Influence of Aboveground Pipeline and Associated Factors on Movement of Winter-Active Boreal Mammals in the Alberta In-Situ Oil Sands

Authors: Charlebois, Michael L., Skatter, Hans G., Skatter, Sondre, and Kansas, John L.

Source: Northwest Science, 96(1-2) : 80-93

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/046.096.0105

Michael L. Charlebois[1], **Hans G. Skatter**, Omnia Ecological Services, 6244 Silver Ridge Drive NW Calgary, Alberta, Canada T3B 3S7

Sondre Skatter, 6225 Brookside Avenue, Oakland, California 94618

John L. Kansas, Kansas and Associates Ltd., 437-20 Discovery Ridge Close SW, Calgary, Alberta, Canada T3H 5X4

Influence of Aboveground Pipeline and Associated Factors on Movement of Winter-Active Boreal Mammals in the Alberta In-Situ Oil Sands

Abstract

Aboveground pipelines (AGP) associated with in-situ oil sands may restrict mammal movement, potentially increasing extinction probability and decreasing reproductive success. Our 12-year study used winter track count techniques to assess the response of winter-active mammals to AGP in northern Alberta, Canada. The primary questions were: which species were most prone to movement obstruction by AGP, facilities or natural factor(s)?; and which factor exerted the strongest influence on crossing likelihood?

A total of 2,068 trails of 12 different species were observed. All species crossed more than half of the time. Focal species crossed on average 80% of the time. Crossing likelihood of white-tailed deer (*Odocoileus virginianus*), ermine (*Mustela erminea*), coyote (*Canis latrans*), lynx (*Lynx canadensis*), and fisher (*Martes pennanti*) were significantly influenced by predictors including pipeline height, pipeline corridor width, infrastructure age, vegetation type, and proximity to infrastructure. Deer and lynx crossing likelihood was positively affected by pipe height. Deer, coyote, and ermine crossing likelihood was positively affected by age of pipe. Fisher and deer crossing likelihood was negatively affected by pipeline corridor widths. Our investigations show that most species cross AGP with high crossing frequencies of pipe heights, ranging from 130 cm to 160 cm.

These findings are important for impact mitigation because of the scarcity of published studies of wildlife movement responses to AGP, our inclusion of small and mid-sized carnivores, and our investigation of multiple factors. We highlight mitigation and design improvements, effects of pipeline corridor widths, and challenges posed by coupling infrastructure with pipelines, serving to reduce movement barriers and fragmentation.

Keywords: aboveground pipeline, winter wildlife monitoring, in-situ oil sands, wildlife movement, right-of-way

Introduction

Among the most significant natural resources of northern Alberta, Canada is the occurrence of extensive oil sands deposits. Oil sands lie beneath 142,000 km^2 of land in the boreal forest of Alberta (CAPP 2018). Due to the nature of these deposits, including their depth, it is estimated that only 20% can be extracted using open-pit mining methods (CAPP 2018). The remaining deeper reserves are only recoverable by in-situ extraction methods, which use drilling, steam injection, combustion, or other sources of heat injected into the reservoir to warm the bitumen (oil sand) so it can be pumped to the surface through recovery wells and transported using aboveground pipelines (AGP). Expansion of AGP networks has the potential to obstruct the movement of some wildlife species, including daily and seasonal movements (Dunne and Quinn 2009, Muhly et al. 2015), dispersal and long-distance range shifts (Dunne and Quinn 2009, Muhly et al. 2015), use of escape routes from natural and artificial catastrophes (Jordaan et al. 2009), and the exchange of genetic material (Dunne and Quinn 2009, Muhly et al. 2015). This ecological uncertainty has resulted in public, academic, and regulatory concern regarding the

[1] Author to whom correspondence should be addressed.
Email: mcharlebois@omniaeco.ca

potential fragmentation and movement effects of in-situ oil sands exploration and development on wildlife habitat and populations in Alberta's oil sands (Jordaan et al. 2009, Johnson et al. 2015, Pattison et al. 2016, De Mars and Boutin 2017, Rosa et al. 2017). Several wildlife studies have shown that habitat connectivity serves to maintain and increase population size and persistence time (Fahrig and Merriam 1985, Heinen and Merriam 1990, Beier 1993). Uninterrupted movement of individuals dispersing from high-quality habitat supporting source populations is key to long-term persistence of meta-populations (Noss and Harris 1986). Restricted movement to and from high-quality resource patches has been shown to increase extinction probability and decrease lifetime reproductive success for some terrestrial species that range widely (Muhly et al. 2015, Fahrig 2001).

Recent estimates indicate that in-situ methods account for approximately 50% of oil sands production (Alberta Government 2022). Rapid improvements to in-situ oil sands extraction technologies since the early 1990s have resulted in a substantial expansion and intensification of development of in-situ oil sands resources (Hein 2000, Schneider and Dyer 2006, Jordaan 2012). As such, in-situ methods of oil extraction are increasingly used to access subsurface bitumen and are characterized by associated infrastructure, including surface well pads, roads, processing facilities, and a network of AGP. This infrastructure is used to transport steam to producing pads, and extracted bitumen back to central processing facilities (CPF) (Jordaan et al. 2009, Muhly et al. 2015). Aboveground pipelines are necessary because of the variable temperatures within the pipeline, thus resulting in expansion and contraction preventing the pipelines from being buried (Dunne and Quinn 2009). The under-pipeline complex clearance in our study averaged 1.5 m but ranged from as low as 10 cm to as high as 6 m from the ground. The pipeline complex generally consisted of two or more parallel pipes, with an average overhead pipeline complex width of 3.4 m (from outer edge to edge). The diameter of individual pipe and the overall pipeline complex width did not vary along the length of the pipeline (Figures 1, 2).

