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FINAL REPORT

# Grizzly bears and pipelines in Alberta: a provincial update

Prepared for
The Alberta Upstream Petroleum Research Fund (AUPRF)

Final Report
fRI Research Grizzly Bear Program

June 13, 2019

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**June 13, 2019**

# Executive Summary

This report, supported by the Alberta Upstream Petroleum Research Fund (AUPRF), provides the first analysis of long term grizzly bear data sets to investigate grizzly bear response to the linear footprints cleared for above or below ground pipelines in Alberta, hereafter referred to as pipeline right of ways (ROWs). Using an extensive set of GPS location data from collared grizzly bears, spanning 13 years (2005-2017) and six of Alberta's seven Bear Management Areas (BMAs), we were able to determine that both male and female bears were using pipeline ROWs and roads more than expected based upon availability, during spring, summer, and fall. Den sites used by female grizzly bears were on average 3.79 km from the nearest pipeline ROW, while den sites used by males were on average 6.79 km from pipeline ROWs. Our findings indicate that during the non-denning seasons, grizzly bears were selecting for younger pipeline ROWs (mean age since last construction~6.5 years), which are known to have a greater abundance of important bear foods such as clover and dandelion. Bears were also selecting for wider corridors containing two or more pipelines within the ROW. During the spring season (May 1$^{st}$ to June 15$^{th}$), sex-age class was also an important predictor of grizzly bear use of pipeline ROWs, with adult female bears more likely to use these features than other sex-age classes. A further examination of movement metrics of collared bears including movement rate, path straightness, and tortuosity (the opposite of path straightness) highlighted key differences in grizzly bear behaviours in areas of high versus low pipeline density. In all sex-age classes, bears reduced their speed and moved more tortuously in parts of their habitat with higher densities of pipelines, which is consistent with foraging behaviour. Additionally, in areas of high pipeline density, movement rates varied between seasons and were slowest and most tortuous in Season 3, which coincides with berry ripening. There is no evidence in our study that suggests bears are using these features to facilitate faster movement or hunting behaviours, and results from our movement analyses seem to further support our hypothesis that bears are selecting pipeline ROWs as important foraging areas.

The selection of pipelines ROWs by grizzly bears, particularly in the spring by adult females who may be supporting cubs, should be a key consideration for members of the petroleum sector in order to manage both human safety and the risk of human-caused grizzly bear mortality.

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# Background and Research Objectives

Understanding grizzly bear habitat use and response to natural resource extraction is essential for effective conservation and recovery efforts in Alberta. In addition, knowledge of grizzly bear response to these activities can provide opportunities for continuous improvement and the development of best practices in the natural resource sector. Ongoing activities related to natural resource extraction in grizzly bear habitat across Alberta has resulted in the creation of an abundance of new access features (e.g., roads, seismic lines, and pipelines) that have led to increasing levels of human access into grizzly bear habitat. The impacts of these resource extraction activities and developments on grizzly bears and their habitat is often challenging to understand. In 2012-2013, under AUPRF funding, the fRI Grizzly Bear Program contributed to this growing body of research by studying to what extent grizzly bears utilize the linear footprint cleared for above or below ground pipelines, hereafter referred to as pipeline right of ways (ROWs), in the Kakwa region of Alberta (located within Bear Management Area [BMA] 2; McKay et al. 2014). The study occurred in a landscape highly influenced by anthropogenic activities such as forest harvesting, mining, recreation, and oil and gas exploration and extraction. This work determined that grizzly bears used pipeline ROWs and roads significantly more than expected based on availability. A number of bear foods were shown to be more common on pipeline ROWs and edges compared to other available habitats, including dandelion, clover and ants, which are known to be important bear foods in the Kakwa region. There were differences between age-sex classes in use of pipeline habitat, with some sexual segregation of habitat use. Bears were more likely to use younger ROWs (mean age ~ 7 years) and ROWs in areas of lower pipeline and road densities.

Results from this previous project in 2012-2013 revealed a new understanding of grizzly bear selection of pipelines in BMA 2, but a significant knowledge gap remained. By incorporating another five years of grizzly bear collar location data and expanding the project scope to include six of Alberta's seven BMAs, this project aimed to build upon the initial work done in 2012-2013 and examine if previous findings remain consistent across the different environments within Alberta's grizzly bear range. Additionally, examining what activities grizzly bears engage in along pipeline ROWs, such as foraging or travelling, could have important implications for assessing the risk of grizzly bear mortality and/or human conflict along these features. As such, the objectives of this project were as follows:

1. **Investigate the degree to which grizzly bears select or avoid pipeline right of ways in relation to patterns of selection of other linear features such as roads and seismic lines.**
2. **Identify the site-specific ecological and landscape factors influencing the selection of pipeline right of ways by grizzly bears.**
3. **Examine movement rates and path straightness in areas of low and high pipeline density in order to better understand the behaviour grizzly bears engage in along pipeline right of ways.**

Each of the above objectives is examined within individual chapters of this report.

# Chapter 1: Selection of linear features by grizzly bears in Alberta

## 1.0 Introduction

With ongoing resource extraction activities and increasing levels of human use within grizzly bear habitat in Alberta (Linke et al. 2005, Berland et al. 2008), understanding grizzly bear habitat use and response to anthropogenic development is important for effective conservation and management. The main objective of our analysis was to determine how grizzly bears respond to pipeline ROWs. However, in investigating grizzly bear use of pipeline ROWs, it is also important to acknowledge the presence of many other types of linear features on the landscape. Therefore, we also investigated the degree to which grizzly bears select or avoid pipeline ROWs in relation to patterns of selection of other linear features such as roads and seismic lines. Selection or avoidance of anthropogenic features can vary with sex and season (Nielsen 2005, Berland et al. 2008, Graham et al. 2010, Roever et al. 2010) and these factors were also considered in our analysis of grizzly bear use of linear features.

## 1.1 Methods

### 1.1.1 Study Area

The study area was located in western Alberta across BMAs 2-7. Encompassing a total area of 70,233 $km^2$, this study area spans across a variety of natural regions including the boreal, foothills, Rocky Mountains, and parkland. Parts of this region are highly influenced by anthropogenic activities such as forest harvesting, mining, recreation, and oil and gas exploration and extraction (Linke et al. 2005, White et al. 2011). This study area also includes large tracts of federal and provincial protected areas such as the Wilmore Wilderness Area, and national parks including Jasper, Banff, and Waterton Lakes, where anthropogenic changes in habitat are less common.

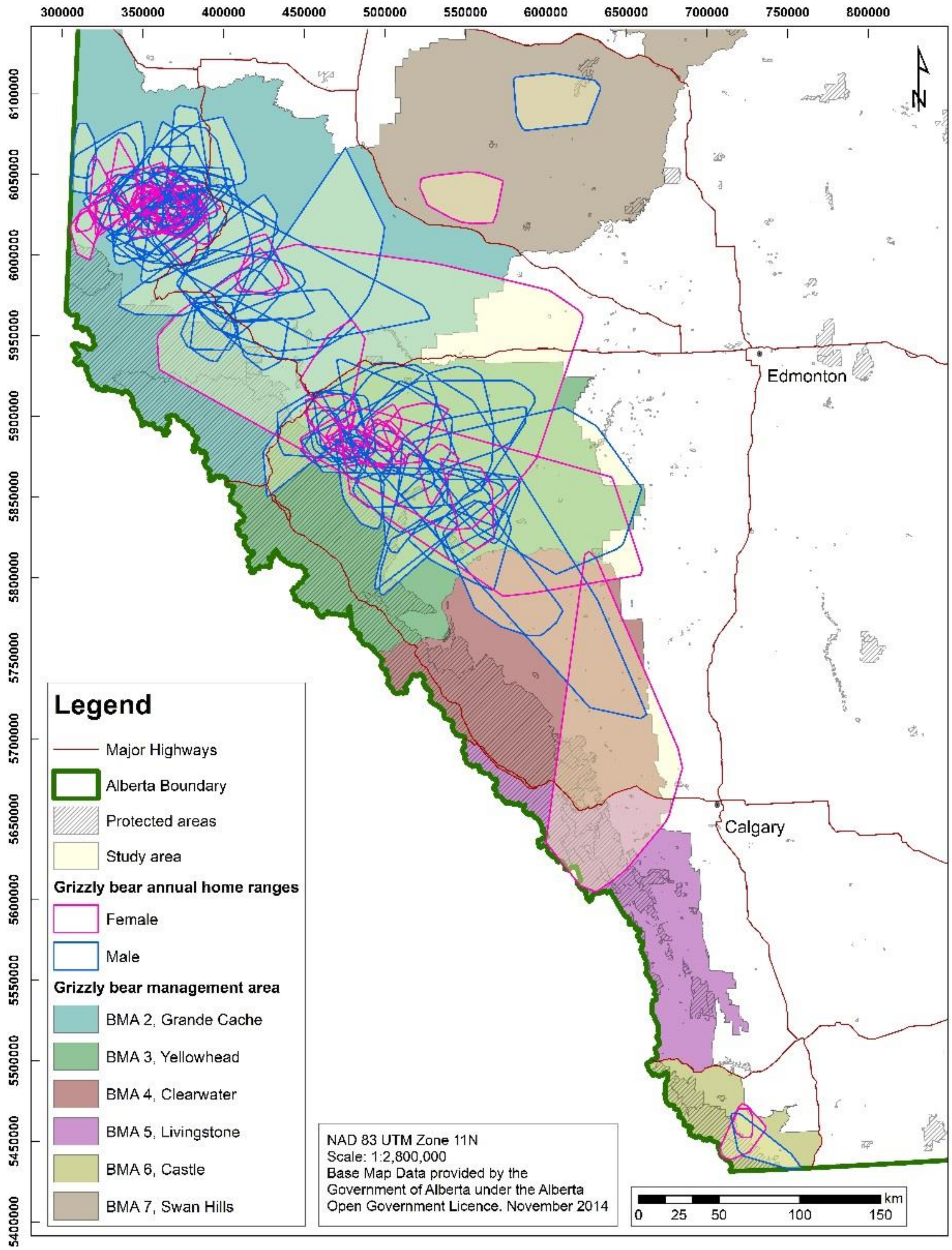


*Figure 1.2. Study area located in western Alberta, consisting of collared grizzly bears' annual home ranges (2005-2017).*

## 1.1.2 Grizzly bear location data

Location data were obtained from collared grizzly bears across BMAs 2, 3, 4, 5, 6, and 7 from 2005 to 2018. Bear capture methods included the use of leg-hold snares, culvert traps, and aerial darting from a helicopter. Capture procedures are described in Cattet et al. (2003a, 2003b). All trapping and collaring efforts met or exceeded the standards of the Canadian Council on Animal Care for the safe handling of bears, and capture protocols were approved annually by the University of Saskatchewan and the Government of Alberta animal care committees. Following research indicating long-term impacts of leg hold snares on grizzly bear health (Cattet et al. 2008), the use of this capture technique was stopped in 2008.

