles for wildlife research. *Wildlife society bulletin* ,*34* (3), 750-758.

Koetke, L. J., Hodder, D. P., Rea, R. V., Johnson, C. J., & Marshall, S. (2023). Landscape disturbance alters the composition and diversity of the diet of moose, a generalist herbivore. *Forest Ecology and Management* , *530* , 120760.

Kuzyk, G., Hatter, I., Marshall, S., Procter, C., Cadsand, B., Lirette, D., Schindler, H., Bridger, M., Stent, P., & Walker, A. (2018). Moose population dynamics during 20 years of declining harvest in British Columbia. *Alces: A Journal Devoted to the Biology and Management of Moose* , *54* , 101-119.

Lamy, K., & Finnegan, L. (2019). Moose Habitat and Populations in Alberta.

Latham, A. D. M., Latham, M. C., McCutchen, N. A., & Boutin, S. (2011). Invading white-tailed deer change wolf–caribou dynamics in northeastern Alberta. *The Journal of Wildlife Management* , *75* (1), 204-212.

Lindsey, P. A., Balme, G., Becker, M., Begg, C., Bento, C., Bocchino, C., Dickman, A., Diggle, R. W., Eves, H., & Henschel, P. (2013). The bushmeat trade in African savannas: Impacts, drivers, and possible solutions. *Biological Conservation* , *160* , 80-96.

Luz, A. C., Paneque-Galvez, J., Gueze, M., Pino, J., Macia, M. J., Orta-Martinez, M., & Reyes-Garcia, V. (2017). Continuity and change in hunting behaviour among contemporary indigenous peoples. *Biological Conservation* , *209* , 17-26.

MacKenzie, D. I., Nichols, J. D., Hines, J. E., Knutson, M. G., & Franklin, A. B. (2003). Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* , *84* (8), 2200-2207.

McKay, T. L., & Finnegan, L. A. (2022). Predator–prey co-occurrence in harvest blocks: Implications for caribou and forestry. *Conservation Science and Practice* ,*4* (12), e12847. https://doi.org/https://doi.org/10.1111/csp2.12847

McKay, T., & Finnegan, L. (2023). Ungulate occurrence in forest harvest blocks is influenced by forage availability, surrounding habitat and silviculture practices.*Ecological Solutions and Evidence* , *4* (2), e12226. https://doi.org/https://doi.org/10.1002/2688-8319.12226

McKenzie, H. W., Merrill, E. H., Spiteri, R. J., & Lewis, M. A. (2012). How linear features alter predator movement and the functional response. *Interface focus* ,*2* (2), 205-216.

Moll, R. J., Poisson, M. K., Heit, D. R., Jones, H., Pekins, P. J., & Kantar, L. (2022). A review of methods to estimate and monitor moose density and abundance. *Alces: A Journal Devoted to the Biology and Management of Moose* , *58* , 31-49.

Natcher, D., Ingram, S., Bogdan, A.-M., & Rice, A. (2021). Conservation and indigenous subsistence hunting in the Peace River region of Canada. *Human Ecology* ,*49* , 109-120.

Neilson, E. W., & Boutin, S. (2017). Human disturbance alters the predation rate of moose in the Athabasca oil sands. *Ecosphere* , *8* (8), e01913.

Palm, E. C., Suitor, M. J., Joly, K., Herriges, J. D., Kelly, A. P., Hervieux, D., Russell, K. L., Bentzen, T. W., Larter, N. C., & Hebblewhite, M. (2022). Increasing fire frequency and severity will increase habitat loss for a boreal forest indicator species. *Ecological applications* , *32* (3), e2549.

Priadka, P., Moses, B., Kozmik, C., Kell, S., & Popp, J. N. (2022). Impacts of harvested species declines on Indigenous Peoples' food sovereignty, well-being and ways of life: a case study of Anishinaabe perspectives and moose. *Ecology and Society* , *27* (1).

Rayne, A., Byrnes, G., Collier-Robinson, L., Hollows, J., McIntosh, A., Ramsden, M., Rupene, M., Tamati-Elliffe, P., Thoms, C., & Steeves, T. (2020). Centring Indigenous knowledge systems to re-imagine conservation translocations.

Ripple, W. J., Abernethy, K., Betts, M. G., Chapron, G., Dirzo, R., Galetti, M., Levi, T., Lindsey, P. A., Macdonald, D. W., & Machovina, B. (2016). Bushmeat hunting and extinction risk to the world's mammals. *Royal Society open science* , *3* (10), 160498.

Ross, P., & Mason, C. W. (2020). We Hardly Have Any Moose Around Here Anymore. *Arctic* , *73* (3), 368-385.