Long-term monitoring studies aimed at investigating the immediate movement responses of boreal forest mammals to AGP and associated infrastructure are scarce. Two research studies have been published that pertain directly to mammal responses to AGP in the oil sands region of Alberta. Dunne and Quinn (2009) used snow tracking and remote cameras to assess the effectiveness of over-pipeline crossing structures. Over-pipeline crossing features are man-made structures that facilitate wildlife crossing over the AGP (Dunne and Quinn 2009). Dunne and Quinn (2009) describe these structures as steel sleeves measuring 19 to 25 m long and 3 to 4 m wide placed over the pipeline and then covered with topsoil and vegetation. Their focus was on large mammals, specifically moose (*Alces alces*) and deer (*Odocoileus* spp.), although additional information was collected on a pooled carnivore species group (gray wolf [*Canis lupus*], coyote [*Canis latrans*], and Canada lynx [*Lynx canadensis*]). They determined that a minimum threshold pipeline clearance of 140 cm was found to be necessary for adult moose to cross underneath AGP infrastructure. They observed that over-pipeline crossing structures facilitated movement across the pipeline and were used more than sections of elevated pipelines by all species. They also considered effects of pipeline age, spatial arrangement, and construction characteristics (e.g., height, width, and length). Of interest, given the variability in how their pipeline of study was built, was that some species demonstrated habituation to pipeline crossing structures and sections of elevated pipeline, resulting in increasing use of over-pipeline crossing structures over time. This finding is supported by research on wildlife use of the highway overpass structures in Banff National Park (Clevenger and Waltho 2000). The research by Dunne and Quinn (2009) was completed in the Peace region of the Alberta oil sands, which is a different landscape than the Athabasca/Cold Lake portion of the oil sands, being characterized by a more settled, human-dominated landscape than our study area.

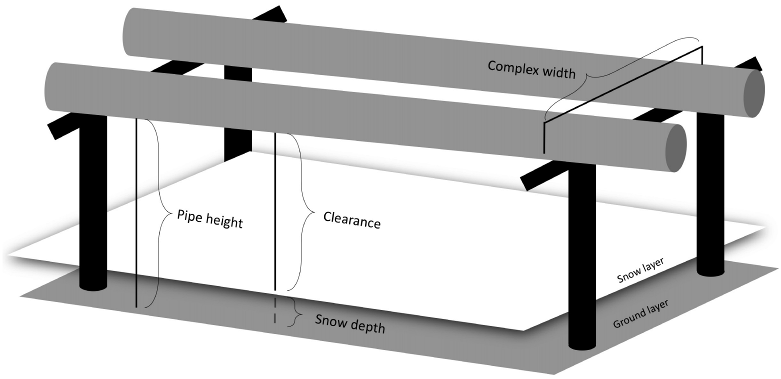

Figure 1. Aboveground pipeline height, width, and clearance diagram (height ranging from 10 cm to 6 m, and width = 3.4 m).

Figure 2. Example photographs showing A) above-ground pipeline paralleling forest; B) above-ground pipeline crossing a riparian area; C) above-ground pipeline paralleling a service road; D) grey wolf (*Canis lupus*) trail under the above-ground pipeline; E) Canada lynx (*Lynx canadensis*) crossing under the above-ground pipeline; and F) white-trailed deer (*Odocoileus virginianus*) crossing under the above-ground pipeline.

Muhly et al. (2015) used radio-telemetry and computer simulations to conclude that AGP crossing likelihoods of 15% to 60% were needed to maintain existing home-range size of woodland caribou (*Rangifer tarandus*). Their analysis indicated that a crossing rate of > 43% was necessary to maintain home ranges and fine-scale movements for > 50% of the simulations. The effect of permeability on home-range size and step length was non-linear, suggesting that small increases in permeability could provide a disproportionately greater benefit to caribou movement.

Our study used 12 years of replicated snow-tracking transect data to assess the immediate responses of a suite of winter active mammals to AGP infrastructure in northern Alberta. A total of 2,068 trails of 10 different mammal species were observed to interact with the AGP over the 12-year study period. Of the 12 mammal species observed, 3 were ungulates (moose, woodland caribou, and white-tailed deer [*Odocoileus virginianus*]), and 9 were carnivores (ermine [*Mustela erminea*], mink [*Mustela vison*], American marten [*Martes americana*], otter [*Lontra canadensis*],

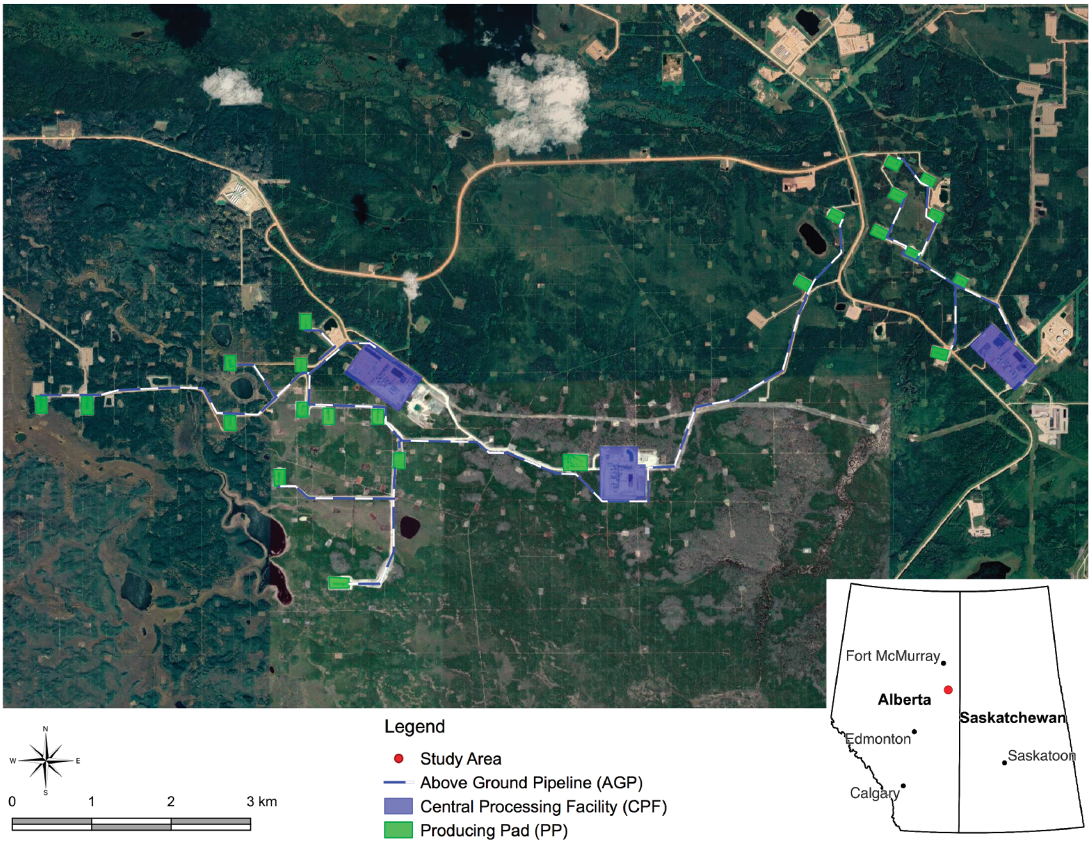

Figure 3. Location of study area and aboveground pipeline (AGP) within the Boreal Plain of northern Alberta, Canada.