Bears were fitted with Televilt (Followit) or Telemetry Solutions GPS collars. Data from collars were collected remotely using monthly Very High Frequency (VHF) data upload equipment during fixed-wing aircraft flights during 2006 to 2012, and/or via satellite transmissions during 2011 to 2017. Televilt collars average 18 m and 265 m error distances for 3D and 2D locations respectively (Sager-Fradkin et al. 2007), and Telemetry Solutions collars are assumed to have similar accuracy. Due to the small spatial scale of linear features in our analysis, we removed 2D locations from our dataset. To further reduce spatial accuracy errors in collar data, locations with positional dilution of precision (PDOP) values greater than 10 were removed (D'Eon and Delparte 2005). Across the years of data collection, collars were programed for a range of GPS acquisition schedules, including hourly fixes, every 30 minutes, every two hours, 4 hour fixes, and 6 hour fixes. To reduce the potential bias in habitat selection analysis introduced by missed GPS fixes or low fix rates (Frair et al. 2004), we limited our dataset to individuals fitted with collars that obtained on average ≥12 fixes per day.

GPS locations were separated by established foraging seasons for our area, including hypophagia (Season 1; May 1$^{st}$ to June 15$^{th}$), early hyperphagia (Season 2; June 16$^{th}$ to July 31$^{st}$), and late hyperphagia (Season 3; August 1$^{st}$ to October 31$^{st}$; Nielsen 2005). Den site locations (when available) were studies separately. To ensure accuracy in seasonal analyses, we retained only individuals with location data present for a minimum of 50% of the days within each season.

Behavioural responses of grizzly bears to anthropogenic features has been shown to differ between age and sex (Graham et al. 2010, Laberee et al. 2014, McKay et al. 2014b), however, here we only included two classes (females and males), as age-sex class was included as an independent variable in our further investigation of parameters influencing the use of pipelines (see Chapter 2).

To identify the area available to each individual animal, annual home ranges were defined using Minimum Convex Polygons (MCPs; Nielsen et al. 2004a, Roever et al. 2008a). 100% MCPs were generated in R using the package adehabitatHR (V0.4.16; Calenge 2019). Random available locations were then generated within MCPs at an equal number to each individual's used locations in that year/season.

## 1.1.3 Linear features data

Linear pipeline data and road data (updated to August 2018) were obtained from Alberta's Digital Integrated Dispositions (AltaLis DIDs), a geospatial mapping product that maintains industrial surface activity information for the purposes of regulatory, permitting, and planning applications by industry, public, and private sectors. In order to temporally align linear features and grizzly bear location data, annual linear feature layers were created. With thousands of industrial activities compiled and maintained within the AltaLIS DIDs product by various Government of Alberta ministries tasked with managing different disposition types, identifying the specific construction dates that each feature appeared on the landscape is a daunting task. When available, the DIDs attribute identifying the date that activity on the feature was approved was assumed to be the date the feature was constructed and present on the landscape. When this attribute was not available, the date the company or individual applied for the activity served as the next best option for assigning a construction date. As most of these features are constructed during winter months (i.e. January-April, November-December), features with approval dates prior to April 1$^{st}$ for a given year were considered to be present (constructed) on the landscape during that year and any subsequent years. Approval dates on or after April 1$^{st}$ were only considered present on the landscape during subsequent years. All road and pipeline features within DIDs were presented in the form of polygons, with footprint widths specific to each feature. Given limitations in the DIDs data, powerlines were not included in this analysis.

Seismic line spatial data was obtained from the Alberta Biodiversity Monitoring Institute (ABMI) 2016 Human Footprint Inventory Program. Conventional seismic lines established between the 1950s and early 2000s are pervasive across the boreal forest, and natural regeneration of these features is slow (Oberg 2001, Lee and Boutin 2005, Van Rensen et al. 2015). In recent years, efforts have been made to reduce the footprint of these features, resulting in “low impact” seismic lines becoming the standard within the industry. Tigner et al. (2014) found that black bear use of seismic lines ≤2 m wide was not different than habitat use of undisturbed forest. Therefore, we did not consider low-impact seismic lines as significant linear features for the purpose of our analysis, and we chose to examine only conventional seismic lines. ABMI classifies all seismic lines constructed prior to 2005 as conventional, with widths averaging 6 m.

To account for collar error when determining bear presence on a linear feature, we buffered roads, pipelines, and seismic lines by 18 m on each side of the linear feature polygon (based on average error distances for Televilt collar 3D locations; McKenzie et al. 2009, 2012). Additionally, in Alberta, there is a tendency towards constructing corridors which include multiple linear features such as roads, pipelines, and powerlines, in combination. To simplify analysis, we constructed a hierarchy for multi-feature corridors in which the entire corridor was classified by the features with the highest precedence. Roads took precedence over pipelines when the two features coincided on the landscape in a single corridor. As the smallest features, seismic lines took the lowest priority, and were overridden by both pipelines and roads. Using the polygons generated by the above process, habitat within the study area was classified into four groups: roads, pipeline ROWs, seismic lines, and all other remaining habitat, broadly classified as non-linear.

In order to examine selection for or avoidance of linear features, the grizzly bear location dataset was further sub-selected to include only collared individuals where at least 5% of their locations for a given year/season occurred on linear features (roads, pipeline ROWs or seismic lines combined).

### 1.1.4 Analysis

For each bear/year included in analysis, we examined that years' fall denning location (when GPS collar data was available), and the proximity to the nearest pipeline, road or seismic line. Then, we compared grizzly bear collar locations from the non-denning season with random or available locations to assess habitat selection for roads, pipelines, seismic lines, and non-linear habitat. Analyses were evaluates in the third-order scale (Johnson 1980) following a "design III" approach, where the individual identity of the animal is maintained for the use and available sample (Thomas and Taylor 1990). Manly Selection Ratios were calculated for female and male grizzly bears across three seasons: hypophagia (Season 1), early hyperphagia (Season 2), and late hyperphagia (Season 3). This index takes into account the proportion of used locations occurring on roads, pipeline ROWs, seismic lines and non-linear habitat, in relation to the availability of each of these habitat types in each individuals' environment. A value greater than 1 indicates positive selectivity for that feature, while a value less than one suggests avoidance of that feature. All analyses were performed in RStudio (v1.1.423), using the package adehabitatHS (v0.3.13).

## 1.2 Results

In total, 32 female and 49 male grizzly bears were included in the analysis, with a total of 317,935 GPS collar locations (Table 1.1).

*Table 1.1. Sample size of bears and GPS locations included in analysis, by sex and season.*

| | Number of unique bears included | | Number of GPS collar locations | |
|---|---|---|---|---|
| **Season** | **Female** | **Male** | **Female** | **Male** |
| 1 | 20 | 30 | 29,297 | 34,395 |
| 2 | 27 | 41 | 53,199 | 62,328 |
| 3 | 29 | 27 | 79,401 | 59,315 |

When examining denning locations, our analysis consisted of 38 known den sites from 24 female grizzly bears, and 23 den sites from 21 males. On average, females selected den sites closer to pipeline ROWs, roads, and seismic lines, compared to males (Figure 1.1). Den sites selected by females were on average 3.79 km from pipelines (+/- 0.83 km), while den sites selected by males were on average 6.79 km from pipelines (+/- 2.22 km; Figure 1.1). These values are related to den site selection distances to established pipelines.