Routh, M. R., & Nielsen, S. E. (2021). Dynamic patterns in winter ungulate browse succession in the Boreal Plains of Alberta. *Forest Ecology and Management* ,*492* , 119242. https://doi.org/https://doi.org/10.1016/j.foreco.2021.119242

Shafiee, M., Keshavarz, P., Lane, G., Pahwa, P., Szafron, M., Jennings, D., & Vatanparast, H. (2022). Food security status of indigenous peoples in Canada according to the 4 pillars of food security: A scoping review. *Advances in Nutrition* , *13* (6), 2537-2558.

Skinner, K., Hanning, R. M., Desjardins, E., & Tsuji, L. J. (2013). Giving voice to food insecurity in a remote indigenous community in subarctic Ontario, Canada: traditional ways, ways to cope, ways forward. *BMC Public Health* ,*13* (1), 1-13.

Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., Taylor, W., Game, E. T., & Wintle, B. A. (2021). Including indigenous knowledge in species distribution modeling for increased ecological insights. *Conservation Biology* ,*35* (2), 587-597.

Smith, L. T. (2021).*Decolonizing methodologies: Research and indigenous peoples* . Bloomsbury Publishing.

Theriault, S. (2011). The food security of the Inuit in times of change: alleviating the tension between conserving biodiversity and access to food. *Journal of Human Rights and the Environment* , *2* (2), 136-156.

Thompson, K. L., Hill, C., Ojeda, J., Ban, N. C., & Picard, C. R. (2020). Indigenous food harvesting as social–ecological monitoring: A case study with the Gitga'at First Nation. *People and Nature* , *2* (4), 1085-1099.

Van Oostdam, J., Donaldson, S. G., Feeley, M., Arnold, D., Ayotte, P., Bondy, G., Chan, L., Dewaily, E., Furgal, C., & Kuhnlein, H. (2005). Human health implications of environmental contaminants in Arctic Canada: a review. *Science of the total environment* , *351* , 165-246.

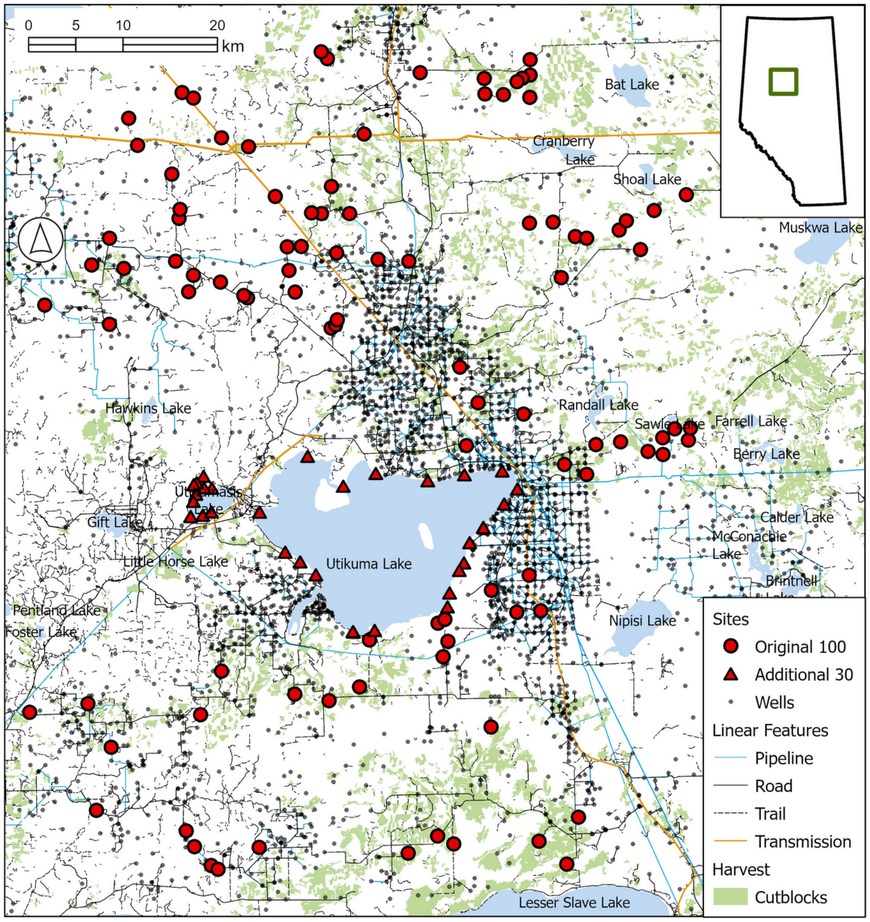
VanStone, J. W. (1974). Athapaskan adaptations: Hunters and fishermen of the subarctic forests. *(No Title)* .

Watts, A. C., Perry, J. H., Smith, S. E., Burgess, M. A., Wilkinson, B. E., Szantoi, Z., Ifju, P. G., & Percival, H. F. (2010). Small unmanned aircraft systems for low-altitude aerial surveys. *The Journal of Wildlife Management* , *74* (7), 1614-1619.

Westman, C. N., & Joly, T. L. (2019). Oil sands extraction in Alberta, Canada: A review of impacts and processes concerning Indigenous peoples. *Human Ecology* ,*47* (2), 233-243.