coyote, red fox [*Vulpes vulpes*], Canada lynx, fisher [*Martes pennanti*], and gray wolf). Our two primary research questions were: 1) which species of boreal mammals are most (or least) obstructed by the presence of AGP and associated facilities?; and 2) which factors (e.g., pipe height versus right-of-way width) exert the strongest influence on crossing likelihood? We tested the predictive strength of several explanatory variables, including vegetation type, proximity to active processing facilities, age of the infrastructure, constructed infrastructure height, winter clearance related to accumulated snow depths, and overall right-of-way widths. Based on our findings, we suggest mitigation measures for future AGP infrastructure to reduce movement barrier and fragmentation effects on boreal mammals.

Methods

Study Area

The study area is in the Lower Athabasca Region of northeastern Alberta, approximately 140 km south-southeast of the city of Fort McMurray, Canada (Figure 3). The entire area lies within the Central Mixedwood Subregion of the Boreal Forest Natural Region (Beckingham and Archibald 1996). The Central Mixedwood Subregion is characterized by generally low topographic relief with rolling to undulating surface expression. Dominant landforms are ground moraine, glacial outwash, and organics (muskeg). Typical soils are Gray Luvisols and Organics, which underlie vegetation dominated by fens, bogs, closed deciduous and coniferous forest, and moist shrublands (Beckingham and

Archibald 1996). Characteristic land uses in the region include in-situ oil sands exploration and production, natural gas exploration and production, forest harvest, motorized recreation, hunting, fishing, trapping, and multi-use transportation corridors. The federally managed Cold Lake Air Weapons Range forms the southern boundary of the study area.

Field Surveys

We surveyed continuous winter trail count transects, following a snowfall event, along the length of the AGP between CPFs and producing well pads (Figure 3). Surveys were completed each year between 2007 and 2014, and 2016 to 2019, between December and April after fresh snowfalls of > 3 cm. Pipeline survey lengths ranged from 2.8 to 8.8 km during individual sample years as more pipeline became available for sampling. The survey route followed the outer edges of the AGP and adjacent right-of-way. All animal trail occurrences, except for unidentified mice (*Cricetidae*), red squirrel (*Tamiasciurus hudsonicus*), unidentified grouse (*Phasianidae*), and snowshoe hare (*Lepus americanus*), were recorded to species using print, stride, and straddle characteristics (Halfpenny et al. 1995). The geographic coordinates (Universe Transverse Mercator) were recorded at each location that a wildlife trail was observed using a hand-held geographic positioning system. Two observers jointly completed all surveys. One observer was adjacent to the pipe complex, which was located along one side of the cleared right-of-way, and a second observer walked the treeline along the far edge of the right-of-way. In this way, we characterized the noted behavior as described.

Individual wildlife trails observed crossing the transect path and interacting with the AGP infrastructure were classified as either having crossed or deflected from the infrastructure to the best of the observer's ability. Each event, when possible, was identified and classified. Successful crossings were characterized as animal trails that intersected the pipeline and continued over or under the pipeline and into the adjacent forest on either side of the corridor. Deflections were characterized as events where the animal paralleled or turned away at the edge of the corridor, the mid-point of the corridor, or at the AGP complex.

We measured a full suite of infrastructure characteristics as well as ecological conditions at each location where a trail crossing or a deflection occurred to understand the potential relationship between a suite of variables and crossing success/failure for the purposes of mitigating potential impacts to wildlife movement. The pipeline complex height, width, and under-pipe clearance and snow depth were measured and recorded where we recorded successful crossing or deflections (Figure 1). Pipeline corridor width (i.e., cleared area), ecosite phase type (ecological land classification), age of pipeline, distance to CPF, and nearest producing pad were other explanatory variables for which data were collected.

Data Analysis

Each observation was associated with a wildlife trail of an identified animal species in the immediate vicinity of a pipeline. Whether or not the trail crossed the pipeline constituted the binary response variable. Crossing likelihood for a species was also computed by adding all the crossings and then dividing by the number of trails (crossing and deflections) for that species.

A generalized linear model (GLM) (McCullagh and Nelder 1989) was used to build models of crossing likelihood for a species using a set of continuous and categorical predictor variables (Table 1). Since the model did not address the abundance of an animal species, just whether it crossed the pipeline or not given that it was found in the pipeline vicinity, there was no need to include predictor variables to correct for the general abundance of an animal species. The continuous variables described quantitative aspects of the pipeline, as well as the combination of snow depth and pipeline height (under-pipe clearance) (Table 1). From 2009, an additional variable, under-pipe clearance, was added to the sampling. A separate analysis for under-pipe clearance for the smaller data set ($n = 1{,}955$), including all other variables as covariables, was completed. The categorical variables describe contextual aspects of

TABLE 1. List of variables or factors considered for aboveground pipeline crossings in the Boreal Plain of northern Alberta, Canada. Pipe clearance (height from top of snow to the bottom of the pipe) was also a continuous variable investigated. However, this variable was not recorded in 2007 and 2008, resulting in 113 fewer observations. A separate analysis for under-pipe clearance for the smaller data set (n = 1,955), including all other variables as covariables, was therefore completed.

Type	Variable	Description
Categorical	Ecosite phase type (habitat)	Alberta ecological land classification type
	Nearest central processing facility	Type of processing facility
	Nearest producing pad	Name of nearest oil producing pad
Continuous	Pipe height (cm)	Height from ground to bottom of pipe.
	Distance to central processing facility (m)	Distance to large central steam and oil processing facility
	Corridor width (m)	Width of overall clearing where pipeline occurs
	Distance to nearest pad (m)	Nearest oil producing pad
	Age of pipe (years)	Time from pipe installment to the trail observation
	Road or pit next to pipe?	0 or 1, treated as continuous variable

the pipeline installation and the nearest associated processing plant, thus potentially affecting the animal's crossing behavior, although not directly impacting the difficulty of crossing the pipeline at any given location. Categorical variables were therefore included as nuisance variables.