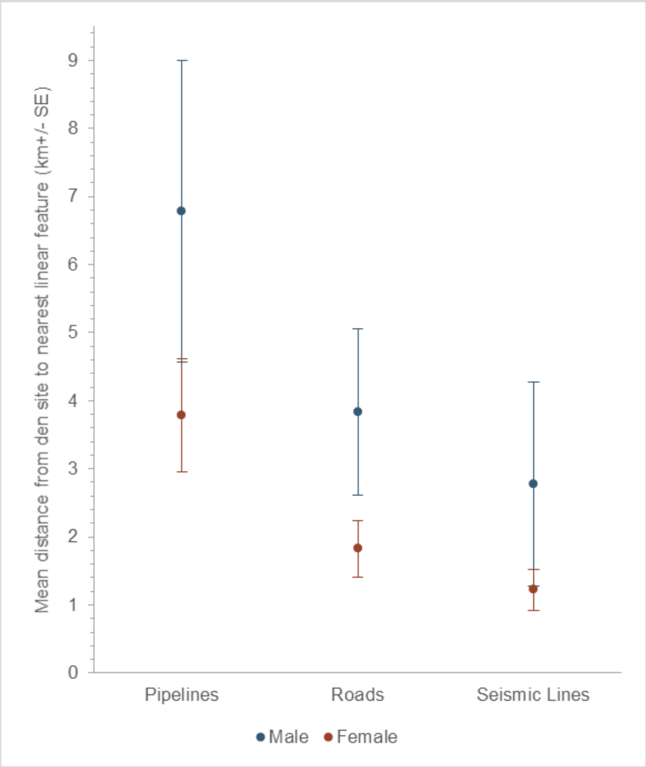


*Figure 1.1 Mean distance (km) of den sites used by male and female grizzly bears to the nearest pipeline, road, and seismic line (+/- standard error).*

Selection of pipelines, roads, seismic lines, and non-linear habitat varied between sexes and seasons (Figure 1.2, Figure 1.3). For females, Manly selection ratio values indicated selection for pipelines in Season 1 (1.15, confidence interval [CI]= 0.61 – 1.7), Season 2 (1.38, CI= 0.76 – 2.0), and Season 3 (1.28, CI= 0.80 – 1.75), although values did not differ significantly from 1 (Figure 1.2). For males, pipelines were significantly selected for in in Season 1 (1.69, CI= 1.06 – 2.33), and selection was indicated Season 2 (1.45, CE= 0.97 – 1.93), and Season 3 (1.24, CE= 0.81 – 1.66), although values did not differ significantly from 1 (Figure 1.3).

Roads were significantly selected for in Season 2 by both females (1.88, CI= 1.09 – 2.66) and males (1.66, CI= 1.17 – 2.15), with indications of both sexes selecting for roads in Season 1 and 3, although values did not differ significantly from 1. Females significantly avoided seismic lines across all three seasons (Figure 1.2). Males avoided seismic lines in Season 1 and 2, with indications of avoidance in Season 3 (although not significant; Figure 1.3). Both females and males showed no significant selection or avoidance of non-linear habitat across the three seasons examined.

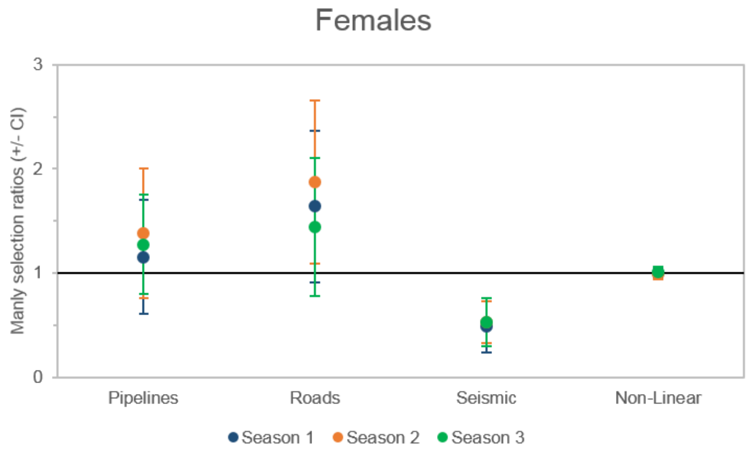


*Figure 1.2. Manly selection ratios for different linear feature types by female grizzly bears. Where the value is larger than one, selectivity for that feature is greater than its availability in the environment. Error bars indicate 95% confidence intervals.*

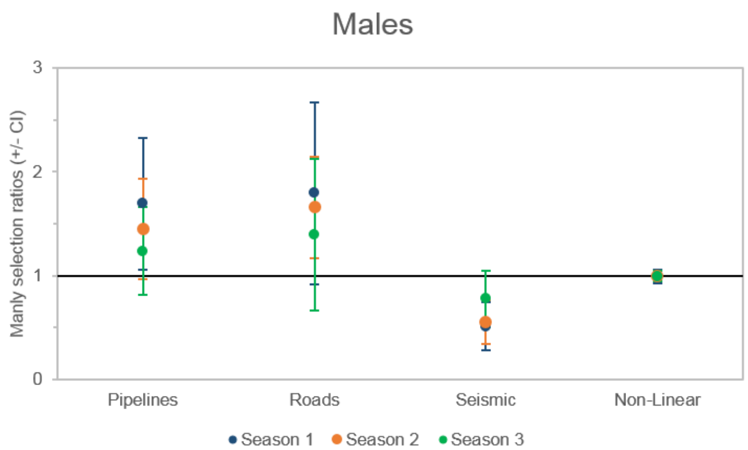


*Figure 1.3 Manly selection ratios for different linear feature types by male grizzly bears. Where the value is larger than one, selectivity for that feature is greater than its availability in the environment. Error bars indicate 95% confidence intervals.*

## 1.3 Discussion

Investigating the selection of pipeline ROWs by male and female grizzly bears in relation to the selection for other linear features is the first step in investigating the effect these features have on grizzly bear habitat selection patterns, activity, and movement. By expanding on the work done by McKay et al. (2014), examining grizzly bear response to oil and gas pipelines in the Kakwa study region of west central Alberta, we were able to incorporate another five years of collared grizzly bear data from an additional five BMAs. Similar to the findings of McKay et al. (2014), both males and females in our study indicated they were using pipeline ROWs and roads more than expected by availability, across all seasons, to varying degrees of significance. Following these initial findings, further investigations into the mechanisms driving this selection, and impacts on grizzly bear movements across the landscape are explored in Chapter 2 and 3, respectively.

In the fire-adapted boreal forest ecosystem, fire suppression has resulted in large tracts of mature stands with fewer natural openings (Nielsen et al. 2004b). The primary disturbance vector on this landscape is now anthropogenic disturbances related to natural resource extraction, including forestry cutblocks, seismic lines, pipelines, and roads. Valuable forage resources for bears, such as herbaceous vegetation, grasses, sedges, and ants, are more abundant and diverse within artificial openings, such as regenerating forestry clearcuts, pipelines, and roadside ditches, compared with surrounding forests (Nielsen et al. 2004c, Roever et al. 2008b). Nielsen et al. (2004c) found that important bear foods, including dandelion (*Taraxacum* spp.), clover (*Trifolium* spp.), and ants, occurred with greater frequency in clearcuts compared to upland forest stands. McKay et al. (2014) found that dandelion, clover, and ants also had a much higher probability of occurrence on pipeline habitats in the Kakwa region, compared to the surrounding forest habitat. Previous research in west-central Alberta found that herbaceous vegetation makes up 10–69% by volume of grizzly bear scat during spring and early summer, and in late June and early July, clover species alone can consist of up to 10% by volume (Munro et al. 2006). Additionally, Munro et al. (2006) found that 23% of scat analyzed in west-central Alberta contained ants, an important protein source for bears in this area. The higher occurrence of these food resources on pipelines may serve as an attractant, for both males and females across the seasons, as our results indicate.

Both male and female grizzly bears showed selection patterns for roads in Season 1 and 2 (to varying degrees of significance), with lower selection in Season 3. Similarly, Graham et al. (2010) found that females with cubs were within 200 m of roads more than expected in spring, and Roever et al. (2008a) showed that grizzly bears selected habitats close to roads in spring and early summer. In research conducted in BMA3, Roever et al. (2008b) found that ants, horsetail (*Equisetum* spp.), dandelion, clover, graminoids, and sedges were more prevalent in roadside ditches than in the forest interior.

Across all seasons, our findings indicate male and female grizzly bears avoid seismic lines. For our research, we only examined the influence of conventional (pre low impact) seismic lines with widths averaging 6 m, constructed prior to 2005. Research by Finnegan et al. (2018) conducted in BMA 2 demonstrated grizzly bears moved away from seismic lines with higher vegetation height, and moved towards seismic lines with lower vegetation height during spring. We hypothesize that by evaluating grizzly bear locations across their range from 2005-2018 in relation to all seismic lines constructed prior to 2005, in some cases constructed as far back in time as the 1960s, a strong avoidance of the older regenerating features with taller vegetation height is resulting in an overall pattern of avoidance (Manly selectivity measures ranging from 0.48 (CI=0.73-0.25) to 0.78 (CI= 1.05-0.27)) across the sexes and seasons.

It is important to note that although grizzly bears used linear features like roads and pipelines more than expected based on availability, grizzly bears spend the majority of their time within non-linear habitat. Pipelines are relatively narrow footprints, compared to other anthropogenic disturbances present on the industrial landscape of west-central Alberta (e.g. forestry cutblocks). While our research indicates that pipelines are not causing avoidance or displacement of grizzly bears, the primary limiting factor for grizzly bears in Alberta is human-caused mortality

(Alberta Environment & Parks 2016). Our research suggests that bears are attracted to pipelines, and the presence of bears on pipelines has the potential to increase their exposure to humans, and subsequently increase the risk of human-caused grizzly bear mortality. Greater understanding of the factors that attract grizzly bears to these features and the behaviour they engage in within these areas, examined in Chapters 2 and 3 respectively, may provide insight into managing risks to people and grizzly bears on pipelines.

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# Chapter 2: Site-specific factors influencing the selection of pipeline right of ways

## 2.0 Introduction

Our analysis in Chapter 1 indicates male and female grizzly bears are selecting for pipeline right of ways (ROWs), to varying degrees of significance, across all three seasons. Given the long history of these features on the landscape and diverse habitats that these features transect, presumably not all pipeline ROWs are of equal habitat value. The probability of wellsite use by grizzly bears has been shown to be affected by bear reproductive status, surrounding road and wellsite densities, and adjacent canopy cover (McKay et al. 2014b), while use of forestry cutblocks has been related to disturbance age, cutblock shape, and site preparation methods (Nielsen et al. 2004). Previous research on bear response to human features has suggested that the level of human activity at a site has a greater influence on grizzly bear behaviour, rather than the anthropogenic feature itself (Martin et al. 2010, Northrup et al. 2012, Ordiz et al. 2013). Similarly, a number of ecological and landscape factors could affect whether individual grizzly bears use or avoid particular pipeline ROWs, including grizzly bear sex-age class, characteristics of the ROW, and the characteristics of the surrounding habitat. Identifying the site-specific factors influencing the selection of pipelines may provide a better understanding of grizzly bears' response to these features, and could help predict when and which pipelines are more likely to be used by bears across our study region.