Zhang, Z. (2016). Variable selection with stepwise and best subset approaches. *Annals of translational medicine* , *4* (7).

Zuur, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* ,*1* (1), 3-14.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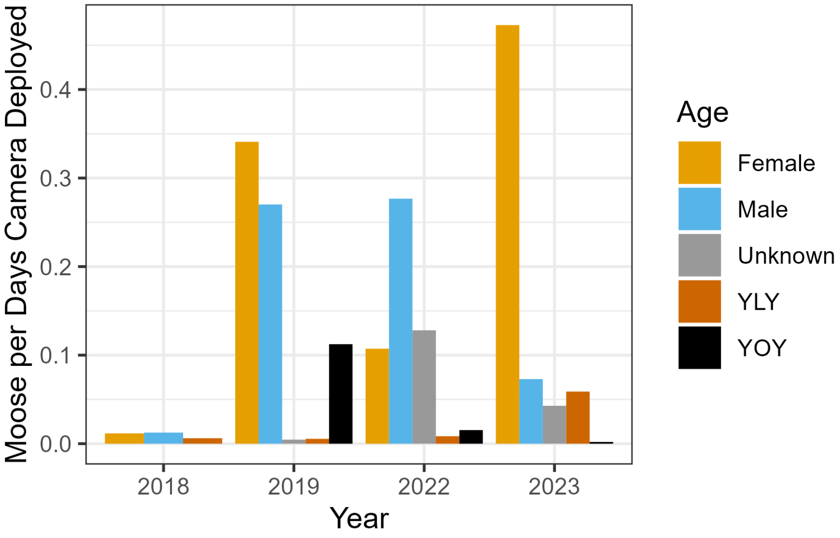
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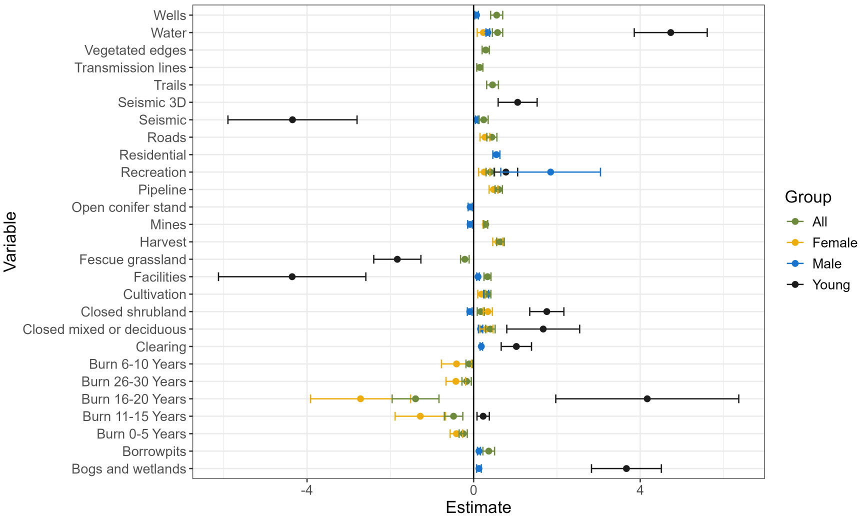
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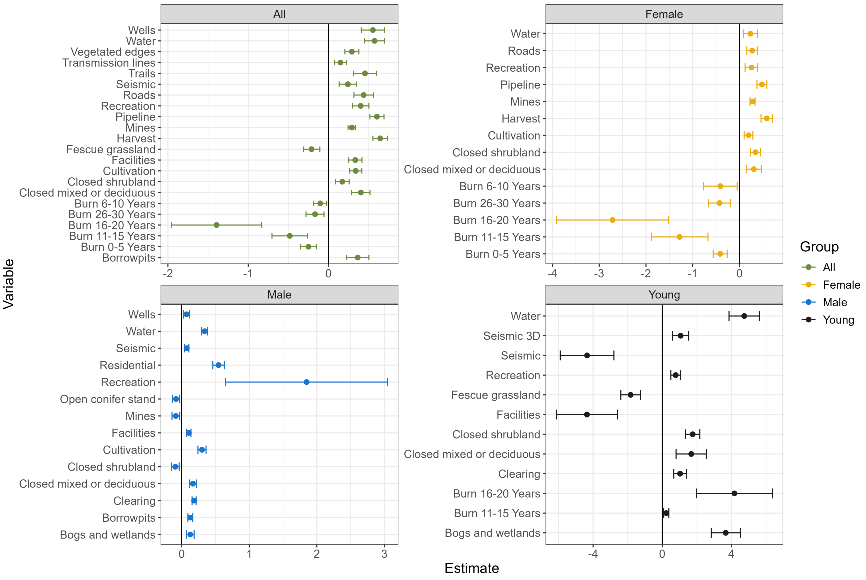
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