Generalized Linear Model

The GLM model used a logit function as the canonical link function (logistic regression) since the response variable, crossing rate, was a binomial random variable. The logistic regression was run for each of the species with more than 50 trails. The 9 predictor variables (Table 1) were included as predictors in the full logistic regression model. Models were created for all possible combinations (512 possibilities, including only the constant term) of the 9 predictors in Table 1. Akaike's Information Criterion (AIC) was used for model selection, and for each species, the model with the lowest AIC was chosen.

The continuous predictor variables were standardized by subtracting the mean and dividing by the standard deviation. Data processing was completed in Matlab version R2018a using the Statistics and Machine Learning Toolbox with the fitGLM function (The MathWorks Inc. 2018).

Results

Species-Specific Crossing Likelihood

A total of 2,068 trails of 12 different mammal species were observed to interact with the AGP over the 12-year study period. Of the 12 mammal species observed, 3 were ungulates (moose, woodland caribou, and white-tailed deer), and 9 were carnivores (ermine, mink, American marten, otter, coyote, red fox, Canada lynx, fisher, and gray wolf). Seven of these species, including moose, woodland caribou, mink, American marten, otter, red fox, and gray wolf, were encountered sporadically in the vicinity of AGP and associated facilities, and as such were not the subject of statistical testing.

The number of trails observed by species and the percentage of successful crossings are summarized in Figure 4. Excluding the results observed for ermine and moose, the crossing rate for all species was greater than 70% (Figure 4). Focal species with 50 or more observations (with crossing rates) included: coyote (241/317 = 76.0%), white-tailed deer (903/1,087 = 83.1%), ermine (204/318 = 64.2%), fisher (43/51=84.3%), and Canada lynx (200/216 = 92.6%) (Figure 3).

Of the species with too few observations for statistical analysis, moose were observed to interact with the AGP only 19 times in 12 years of monitoring. All interactions resulted

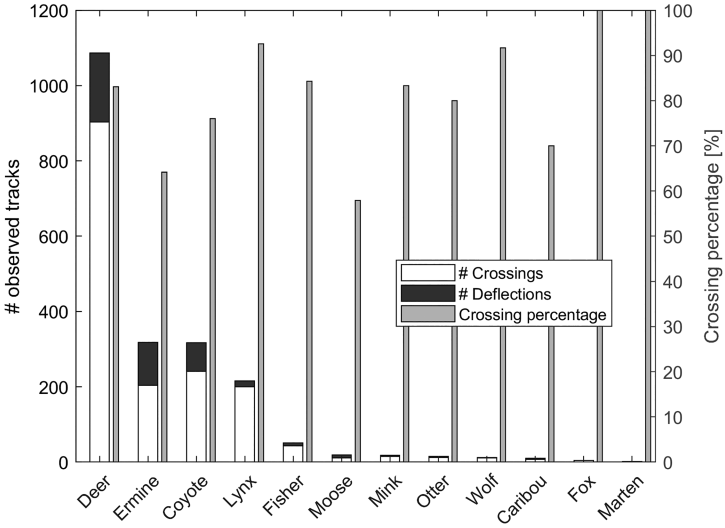

Figure 4. Number of trails observed and percent of successful crossings for an aboveground pipeline in the Boreal Plain of northern Alberta, Canada.

in successful crossings, with height of pipeline at crossing points ranging from 200 to 450 cm (mean = 290 cm). Of the 18 mink trails observed, 15 were successful crossings at pipeline heights ranging from 62 to 425 cm (mean = 215 cm). Otters were observed to cross the AGP 12 of 15 times at pipe heights ranging from 130 to 500 cm (mean = 291 cm). Crossings by mink and otter occurred mainly at locations where the AGP transected incised stream valleys and under-pipeline clearance was naturally large. Gray wolves crossed the AGP at 11 of 12 observations ranging in pipe height from 115 to 450 cm (mean = 183 cm). Woodland caribou were observed to cross the AGP 7 of 10 times at pipe heights ranging from 120 to 190 cm (mean = 156 cm). Red fox were observed to cross the AGP 4 times at pipe heights ranging from 85 to 140 cm (mean = 124 cm). Finally, American marten were observed to cross the AGP only one time at a height of 200 cm.

We also observed the following mean pipe heights at deflection sites: caribou (143 cm), deer (117 cm), coyote (121 cm), lynx (121 cm), wolf (140 cm), fisher (114 cm), ermine (142 cm), otter (130 cm), and mink (132 cm).

GLM Model Results

The selected factors in the GLM models included 5 continuous and 3 categorical predictor variables (Table 2). For each of the continuous predictors in the models, as listed in Table 2, the marginal predicted crossing likelihood are plotted over the range of the predictor variable in Figure 5. Under-pipe clearance was not selected when run on the smaller dataset, and therefore did not significantly affect predicted crossing rate. Pipe height positively affected 5 species, including coyote, deer, ermine, fisher, and lynx. Distance to CPF and distance to nearest producing pad positively affected fisher predicted crossing rate. Corridor width negatively affected deer predicted crossing rate. Age of pipe positively affected coyote, deer, ermine, and fisher predicted crossing rates.

Discussion

Our findings show that all winter-active boreal mammal species crossed the AGP at more than 50% of interactions. Further, our focal species, with greater than 50 observations, were noted to cross the AGP on average 80% of the time. Crossing likelihood of certain focal species was significantly influenced by a variety of specific predictors relating either directly to the pipeline itself (e.g., pipeline height and time since pipeline construction) or to the proximity and occurrence of other adjacent factors (e.g., pipeline corridor width, adjacent vegetation type, producing pads). These findings are important and useful for ongoing impact mitigation because of: 1) the scarcity of published studies of multi-species wildlife movement response to AGP in the in-situ oil sands; 2) our inclusion of crossing likelihood of small and mid-sized carnivores (ermine, fisher, lynx, and coyote) as opposed to focusing primarily on

TABLE 2. Significant factors and impact on aboveground pipeline crossing likelihood for selected species in the Boreal Plain of northern Alberta, Canada. The regression coefficients, using the standardized predictor variables for better comparison, are shown in the third column. N/A indicates that the predictor was categorical.