## 2.1 Methods

### 2.1.1 Grizzly bear location data

Location data were obtained from collared grizzly bears from 2005 to 2017, as described in Chapter 1 of this report. Data from Chapter 1 were further subset to include only individuals and seasons where at least 5% of an individual's locations in a given season were located on pipeline ROWs. Locations occurring on pipeline feature layers created in Chapter 1 were retained for this analysis, with all other non-pipeline locations were removed. For two individuals (a subadult female and a subadult male), home ranges and used pipeline ROW locations extended beyond the spatial extent of our predictor variable layers, therefore 1.13% and 21.99% of used their respective used locations falling outside this extent were removed from analysis. In total, 29 unique bears were retained for final analysis, with 5,443 used locations on pipeline ROWs (Table 2.1). 100% minimum convex polygons (MCPs) were delineated around used pipeline locations for each individual/year/season. Within each MCP, random available locations were then generated on pipeline ROWs, using annual pipeline layers created in the prior analysis (Chapter 1), at an equal number to each individual's used pipeline locations.

*Table 2.1. Total number of bears and GPS locations included in analysis, by sex-age class and season.*

| | Number of unique bears included | | | | Number of GPS collar locations | | | |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Adult F** | **Adult M** | **SubAd F** | **SubAd M** | **Adult F** | **Adult M** | **SubAd F** | **SubAd M** |
| 1 | 3 | 1 | 5 | 4 | 282 | 79 | 501 | 274 |
| 2 | 7 | 2 | 6 | 4 | 1,034 | 99 | 825 | 296 |
| 3 | 3 | 2 | 3 | 5 | 718 | 421 | 490 | 424 |

Collar data retained for this analysis was primarily distributed across BMA2 and BMA3, with one female bear in BMA7 and one male home range extending into BMA4 (Figure 2.1).

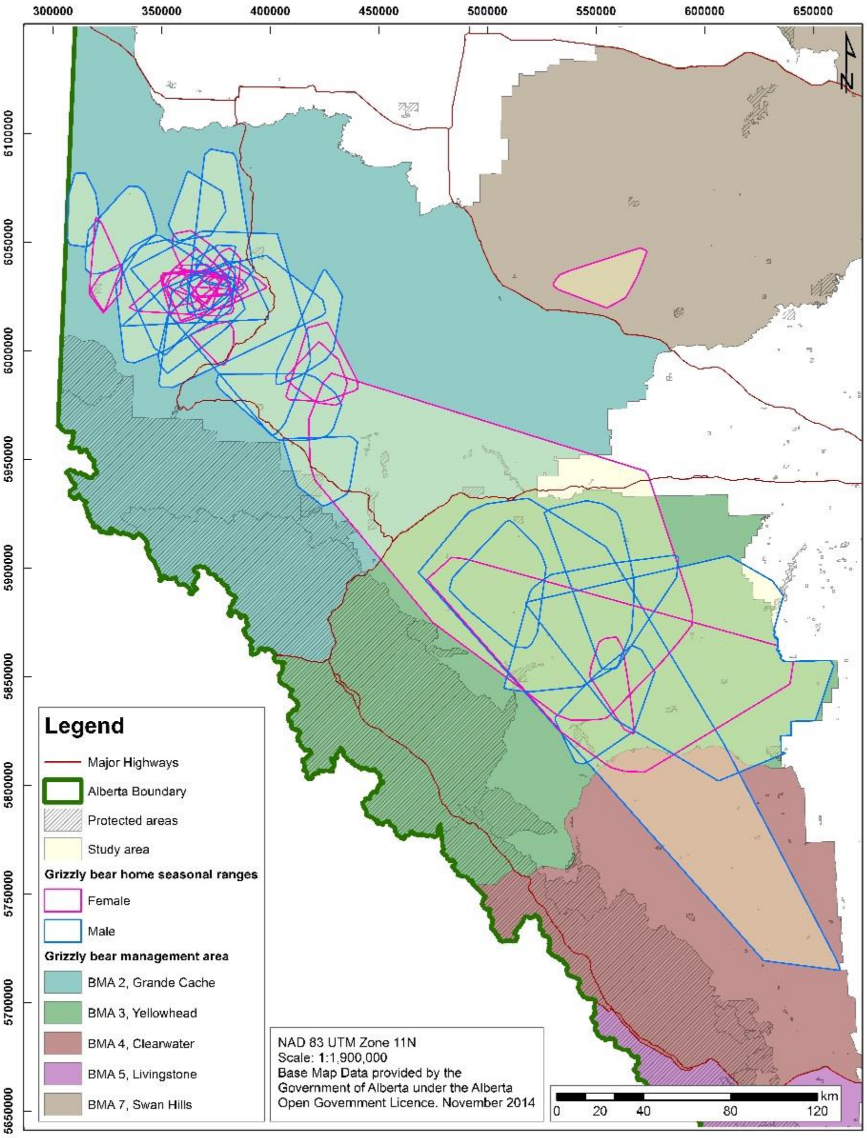


*Figure 2.1. Study area located in western Alberta, consisting of collared grizzly bears' seasonal home ranges (2005-2017).*

### 2.1.2 Site specific predictor variables

We investigated the influence of grizzly bear sex and age class, adjacent habitat types, surrounding anthropogenic disturbance, and pipeline characteristics on grizzly bear use of pipelines ROWs.

*Bear sex-age class*

Behavioural responses to anthropogenic features have been shown to differ by grizzly bear age and sex (Graham et al. 2010, Laberee et al. 2014, McKay et al. 2014b), therefore we included these variables in our models examining parameters influencing pipeline use. Grizzly bears ≥ 5 years old were considered adults. Bears were classified as subadults if they were <5 years old, > 2 years old, and independent from their mother. Age determination was completed using cementum analysis of a pre-molar tooth extracted at capture. Final sex-age classes included: 1) adult females, 2) subadult females, 3) adult males, and 4) subadult males. Reproductive status of adult females (presence or absence of cubs) was investigated during preliminary data exploration, but due to small samples sizes and uncertainty in cub survival across the seasons, reproductive status was not included as a model variable and all adult females were included in a single category.

*Habitat*

Adjacent habitat has the potential to influence habitat selection decisions and small scale habitat use on linear features such as pipeline ROWs. Characteristics of the landscape surrounding a pipeline were calculated at two scales: within a 408 m radius of the use and available pipeline locations (based on the average hourly travel distance for adult male grizzly bears in west-central Alberta; Graham and Stenhouse 2014), and within a 7.44 km radius (based on the average daily travel distance of female and subadult bears in BMA 3; Boulanger et al. 2013). Landcover was classified into five broad classes: 1) upland treed, 2) wetland tree/herb, 3) upland herb/shrub, 4) water, 5) barren (bare alpine/rock and anthropogenic features including mine sites, road surface, wellsites, and cutblocks <= 3 years old). Within both buffer sizes, the proportion of each habitat class was calculated around every used and available location.

*Anthropogenic disturbance*

The density of anthropogenic features varies across the study area, with different levels of habitat alteration and human presence. We considered road densities and pipeline densities as indicators of the level of anthropogenic disturbance in the area surrounding each used and available pipeline location. To calculate linear feature density, we converted the annual road and pipeline polygon layers to polyline format. First, we clipped these polygons to the extent of the bear MCPs for the corresponding year. Boundaries between adjacent polygons were dissolved to consolidate those that overlapped. We converted the polygons to raster format and thinned features to a maximum width of 10 m. Rasters were then converted to polylines and simplified to remove additional short branches that were an artifact of polygon width. We generated road and pipeline density rasters at a 20 m resolution using a moving window with a 7.44 km radius, based on the average daily travel distance of female and subadult bears in BMA3 (Boulanger et al. 2013). The resulting raster values represented average road and pipeline density (km/km$^2$) within the search neighborhood.

*Pipeline specific factors*
Pipeline age (years since clearing and construction) may be an indicator of vegetation succession and abundance of bear foods on pipeline ROWs. Therefore, we hypothesized that potential differences in grizzly bear use of pipelines could be influenced by the number of years since pipeline construction or clearing. Two different parameters were extracted for vegetation succession on pipelines, including 1) the number of years since the pipeline was first cleared for construction (original pipeline age), and 2) the number of years since the most recent construction of an additional pipeline within the ROW (disturbance age). These parameters were based on approximate construction dates calculated in the original dataset. Each pipeline location was also classified as a single pass pipeline (only one pipeline constructed within the ROW) or multi-pass pipeline (ROW disturbed more than once, with at least two or more lines within the corridor). For single pass pipelines, the most recent construction was the original clearing, and the dates for each event were identical.

### 2.1.3 Analysis
Given that observations were on pipelines, our analysis design followed a fourth-order scale of habitat selection (Johnson 1980). The individual identity of each animal was also maintained (design III; Thomas and Taylor 1990).

Similar to the approach of McKay et al. (2014a), we generated 14 *a priori* candidate models corresponding to a set of variables, or combination of variables that we hypothesized as being important to grizzly bears (Table 2.2). Model combinations were focused around bear specific factors (sex-age class), based on previous data suggesting that habitat selection patterns differ by sex-age class. Interaction factors were also limited to sex-age class and anthropogenic disturbance parameters, as the response to anthropogenic features is the main focus of our investigation. We used generalized linear models in RStudio (v1.1.423), using the package lme4 (v1.1-19), running the 14 candidate models separately across the three seasons. For each season, we used a variant of Akaike's Information Criterion (AIC) that was corrected for small sample sizes ($\Delta AIC_C$, Johnson and Omland 2004, Horne and Garton 2006) to select the best model from the candidate set.

Linear predictor variables were assessed for collinearity through Pearson's correlation coefficients ($r$), and variance inflation factors (VIF). Variable combinations with $r \geq 0.6$ or VIF >1.5 were considered to be correlated, and were not included together in any candidate model. When modeling the influence of both small scale and large scale surrounding habitat, the proportion of upland treed and upland herb/shrub habitats showed strong inverse correlations ($r$=-0.8 at both scales). When used in combination with the other habitat variables, upland treed explaining more variation in the data, therefore upland herb/shrub was removed from candidate models. The proportion of a given variable at the small scale was often found to be correlated to its proportion at the larger scale, therefore an additional model was created, selecting the best performing scale for each habitat class, large or small (Table 2.2, models 13 and 14). During data exploration, road density and pipeline density were found to be highly correlated ($r$= 0.8). Density variables were assessed separately for each of the model sets, with pipeline density consistently explaining more variation in the data. Therefore, pipeline density was retained as a measure of anthropogenic disturbance, and road density was not included in final candidate models (Table 2.2, models 3-8). When examining pipeline-specific factors, original pipeline age and disturbance age were also found to be highly correlated, with preliminary analyses demonstrating disturbance age explained more variation in the data, and therefore original pipeline age was not included in the models.

*Table 2.2. A priori candidate models used to describe selection of pipeline ROWs by grizzly bears in the foothills of west-central Alberta, Canada.*

| | Model Description | Variables |
|---|---|---|
| 1 | Bear sex/age class | Sex/age class |
| 2 | Bear sex/age class and food availabilty | Sex/age class + Disturbance age |
| 3 | Bear sex/age class, food availabilty, and level of human disturbance | Sex/age class + Disturbance age + Pipleine density |
| 4 | Pipeline specific factors | Disturbance age + Pipeline density + Multipass |
| 5 | Pipeline specific factors and bear sex/age class | Disturbance age + Pipeline density + Multipass + Sex/age class |
| 6 | Level of human disturbance | Pipeline density |
| 7 | Level of human disturbance and bear sex/age class | Pipeline density + Sex/age class |
| 8 | Level of human disturbance, bear sex/age class, and interaction | Pipeline density + Sex/age class + (Pipeline density * Sex/age class) |
| 9 | Food availabilty and large scale habitat (proportion of each habitat class in 7.44km radius) | Disturbance age + UplandTreed + Wetland + Water + Barren |
| 10 | Food availabilty, large scale habitat (proportion of each habitat class in 7.44km radius), and bear sex/age class | Disturbance age + UplandTreed + Wetland + Water + Barren + Sex/age class |
| 11 | Food availabilty and small scale habitat (proportion of each habitat class in 408m radius) | Disturbance age + UplandTreed + Wetland + Barren |
| 12 | Food availabilty, small scale habitat (proportion of each habitat class in 408m radius), and bear sex/age class | Disturbance age + UplandTreed + Wetland + Barren + Sex/age class |
| 13 | Food availabilty and small scale habitat or large scale habitat | Disturbance age + UplandTreed_7440 + Wetland_408 + Water_7440 + Barren_7440 |
| 14 | Food availabilty, small scale habitat or large scale habitat, and bear sex/age class | Disturbance age + UplandTreed_7440 + Wetland_408 + Water_7440 + Barren_7440 + Sex/age class |

## 2.2 Results

During Season 1 (May 1st to June 15th), the top model, accounted for 0.99 of the total $AIC_c$ weight ($AIC_cw$; Table 2.3 model 5), included variables for pipeline specific factors and bear sex-age class. The age of the most recent disturbance age on the ROW had a negative influence on use of pipelines, with the probability of use decreasing with increasing disturbance age (Table 2.4). The mean disturbance age of used pipelines across seasons was 7.2 years, versus 9.8 years for available pipelines (Figure 2.2). The probability of pipeline use increased as pipeline densities increased in the surrounding area. Bears were also more likely to select multipass pipeline ROWs (corridors containing two or more lines in the same ROW). Adult females were more likely to select pipeline ROWs than adult males, while subadult males and subadult females were less likely to select pipeline ROWs that adult males (Table 2.4).

In Season 2 (June 16th to Jul 31st), the top model consisted of only pipeline specific factors, and accounted for 0.93 of the total $AIC_cw$ (Table 2.3, model 4). Again, bears were more likely to select for multipass ROWs, and disturbance age had a negative influence on use of pipelines. During Season 2, the mean disturbance age of used pipelines was 6.9 years, versus 8.3 years for available pipelines (Figure 2.2). In contrast, increasing pipeline density had a negative influence on use of pipelines, with the probability of use decreasing with increasing pipeline density in the surrounding 7.44 km radius (Table 2.4).

Similar to Season 2, the top model selected in Season 3 (Aug 1st to Oct 15th) contained only pipeline specific factors, and accounted for 0.81 of the total $AIC_c w$ (Table 2.3, model 4). Again, bears were selecting for younger pipelines; the mean disturbance age of used pipelines across seasons was 5.7 years, versus 9.6 years for available pipelines (Figure 2.2). Bears were also more likely to select multipass pipeline ROWs, and the probability of pipeline use increased as pipeline densities increased in the surrounding area (Table 2.4).

*Table 2.3. AIC- selected models (bolded) for Season 1, Season 2, and Season 3.*

| | | | Season 1 | | | Season 2 | | | Season 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Model Decription** | **K** | **$AIC_c$** | **$\Delta AIC_c$** | **$AIC_c w$** | **$AIC_c$** | **$\Delta AIC_c$** | **$AIC_c w$** | **$AIC_c$** | **$\Delta AIC_c$** | **$AIC_c w$** |
| 1 | Bear sex/age class | 2 | 3157.7 | 173.7 | <0.0001 | 6257.4 | 89.0 | <0.0001 | 5700.1 | 326.8 | <0.0001 |
| 2 | Bear sex/age class and food availabilty | 3 | 3121.3 | 137.2 | <0.0001 | 6229.3 | 60.9 | <0.0001 | 5516.8 | 143.5 | <0.0001 |
| 3 | Bear sex/age class, food availabilty, and level of industrial disturbance | 4 | 3011.4 | 27.3 | <0.0001 | 6230.1 | 61.7 | <0.0001 | 5517.7 | 144.4 | <0.0001 |
| **4** | **Pipeline specific factors** | **4** | 2997.7 | 13.7 | 0.0011 | **6168.4** | **0.0** | **0.9301** | **5373.4** | **0.0** | **0.8056** |
| **5** | **Pipeline specific factors and bear sex/age class** | **5** | **2984.0** | **0.0** | **0.9989** | 6173.6 | 5.2 | 0.0699 | 5376.2 | 2.8 | 0.1944 |
| 6 | Level of industrial disturbance | 2 | 3080.2 | 96.2 | <0.0001 | 6253.2 | 84.8 | <0.0001 | 5694.4 | 321.0 | <0.0001 |
| 7 | Level of industrial disturbance and bear sex/age class | 3 | 3054.3 | 70.3 | <0.0001 | 6259.2 | 90.8 | <0.0001 | 5700.2 | 326.8 | <0.0001 |
| 8 | Level of industrial disturbance, bear sex/age class, and interaction | 4 | 3004.9 | 20.9 | <0.0001 | 6245.6 | 77.2 | <0.0001 | 5639.5 | 266.1 | <0.0001 |
| 9 | Food availabilty and large scale habitat | 6 | 3108.2 | 124.1 | <0.0001 | 6221.2 | 52.8 | <0.0001 | 5497.9 | 124.6 | <0.0001 |
| 10 | Bear sex/age class, food availabilty, and large scale habitat | 7 | 3108.6 | 124.5 | <0.0001 | 6225.3 | 56.9 | <0.0001 | 5497.4 | 124.0 | <0.0001 |
| 11 | Food availabilty and small scale habitat | 5 | 3075.5 | 91.5 | <0.0001 | 6208.7 | 40.3 | <0.0001 | 5509.0 | 135.7 | <0.0001 |
| 12 | Bear sex/age class, food availabilty, and small scale habitat | 6 | 3079.4 | 95.4 | <0.0001 | 6212.8 | 44.4 | <0.0001 | 5509.4 | 136.1 | <0.0001 |
| 13 | Food availabilty and small scale habitat or large scale habitat | 6 | 3088.2 | 104.2 | <0.0001 | 6209.2 | 40.8 | <0.0001 | 5498.6 | 125.2 | <0.0001 |
| 14 | Bear sex/age class, food availabilty and small scale habitat or large scale habitat | 7 | 3104.2 | 120.2 | <0.0001 | 6212.8 | 44.5 | <0.0001 | 5507.9 | 134.5 | <0.0001 |

*Table 2.4. Estimated seasonal AIC-selected model coefficients. Sex-age class was not included in top models for Seasons 2 and 3.*

| | Season 1 | | Season 2 | | Season 3 | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **S.E.** | **Coefficient** | **S.E.** | **Coefficient** | **S.E.** |
| Disturbance age | -0.027 | 0.005 | -0.014 | 0.003 | -0.041 | 0.004 |
| Pipeline density | 1.025 | 0.110 | -0.009 | 0.080 | 0.014 | 0.113 |
| Multipass | 0.493 | 0.091 | 0.486 | 0.064 | 0.790 | 0.066 |
| Adult Female | 0.079 | 0.109 | – | – | – | – |
| Subadult Female | -0.055 | 0.182 | – | – | – | – |
| Subadult Male | -0.524 | 0.129 | – | – | – | – |