Species	Predictor included in GLM	Impact on crossing likelihood with confidence interval
Deer	Pipe height (cm)	0.91 (0.59, 1.23)
	Corridor width (m)	–0.59 (–0.83, –0.34)
	Age of pipe (years)	1.39 (0.99,1.8)
	Ecosite phase type (habitat)	N/A
	Nearest central processing facility	N/A
	Nearest producing pad	N/A
Ermine	Pipe height (cm)	0.23 (–0.09, 0.56)
	Age of pipe (years)	1.13 (0.66, 1.59)
	Ecosite phase type (habitat)	N/A
	Nearest producing pad	N/A
Coyote	Pipe height (cm)	0.20 (–0.08, 0.47)
	Age of pipe (years)	0.47 (0.17, 0.78)
Lynx	Pipe height (cm)	0.69 (0.06, 1.32)
Fisher	Pipe height (cm)	3.38 (0.55, 6.22)
	Distance to central processing facility (m)	2.28 (–0.24, 4.79)
	Distance to nearest producing pad (m)	3.99 (0.65, 7.33)
	Age of pipe (years)	2.49 (–0.35, 5.32)

ungulates (moose, caribou, and deer); and 3) our focus on investigating a range of factors other than pipeline height.

Ungulate Interactions with AGP

Dunne and Quinn (2009) used snow tracking to examine the influence of 5 environmental and pipeline configuration variables on AGP crossing likelihood of moose and deer. Moose crossing rates (*n* = 46) were 77.1% and 65.5% for AGP stretches with and without over-pipeline crossing structures, respectively. Moose preferred to cross at notably lower average pipeline clearances (143 to 256 cm) than for our current study (mean = 290 cm). Our findings support Dunne and Quinn's (2009) conclusions that pipeline clearance is a strong predictor of moose crossing sites. The limited numbers of moose occurrences in our study are likely a reflection of the known low and declining density of moose in the vicinity of the AGP and associated in-situ oil production facilities in the study area (Kansas et al. 2013), the primary causes of which are currently unknown (Chapman and Gilligan 2013). In addition, our study area was in a different landscape compared to that of Dunne and Quinn (2009) and may be of lower habitat suitability for moose.

Deer crossing rates (*n* = 312) from the Dunne and Quinn (2009) study were higher (90.3% to 94.9%) than our study (83.1%), and the average pipeline clearance at crossings (121 cm versus 152 cm) was lower. Dunne and Quinn (2009) reported that deer showed little aversion to crossing AGP and that deer crossing rates were uniform across a wide range of pipe height classes. Anecdotal reports for the region studied by Dunne and Quinn (2009) indicate that deer are more habituated to the presence of humans and infrastructure compared to our study area. However, this was broadly consistent with the findings of our study, and in addition to pipeline height, age of pipe had a significant influence on crossing likelihood by deer. Differences in the age of pipe and the overall corridor width associated with the AGP may explain the differences in average pipeline height at deer crossing sites between the two studies.

Dunne and Quinn (2009) reported an average pipeline corridor width of 40 m, which was considerably less than the 80 m average width observed in our study. The wider corridor for

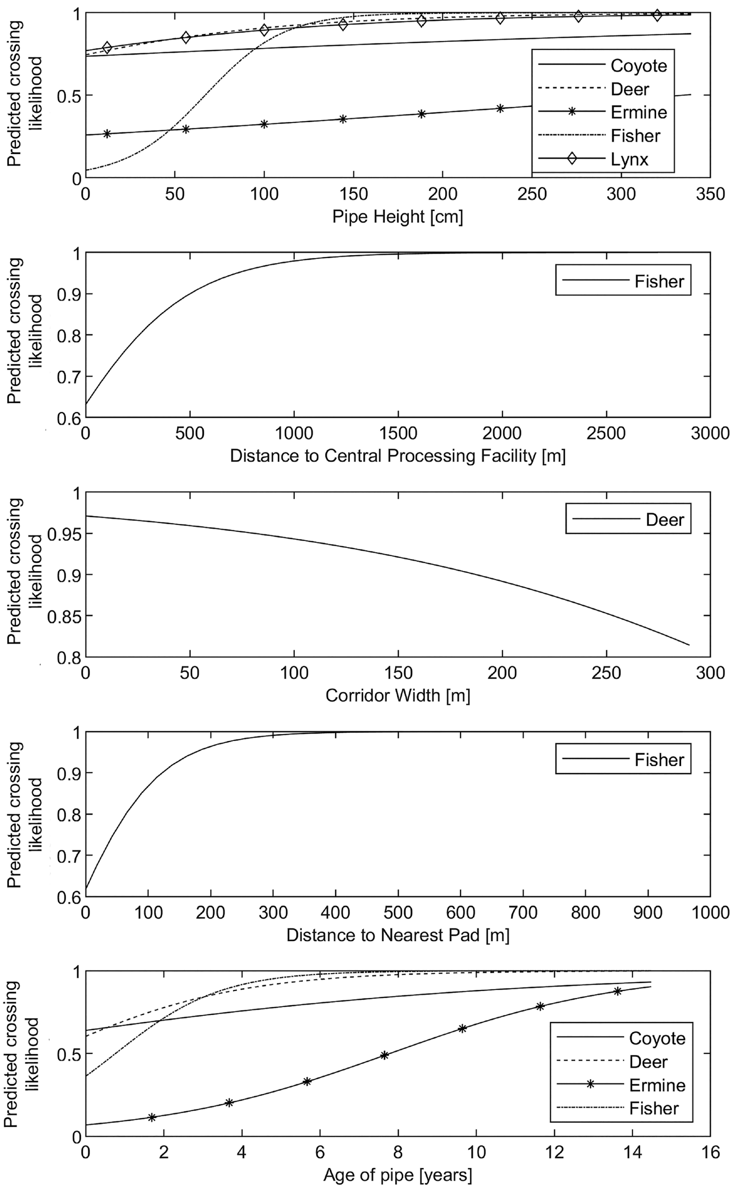

Figure 5. Predicted crossing likelihood for each of the predictor variables, averaged over the remaining model covariates such that the plot becomes a marginal probability.

our study results from the occurrence of more soil borrow pits, equipment lay-down yards, and roads along the AGP corridors. Dunne and Quinn (2009) sampled two stretches of AGP mainly in the winter of 2007. One section was a 5.5-km stretch of pipeline that was built at the beginning of the study in March 2006. The second was a 1.6-km section of pipeline constructed in 2000. The majority (54%) of deer/AGP interactions were recorded on the 5.5-km stretch just 7 to 12 months after construction. Trail intercepts for our study were at pipeline segments constructed an average of 4.5 years after construction (range = 1 to 10 years).