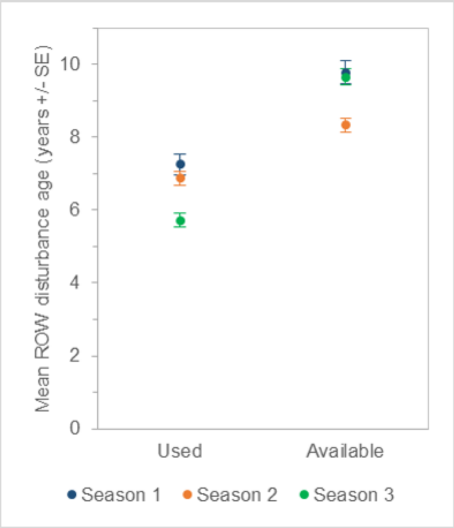


*Figure 2.2. Mean disturbance age of pipeline ROWs which were used by, or available to, grizzly bears during Season 1, Season 2, and Season 3 (+/- standard error).*

## 2.3 Discussion

During Season 1 (May 1st to June 15th), sex-age class was an important predictor of grizzly bear use of pipeline ROWs, while this factor was not included in top models for Season 2 (June 16th to July 31st) or Season 3 (August 1st to October 15th). Our findings indicate that in the spring, adult females were more likely to use pipeline ROWs than other sex-age classes. Other authors have also reported sexual segregation of habitat use in grizzly bears. Rode et al. (2006) suggested that females with cubs of the year (COY) may perceive the risk of male grizzly bears as greater than the risk of human interaction In Sweden, Steyaert et al. (2013) reported a strong pattern of spatiotemporal segregation in habitat selection between female brown bears with COY and adult males during the mating season (May 1 to July 15). Females with COY, in contrast to adult males, selected habitats in less rugged landscapes, in more open habitat types, in relative close proximity to anthropogenic features such as roads and settlements. The authors also noted a shift in habitat selection after the mating season ended, when females with COY followed habitat selection patterns more similar to their conspecifics (Steyaert et al. 2013). Previous work in Alberta has found that females used areas near roads more than males during the spring season (Graham et al. 2010). Mattson et al. (1987) and McLellan and Shackleton (1988) also noted that males were farther from roads than females and suggested that females may spend time near roads to avoid males. Laberee et al. (2014) reported adult female grizzly bears in the Kakwa region were closer than expected to oil and gas features in the spring and summer including pipelines, roads, and wellsites, and this effect was strongest in adult females compared to other sex-age groups. Similarly, McKay et al. (2014b) found females with young in the Kakwa region of Alberta were more likely to use wellsites than both males and single females, and males used wellsites less than all females. While our study did not differentiate between females with and without cubs due to limitations in reproductive data, it appears that some sexual segregation of habitat use could be taking place on pipelines during the spring, when COY are less mobile. The reason behind lower male use of pipeline ROWs, allowing for females to select these features as a security strategy, particularly in the spring when grasses and forbs provide a rich and accessible food source, remain unknown. It is possible that males feed on different foods at that time (e.g., ungulate calves), causing males to select for features other than pipeline ROWs.

Pipeline-specific variables such as disturbance age, pipeline density, and multipass ROW were retained in top models across all three seasons. Disturbance age (age of the most recent pipeline construction in the ROW) can be considered to serve as an index of vegetation succession, and provide insight into the availability of important grizzly bear foods. Across all three seasons, mean disturbance age on used pipeline ROWs was significantly younger then available pipeline ROW locations, with models showing the probability of use decreasing as disturbance age increased. Research by McKay et al. (2014a) investigating bear food species on pipelines in the Kakwa region of Alberta demonstrated higher abundance of early colonizing plant species such as dandelion and clover on pipeline ROWs, when compared to the surrounding habitat types. These plants are an important part of the diet for grizzly bears in the foothills of west-central Alberta (Munro et al. 2006). As vegetation succession progresses with time since clearing, the plant community on a pipeline ROW may change to one dominated by grass, willow, and alder, resulting in less desirable foraging opportunities. However, this succession to shrub communities may be slower on wider features, containing more than one pipeline in the ROW. Across all three seasons in our study, bears were found to select for pipeline ROWs containing two or more pipelines, referred to a multipass ROWs. Wider multipass ROW would permit more light to enter the corridor, facilitating quicker snow melt and green-up of the vegetation during spring months, and potentially promoting the growth of more forest-edge species preferred by grizzly bears. Further work examining the relationship between bear food presence/abundance, adjacent habit, and width of the corridor could provide a clearer picture of bear food availability on pipeline ROWs.

It is likely that pipeline ROWs in our study area provide a concentrated source of bear foods, and these food resources could be an important factor driving grizzly bear use. Additionally, it has been speculated that pipeline ROWs may be used by grizzly bears for travel corridors, with ROWs becoming less suitable for fast movement as vegetative cover increases. Investigation into grizzly bear movement rates in relation to pipeline ROWs, and their function as travel corridors or foraging areas is further examined in Chapter 3.

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# CHAPTER 3: COMPARISON OF GRIZZLY BEAR MOVEMENT IN AREAS OF LOW AND HIGH PIPELINE DENSITY

## 3.0 INTRODUCTION

Analysis of wildlife movement can be a useful complement to habitat selection studies and provide additional insight into behaviour and how animals interact with their environment. Movement rate and path straightness (i.e. the inverse of tortuosity) are two informative metrics, where slower, more tortuous paths suggest an attempt to maximize foraging efficiency and faster, straighter movements signify travelling (Etzenhouser et al. 1998). Grizzly bear movement rates have been assessed previously and were found to depend on age and sex class, as well as season (Graham and Stenhouse 2014), but path tortuosity has seldom been considered.

Few studies have examined landscape-level wildlife movement patterns in relation to linear feature density, and it remains unclear how grizzly bears respond to pipelines. Bear movement on and near pipeline ROWs may be linked to activities such as foraging, hunting for prey, or travelling, as proposed with seismic lines (Finnegan et al. 2018), and could be shaped by the likelihood of human contact, as observed with other species (Whittington et al. 2004). Given the prominence of pipelines across grizzly bear habitat in western Alberta, determining the influence of these features on movement will broaden our understanding of how grizzly bears are affected by these features, which can support their conservation and management within human-altered landscapes. Our objectives here are to compare grizzly bear movement rates and path straightness for various age-sex classes in areas of low and high pipeline density, and determine whether these metrics vary across seasons.

## 3.1 METHODS

The study area and bear location dataset for the movement analysis were the same as those of Chapter 2, based on bears with at least 5% of their locations occurring on pipeline ROWs.

Pipeline density rasters described in Chapter 2 were divided into low and high density areas by first calculating the mean of each annual raster, and then averaging across years to obtain an overall mean of 0.46 km/km$^2$. Each raster was reclassified based on this threshold into low (value=1) and high (value=2) density categories, with both of these relatively evenly represented. We extracted these binary values to the bear locations per year, and then determined sample size for each density category, season, and age-sex class (Table 3.1). A small portion of the study area was characterized by a pipeline density of zero, and was excluded.

*Table 3.1. Sample size for grizzly bear movement analysis by pipeline density category, season, and age-sex class.*

| Pipeline Density Category | Season | Sex | Age Class | Sample Size |
|---|---|---|---|---|
| Low | 1 | Female | Adult | 4 |
| | 1 | Female | Subadult | 1 |
| | 1 | Male | Adult | 6 |
| | 1 | Male | Subadult | 3 |
| | 2 | Female | Adult | 10 |
| | 2 | Female | Subadult | 2 |
| | 2 | Male | Adult | 6 |
| | 2 | Male | Subadult | 3 |
| | 3 | Female | Adult | 4 |
| | 3 | Female | Subadult | 1 |
| | 3 | Male | Adult | 3 |
| | 3 | Male | Subadult | 4 |
| High | 1 | Female | Adult | 3 |
| | 1 | Female | Subadult | 1 |
| | 1 | Male | Adult | 6 |
| | 1 | Male | Subadult | 4 |
| | 2 | Female | Adult | 10 |
| | 2 | Female | Subadult | 2 |
| | 2 | Male | Adult | 6 |
| | 2 | Male | Subadult | 4 |
| | 3 | Female | Adult | 6 |
| | 3 | Female | Subadult | 2 |
| | 3 | Male | Adult | 3 |
| | 3 | Male | Subadult | 5 |

To examine movement paths, we first sorted the locations in chronological order for each bear. As GPS fix frequency varied among years, for consistency, we filtered locations according to the coarsest temporal resolution and thus retained only hourly locations. We checked for erroneous records and removed two duplicates. To segment the entire seasonal paths of each bear into shorter sample units, we divided paths when an individual moved into an area of different pipeline density, the interval between GPS fixes exceeded one hour, or the day changed. Paths with fewer than three locations were excluded from the analysis.

We used the 'amt' package in R to calculate average step length, equivalent to movement rate (m/h), and path straightness per bear by density category, season, and year. Straightness is measured as the Euclidean distance between the first and last point in a path, divided by total path length (Batschelet 1981); it varies from 0 to 1, with higher values indicating straighter paths (Almeida et al. 2010). We examined the range of values produced and removed two outliers. We then averaged these movement metrics among bears in each age-sex class.

## 3.2 Results

### 3.2.1 Movement rate

Average movement rates for all age-sex classes was higher in areas of low pipeline density, which also had greater variation in values (Table 3.2, Figure 3.1). Adult females moved the slowest among classes in both low and high pipeline density areas (363 and 333 m/h, respectively), however, no single age-sex class was consistently the fastest. Subadult males demonstrated the highest average movement rate in low density areas (763 m/h), whereas subadult females had the highest rate in high density areas (529 m/h). Subadults of both sexes moved faster than adults in low density areas, but not in those of high density for males, where adult males moved more quickly.