The higher crossing rates for deer observed by Dunne and Quinn (2009) could in part be attributed to lesser use of the pipeline corridors for foraging purposes and the proximity of other forage opportunities (e.g., cultivated fields). Herbaceous forage quantity was likely more abundant on our older pipeline corridors, which was evidenced by the numerous observations of foraging directly beneath and adjacent to AGP bundles. Deer crossing likelihood during our longer-term study decreased with increasing corridor width. Deer crossing likelihood generally increased with time since pipeline construction which may be a sign of habituation or a learned generational effect as described by research in Banff National Park (Clevenger and Waltho 2000, Clevenger et al. 2001). The older, forage-rich AGP stretches in our study may also have contributed to some level of habituation of deer to the AGP over time or provided a source of forage that was not otherwise available.

Mammalian Carnivore Interactions with AGP

Mid- to large-size carnivorous mammals are generally considered to have a heightened risk of local extinction from habitat fragmentation because of their large home ranges, low numbers, direct persecution by humans, and legal hunting and trapping (Weaver et al. 1996, Ray 2000, Crooks 2002). The nine species of mammalian carnivores encountering the AGP in our study represent a wide range of body sizes, prey preferences, habitat requirements, home-range sizes, reproductive productivity, and dispersal capabilities. Unique combinations of the above traits likely contribute to a given species' ability to tolerate the fragmentation effects of potential movement obstruction from AGP.

We are aware of only one peer-reviewed research paper that examined the influence of oil sands AGP on the movement of mammalian carnivores. Dunne and Quinn (2009) recorded and pooled interactions of three winter-active carnivores at AGP installations over a 2-year period. As was the case for our study, Dunne and Quinn (2009) observed relatively high (> 70%) crossing rates for coyote (96.1%, n = 104), wolf (88.0%, n = 25), and lynx (71.4%, n = 7). Their pooled observations found that the average carnivore crossing occurred at a pipeline clearance of 115 cm. Pooled carnivore crossing heights from Dunne and Quinn (2009) were notably lower than for our study. We observed mean AGP heights at crossings for coyote, lynx, and wolf of 145 cm, 162 cm, and 183 cm, respectively. Average crossing heights of fisher and ermine were 132 cm and 142 cm, respectively. AGP corridors in our study crossed several incised stream channels with pipeline heights at these locations ranging from 3 to 6 m. Carnivore travel along wooded stream corridors under AGP likely led to the increased average crossing heights. Mink and otter are semiaquatic furbearers that are tied closely to riparian and wetland habitats, which are uncommon along the AGP route.

AGP heights at deflection locations may provide a better understanding of pipeline crossing tolerances for carnivores. The high crossing likelihood and the similarity of pipeline height at deflections of the three most common meso-carnivores in the Alberta oil sands (coyote, lynx, and fisher) is of interest given the differences in their life history requirements and conservation status. Fisher and lynx are both listed as sensitive by the Provincial government, meaning they are not endangered but require active management or conservation to prevent them from becoming at risk. Habitat fragmentation, avoidance of extensive open habitats, and reductions in dispersal opportunities have been implicated as potential impact agents for both lynx (Bayne et al. 2008, Murray et al. 2008, Vanbianchi et al. 2017) and fisher (Proulx et al. 2004, Sauder and Rachlow 2014, Zielinksi 2014) populations. Despite the above conservation concerns, lynx crossing probability was not significantly influenced by clearance or width, distance to CPF or producing well pads, time since construction, ecosite phase type, or presence of roads and borrow pits along AGP corridors. Fisher crossing probability, on the other hand, was affected by pipe height, distance to central processing facilities, and producing pads as well as age of pipe. The avoidance of areas with anthropogenic features is not surprising. In a study conducted in the same geographic region, Skatter et al. (2020) noted that fisher avoided use of linear features (low impact seismic lines). Franklin et al. (2019) also noted reduced use of forest stands when forest harvest operations reduced stand retention levels below 50%.

The lower crossing likelihoods of coyote and ermine do not come as a surprise given the nature of these two species. Coyotes are a generalist forager with a primary preference for snowshoe hares and secondarily microtine rodents in the boreal forest (O'Donoghue et al. 1998, Buskirk 2000). Lower coyote crossing likelihood may be attributed to the use of edge habitat as a travel and/or forage opportunity, rather than it being perceived as a barrier. Oehler and Livaitis (1996) demonstrated that predators exhibited an affinity for edges during winter months, which coincided with our sampling. Ermine are a small-bodied carnivore with small home ranges that prefer early succession wet-graminoid and shrubland habitats where microtine rodents are abundant (Linnell et al. 2017). Neither ermine nor coyotes typically avoid open areas, and both are relatively tolerant of human activity and infrastructure (Ray 2000, Bayne et al. 2004). Like white-tailed deer, coyote and ermine were observed using the graminoid-rich pipeline corridor edges and verges, potentially as a food source. The crossing behavior of these two tolerant species appears to be framed within the context of their localized day-to-day foraging in preferred habitat as opposed to being forced to cross the AGP to access habitat patches on the other side of the corridor.

Management Considerations

The Alberta government published an AGP wildlife crossing directive (Government of Alberta 2014) for in-situ oil sands projects. The intent of the directive was: 1) to provide guidance to oil and gas operators in the construction and configuration of AGP to provide wildlife with reasonable opportunities for movement across AGP; 2) to establish a required minimum number of wildlife crossings per segment of pipeline; and 3) to set minimum design criteria for wildlife crossing opportunities. The directive indicates that over- and under-pipeline crossings can be used or constructed but that under-pipe crossings are preferred. The directive also indicates that crossing locations should consider wildlife habitat corridors and aim to preserve movement corridors for the full range of species expected to occur. The current minimum design standards would result in 4 crossings per 1000 m in woodland caribou range and 3 outside of caribou ranges. The net result would be that 8% of the total length of a pipeline in caribou habitat would provide an under-pipe crossing opportunity.

Although the Government of Alberta (2014) directive provides specific guidance for AGP under-pipe crossing height and spacing, it pays less attention to other variables that may influence wildlife crossing of AGP and their associated rights-of-ways. For example, long-term highway crossing research in Banff National Park by Clevenger et al. (2001) and Clevenger and Waltho (2005) determined that human use/presence in the immediate vicinity of bridge openings was a primary factor limiting use of bridges and culvert over- and under-passes by wildlife. Researchers have also determined that in busy areas, traffic volume, road widths, the amount of shrub/tree cover, line of sight, and openness of crossing structures all played significant roles in crossing effectiveness (Clevenger and Waltho 2000, 2005; Clevenger et al. 2001).