*Table 3.2: Average movement rate (m/h) per grizzly bear age-sex class in areas of low and high pipeline density category in western Alberta.*

| Pipeline Density Category | Sex | Age Class | Average Movement Rate (m/h) |
|---|---|---|---|
| Low | Female | Adult | 363 |
| Low | Female | Subadult | 657 |
| Low | Male | Adult | 595 |
| Low | Male | Subadult | 763 |
| High | Female | Adult | 333 |
| High | Female | Subadult | 529 |
| High | Male | Adult | 514 |
| High | Male | Subadult | 446 |

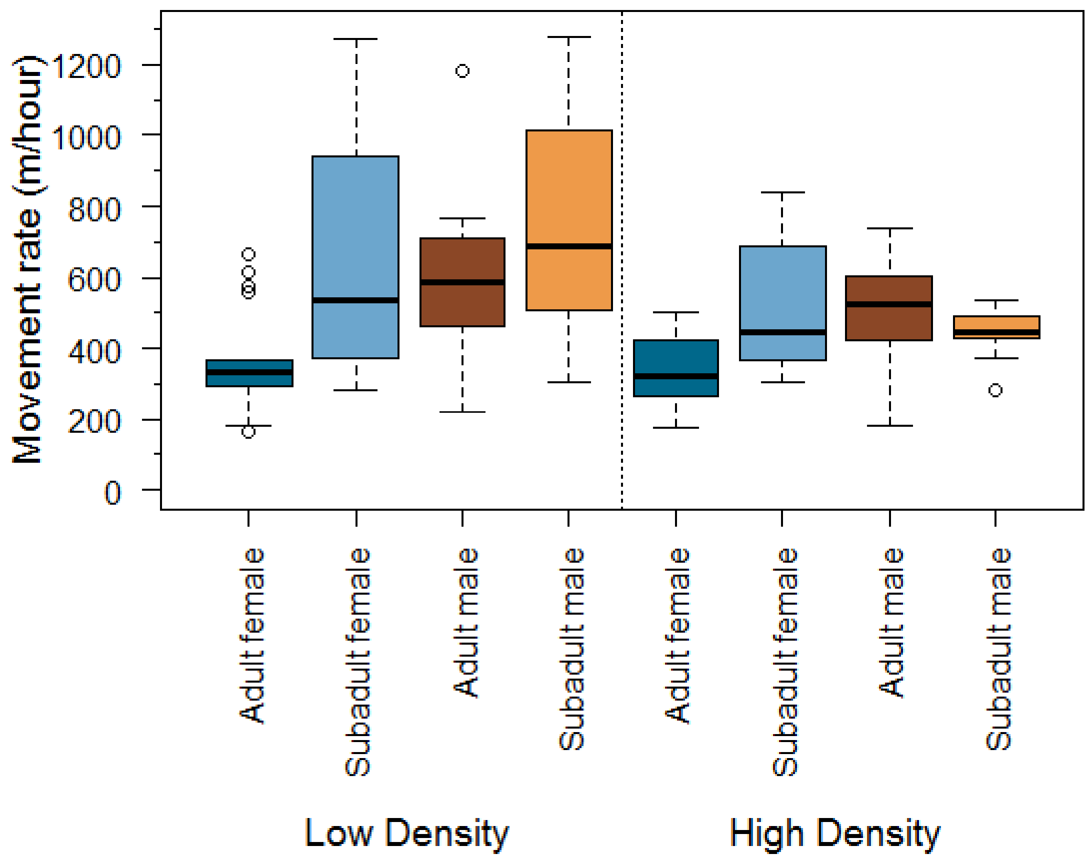


*Figure 3.1. Movement rate (m/h) per grizzly bear age-sex class in areas of low and high pipeline density in western Alberta. Horizontal black lines within boxes indicate median movement rates.*

Average movement rate for each season, as well as the magnitude of change across seasons, varied with both pipeline density as well as age-sex class. In both low and high density areas, average movement rate among all age-sex classes was highest in Season 1 (810 and 518 m/h, respectively), and lowest in Season 3 (486 and 382 m/h) (Table 3.3, Figure 3.2). The highest movement rate overall was that of subadult females in Season 1 (1275 m/h) in low density areas, albeit based on a single bear, while the lowest was that of adult females in Season 1 in high density areas (237 m/h). Seasonal differences were more apparent in areas of low pipeline density, where the average change from one season to the next among all age-sex classes was 256 m/h, compared to 107 m/h for high density areas. Female movement rates fluctuated more than those of males, with the contrast especially noticeable in high density areas. Subadults demonstrated more variation in movement rates than adults, which was particularly evident in areas of low pipeline density.

*Table 3.3. Average movement rate (m/h) per grizzly bear age-sex class and season in areas of low and high pipeline density in western Alberta.*

| Pipeline Density Category | Season | Sex | Age Class | Average Movement Rate (m/h) |
|---|---|---|---|---|
| Low | 1 | Female | Adult | 465 |
| | 1 | Female | Subadult | 1275 |
| | 1 | Male | Adult | 615 |
| | 1 | Male | Subadult | 883 |
| | 2 | Female | Adult | 362 |
| | 2 | Female | Subadult | 535 |
| | 2 | Male | Adult | 610 |
| | 2 | Male | Subadult | 496 |
| | 3 | Female | Adult | 265 |
| | 3 | Female | Subadult | 283 |
| | 3 | Male | Adult | 523 |
| | 3 | Male | Subadult | 873 |
| High | 1 | Female | Adult | 237 |
| | 1 | Female | Subadult | 842 |
| | 1 | Male | Adult | 542 |
| | 1 | Male | Subadult | 451 |
| | 2 | Female | Adult | 380 |
| | 2 | Female | Subadult | 527 |
| | 2 | Male | Adult | 532 |
| | 2 | Male | Subadult | 464 |
| | 3 | Female | Adult | 303 |
| | 3 | Female | Subadult | 374 |
| | 3 | Male | Adult | 425 |
| | 3 | Male | Subadult | 426 |

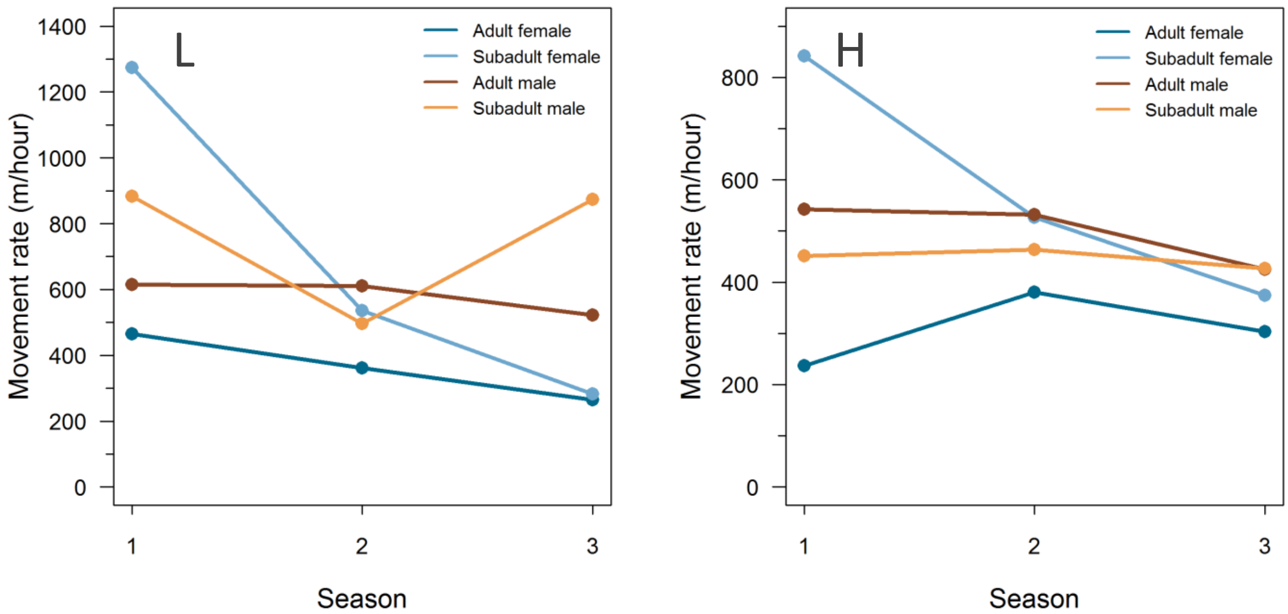


*Figure 3.2: Average movement rate (m/h) per grizzly bear age-sex class and season in areas of low (L) and high (H) pipeline density in western Alberta.*

## 3.2.2 Path straightness

Movement paths were straighter on average in areas of low pipeline density for all age-sex classes except adult males, for which straightness was equal for both density categories (Table 3.4, Figure 3.3). The variation in straightness values (ranging from 0 as tortuous to 1 as straight) was also greater for low density areas. No single age-sex class had consistently the straightest or, alternatively, the most tortuous paths. Paths of subadult males were the straightest in low density areas (0.75), while those of adult females were the most tortuous (0.63). In high density areas, adult males had the straightest paths (0.64), and the most tortuous paths were associated with subadult males (0.58). Subadults of both sexes were characterized by straighter paths than adults in low density areas, whereas the opposite was observed in those of high density.