At the level of crossing success observed during our study, the AGP network that was sampled exceeded the minimum standards set out by the Government of Alberta directive (Government of Alberta 2014). Because of variable sampling lengths and ongoing pipeline construction, the transect sampling length varied somewhat between 2007 and 2019. From 2007 to 2010, 12.6% of the pipeline length provided the prescribed under-pipe clearance of at least 175 cm, between 2011 and 2014 this increased to 26%, and it was 24% in 2019. Whether or not the 8% total > 180 cm criterion (and the requirement for 4 crossing stretches of > 20 m per 1000 m segment) set out by the Alberta government would result in the same high levels of crossing success found in this study is unknown and warrants further investigation. Our finding that deer and fisher showed a higher crossing rate when the corridor was narrower is an important factor for consideration during design, construction, and post-construction mitigation/reclamation. Increased cover of trees/shrubs has been shown to be a significant factor in wildlife crossing success for many species, including hare species (Clevenger et al. 2001), ermine (Clevenger et al. 2001), bobcat (*Lynx rufus*) (Nj et al. 2004), coyote (Clevenger et al. 2001, Nj et al. 2004), and deer (*Odocoileus* spp.) (Nj et al. 2004).

In addition to gaining further understanding of winter-active animal response to AGP, we have gained some insight into how these species interact with other disturbances on this landscape. For example, the finding that fisher crossings were negatively impacted by increases in corridor width more than other factors demonstrates that conservation efforts for mitigating fragmentation needs to consider more than just pipeline configurations. Overall, for deer and fisher, wider corridors may act as a barrier to movement through either perceived lack of connectivity or perhaps reduced security.

Conclusions

Our long-term field investigations show that most winter-active boreal mammals (coyote, lynx, fisher, ermine, wolf, and white-tailed deer) in the Alberta oil sands readily cross AGP, with high crossing frequencies of pipe heights ranging from 130 cm to 160 cm. Riparian obligates such as moose, mink, and otter cross at greater average pipe heights because of the high clearances associated with incised stream valleys. It is anticipated that oil sands development that is focused on in-situ methods will result in a proliferation of AGP networks that have potential to impact boreal mammal movements. As such, it will be necessary for the Alberta Government AGP regulations to evolve and incorporate not only AGP height and crossing opportunity frequency standards, but also incorporate other best management standards such as crossing placement (e.g., by vegetation type or along game trails), assessment of the overall corridor configuration (e.g., overall width), and exploring opportunities for insulating sections of AGP corridor from other confounding factors (e.g., sections without roads). This last element may have to be considered more fully to evaluate the potential trade off from having a separate corridor and increased linear disturbance. Finally, while this study had a multi-species focus and could only be completed during snow-cover months, sample sizes for some species were too low to facilitate quantitative analysis, and others were simply not detected. Although our study detected the full range of winter-active species expected to occur, when compared to other work recently completed in the area (Skatter et al. 2020), future monitoring work is required to address less commonly detected species by using habitat-stratified surveys to target these species (e.g., woodland caribou) or by combining the monitoring data from similar or comparable projects (i.e., meta-analysis). Future studies should also consider the potential limitation of not detecting species that are avoiding AGP and their corridors altogether, thus avoiding detection. Further research could also build on our study by sampling different in-situ oil sand projects to facilitate multi-study comparisons to account for small study area sizes and potentially small number of detections.

Acknowledgments

This research was funded by Devon Canada Corporation (now Canadian Natural Resources Limited), Calgary, Canada. Over the years, several different people have contributed to the completion of field surveys. We thank field personnel including Greg Sanders, Emil Booyink, David Almanza, Cameron Barr, Javier Vargas, Greg Herman, Peter Balagus, Chloe Bryant, and Nathan Erik. We thank Richard Ashton for GIS support throughout the project including field maps, spatial analysis and figure production. We also acknowledge the contribution by Amit Saxena and Jeremy Reid of Devon Canada (now Canadian Natural Resources Limited) for support in project planning and logistical support and contributions to reviews of this manuscript. We also thank two anonymous reviewers for their comments to an earlier version of this manuscript.

Literature Cited

Alberta Government. 2022. Alberta oil sands facts and statistics. Alberta Energy. Edmonton, AB. Available online at https://www.alberta.ca/oil-sands-facts-and-statistics.aspx#:~:text=Alberta's%20oil%20sands%20has%20the,bbl%2Fd)%20in%202017 (accessed 10 March 2022).

Bayne, E. M., S. Boutin, and R. A. Moses. 2004. Are boreal forest mammals good indicators of cumulative effects? Project Reports 2003/2004. University of Alberta, Sustainable Forest Management Network, Edmonton.

Bayne, E. M., S. Boutin, and R. A. Moses. 2008. Ecological factors influencing the spatial pattern of Canada lynx relative to its southern range edge in Alberta, Canada. Canadian Journal of Zoology 86:1189-1197.

Beckingham, J. D., and J. H. Archibald. 1996. Field Guide to Ecosites of Northern Alberta. Natural Resources Canada, Canadian Forest Service. Northern Forest Centre. Edmonton, AB.

Beier, P. 1993. Determining minimum habitat areas and habitat areas for cougars. Conservation Biology 7:94-108.

Buskirk, S. W. 2000. Habitat fragmentation and interspecific competition: implications for lynx conservation. *In* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires (editors), Ecology and Conservation of Lynx in the United States, USDA Forest Service General Technical Report RMRS-GTR-30WWW, Rocky Mountain Research Station, Fort Collins, CO. Pp. 83-100.

[CAAP] Canadian Association of Petroleum Producers. 2018. What are the Oil Sands? Canadian Association of Petroleum Producers, 350, 7 Avenue, S.W., Calgary, AB. Available online at https://www.capp.ca/oil/what-are-the-oil-sands/ (accessed 10 March 2022).

Chapman, G., and J. Gilligan. 2013. WMU 517 Winefred Lake aerial moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) survey January 2013. Alberta Environment and Sustainable Resource Development Operations Division, Edmonton.

Clevenger, A. P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349.

Clevenger, A. P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47-56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Conservation Biology 121:453-464.

Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

De Mars, C. A., and S. Boutin. 2017. Nowhere to hide: effects of linear features on predator-prey dynamics in a large mammal system. Journal of Animal Ecology 87:274-284.

Dunne, B. M., and M. S. Quinn. 2009. Effectiveness of above-ground pipeline mitigation for moose (*Alces alces*) and other large mammals. Biological Conservation 142:332-343.

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100:65-74.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66:1762-1768.

Government of Alberta. 2014. Above ground pipeline wildlife crossing directive. Directive No. 7, Alberta Environment and Sustainable Resource Development, Public Land Management, Lower Athabasca Region. Available online at https://open.alberta.ca/dataset/0f2c4421-7a65-4656-a3ff-360e5c69836f/resource/7bb5dc14-884c-4ef8-be1e-dd1cf5900c58/download/2014-above-ground-pipeline-wildlife-crossing-directive-updated-feb-03-2014.pdf (accessed 10 March 2022).

Franklin, C. M. A., S. E. Macdonald, and S. E. Nielsen. 2019. Can retention harvests help conserve wildlife? Evidence for vertebrates in the boreal forest. Ecosphere 10(3):e02632.

Halfpenny, J. C., R. W. Thompson, S. C. Morse, T. Holden, and P. Pezendes. 1995. Snow tracking. *In* W. Zielinski, and T. Kucera (editors), American Marten, Fisher, Lynx, and Wolverines: Survey Methods for Their Detection, USDA Forest Service General Technical Report PSW-GTR-157, Pacific Southwest Research Station. Albany, CA. Pp. 91-163.

Hein, F. J. 2000. Historical overview of the Fort McMurray area and oil sands industry in northeast Alberta. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2000-05, Edmonton.

Heinen, K., and G. Merriam. 1990. The elements of connectivity where corridor quality is variable. Landscape Ecology 4:157-170.

Johnson, C. J., L. P. W. Ehlers, and D. R. Seip. 2015. Witnessing extinction—cumulative impacts across landscapes and the future loss of an evolutionarily significant unit of woodland caribou in Canada. Biological Conservation 186:176-186.

Jordaan, S. M. 2012. Land and water impacts of oil sands production in Alberta. Environmental Science and Technology 46:3611–3617.

Jordaan, S. M., D. W. Keith, and B. Stelfox. 2009. Quantifying land use of oil sands production: a life cycle perspective. Environmental Research Letters 4:1-15.

Kansas, J., A. Saxena, and M. Charlebois. 2013. Empirical EIA with long-term monitoring. Proceedings—33rd Annual Meeting of the International Association of Impact Assessment. Calgary, AB. Available online at https://conferences.iaia.org/2013/pdf/Final%20papers%20review%20process%2013/EMPIRICAL%20EIA%20WITH%20LONG-TERM%20WILDLIFE%20MONITORING.pdf (accessed 10 March 2022).

Linnell, M. A., C. W. Epps, E. D. Forsman, and W. J. Zielinski. 2017. Space use, movements, and rest site use by short-tailed weasels (*Mustela erminea*) in managed forests of western Oregon. Wildlife Biology 1:1-9.

The MathWorks Inc. 2018. MATLAB. Version 9.4.0 (R2018a). Natick, MA.

McCullagh, P., and J. Nelder. 1989. Generalized Linear Models, Second Edition. Chapman and Hall/CRC. London.

Muhly, T., R. Serrouya, E. Neilson, H. Li, and S. Boutin. 2015. Influence of in-situ oil sands development on caribou (*Rangifer tarandus*) movement. PLOS One 10:p.e0136933.

Murray, D. L., T. D. Steury, and J. D. Roth. 2008. Assessment of Canada lynx research and conservation needs in the southern range: another kick at the cat. Journal of Wildlife Management 72:1463-1472.

Nj, S. J., J. W. Dole, R. M Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499-507.

Noss, R. F., and L. D. Harris. 1986. Nodes, networks and MUMs: preserving diversity at all scales. Environmental Management 10:299-309.

O'Donoghue, M., S. Boutin, C. J. Krebs, G. Zuleta, D. L. Murray, and E. J. Hofer. 1998. Functional responses of coyotes and lynx to the snowshoe hare cycle. Ecology 79:1193-1208.

Oehler, J. D., and J. A. Litvaitis. 1996. The role of spatial scale in understanding responses of medium-sized carnivores to forest fragmentation. Canadian Journal of Zoology 74:2070-2079.

Pattison, C. A., M. S. Quinn, P. Dale, and C. P. Cattarall. 2016. The landscape impact of linear seismic clearings for oil and gas development in boreal forest. Northwest Science 90:340-354.

Proulx, G., K. B. Aubry, J. D. S. Birks, S. W. Buskirk, C. Fortin, H. C. Frost, W. B. Krohn, L. Mayo, V. Monakov, D. C. Payer, M. Santos-Reis, R. D. Weir, and W. J. Zielinski. 2004. World Distribution and Status of the Genus *Martes* in 2000. Springer Science Business Media. New York, NY. Pp. 21–76.

Ray, J. C. 2000. Mesocarnivores of northeastern North America: status and conservation issues. WCS Working Paper 15. Wildlife Conservation Society, Bronx, NY.

Rosa, L., K. F. Davis, M. C. Rulli, and P. D'Odorico. 2017. Environmental consequences of oil production from oil sands. Earth's Future 5:158-170.

Sauder, J. D., and J. L. Rachlow. 2014. Both forest composition and configuration influence landscape-scale habitat selection by fishers (*Pekania pennanti*) in mixed coniferous forests of the northern Rocky Mountains. Forest Ecology and Management 314:75-84.

Schneider, R., and S. Dyer. 2006. Death by a thousand cuts: impacts of in situ oil sands development. The Pembina Institute for Appropriate Development and Canadian Parks and Wilderness Society. Edmonton, AB.

Skatter, H. G., J. L. Kansas, M. L. Charlebois, and S. Skatter. 2020. Long-term snow track monitoring to understand factors affecting boreal forest mammal density in an expanding in situ oil sands area. Canadian Wildlife Biology and Management 2:107-131.

Vanbianchi, C., W. L. Gaines, M. A. Murphy, J. Pither, and K. E. Hodges. 2017. Habitat selection by Canada lynx: making due in heavily fragmented landscapes. Biodiversity and Conservation 26:3343-3361.

Weaver, J. L., P. C. Paquet, L. F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10:964-976.

Zielinski, W. J. 2014. The forest carnivores: marten and fisher. USDA Forest Service General Technical Report PSW-GTR-247. Pacific Southwest Research Station, Albany, CA.

Received: 13 January 2021
Accepted: 28 March 2022