*Table 3.4 Average path straightness (ranging from 0 as tortuous and 1 as straight) per grizzly bear age-sex class in areas of low and high pipeline density in western Alberta.*

| Pipeline Density Category | Sex | Age Class | Average Path Straightness |
|---|---|---|---|
| Low | Female | Adult | 0.63 |
| Low | Female | Subadult | 0.74 |
| Low | Male | Adult | 0.64 |
| Low | Male | Subadult | 0.75 |
| High | Female | Adult | 0.60 |
| High | Female | Subadult | 0.59 |
| High | Male | Adult | 0.64 |
| High | Male | Subadult | 0.58 |

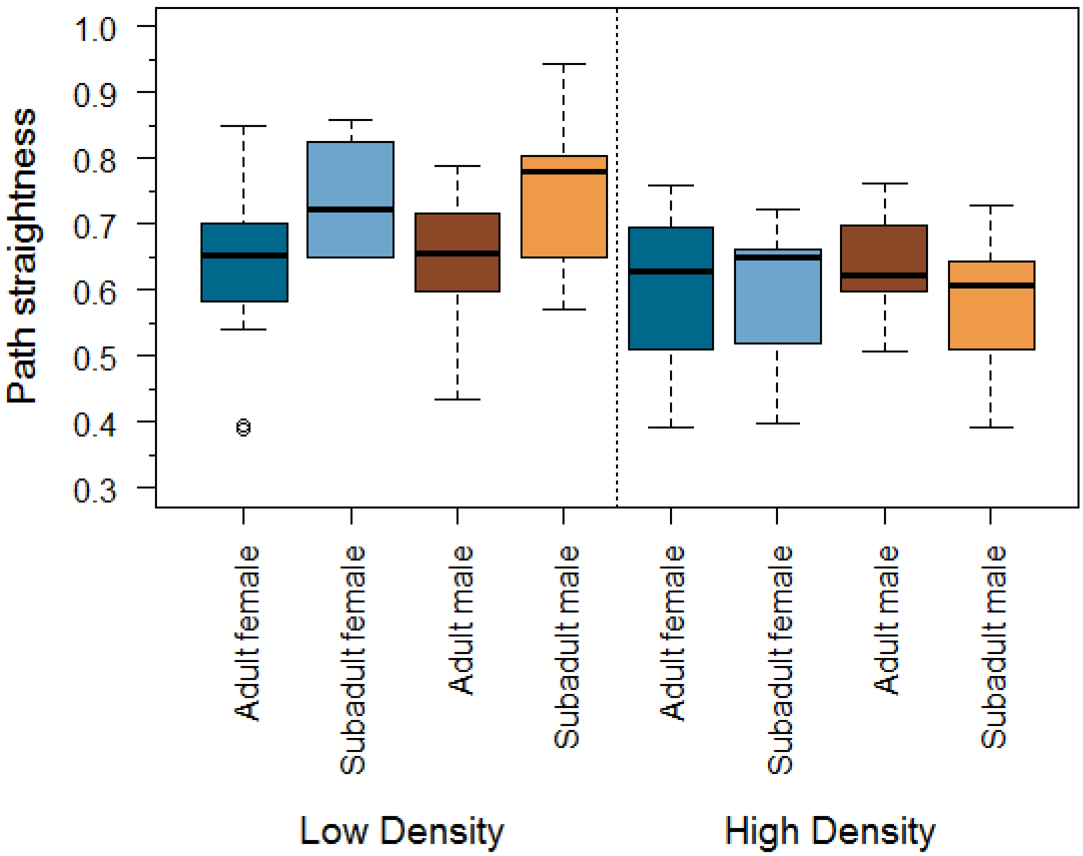


*Figure 3.3. Path straightness (ranging from 0 as tortuous and 1 as straight) per grizzly bear age-sex class in areas of low and high pipeline density in western Alberta. Horizontal black lines within boxes indicate median values.*

Average path straightness per season, and the magnitude of change across seasons, differed due to both pipeline density and age-sex class. In low density areas, average path straightness among all age-sex classes was equally high in Seasons 1 and 3 (0.69), and slightly lower in Season 2 (0.68). Average path straightness in high density areas was highest in Season 2 (0.64) and lowest in Season 3 (0.54). Subadult females demonstrated both the straightest (0.86) and most tortuous (0.46) paths overall, in low and high density areas, respectively, during Season 3; however, these results were based on a single bear (Table 3.5, Figure 3.4) and therefore should be viewed with caution. Seasonal differences were marginally clearer in areas of low pipeline density, where the average change from one season to the next among all age-sex classes was 0.10, compared to 0.09 for high density areas. Female path straightness fluctuated more than that of males, with the contrast particularly evident in low density areas. Subadults exhibited more variation than adults in areas of low density, while the opposite occurred in high density areas.

*Table 3.5. Average path straightness (ranging from 0 as tortuous and 1 as straight) per grizzly bear age-sex class and season in areas of low and high pipeline density in western Alberta.*

| Pipeline Density Category | Season | Sex | Age Class | Average Path Straightness |
|---|---|---|---|---|
| Low | 1 | Female | Adult | 0.56 |
| | 1 | Female | Subadult | 0.79 |
| | 1 | Male | Adult | 0.61 |
| | 1 | Male | Subadult | 0.79 |
| | 2 | Female | Adult | 0.68 |
| | 2 | Female | Subadult | 0.65 |
| | 2 | Male | Adult | 0.67 |
| | 2 | Male | Subadult | 0.73 |
| | 3 | Female | Adult | 0.57 |
| | 3 | Female | Subadult | 0.86 |
| | 3 | Male | Adult | 0.61 |
| | 3 | Male | Subadult | 0.73 |
| High | 1 | Female | Adult | 0.52 |
| | 1 | Female | Subadult | 0.72 |
| | 1 | Male | Adult | 0.67 |
| | 1 | Male | Subadult | 0.55 |
| | 2 | Female | Adult | 0.66 |
| | 2 | Female | Subadult | 0.66 |
| | 2 | Male | Adult | 0.67 |
| | 2 | Male | Subadult | 0.55 |
| | 3 | Female | Adult | 0.55 |
| | 3 | Female | Subadult | 0.46 |
| | 3 | Male | Adult | 0.53 |
| | 3 | Male | Subadult | 0.62 |

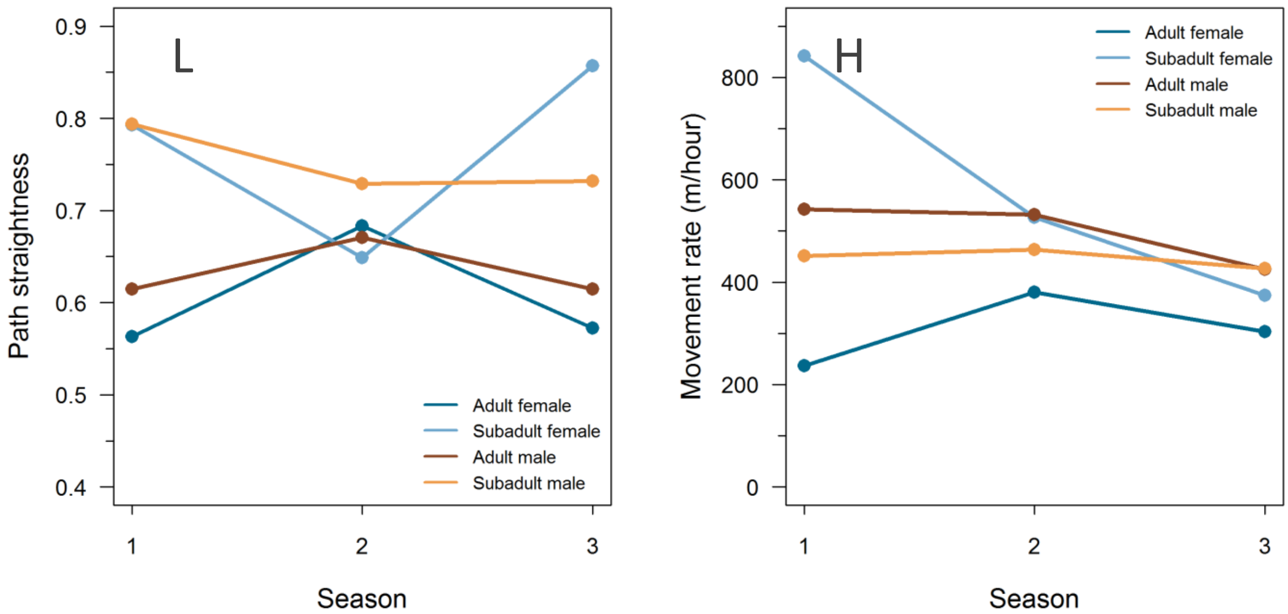


*Figure 3.4. Average path straightness (ranging from 0 as tortuous and 1 as straight) per grizzly bear age-sex class and season in areas of low (L) and high (H) pipeline density in western Alberta.*

## 3.3 Discussion

Our results indicate that grizzly bear movement differs between areas of low and high pipeline density within their home range, and is influenced by both age-sex class and season. All bears moved faster and in straighter paths in low pipeline density areas. Conversely, in grizzly bear habitat containing more pipelines, bears reduced their speed and moved more tortuously, which is consistent with foraging behaviour (Etzenhouser et al. 1998).

These finding suggests that food availability and food searching behaviour may be an important factor affecting bear behaviour on and in the vicinity of pipelines, supporting the conclusions of previous chapters. As discussed earlier, some key food resources, such as dandelion and clover (Munro et al. 2006), are positively associated with disturbance and more abundant in artificial canopy openings than intact forest (Nielsen et al. 2004, Roever et al. 2008). Pipelines ROWs provide a considerable supply of these species along with numerous other vegetation resources including *Equisetum spp.* and *Rubus spp.* (McKay et al. 2014). Increased pipeline density could therefore correspond to greater landscape-level foraging potential for some important food species.

Temporal variation in food availability on pipelines may also partly explain changes in bear movement across seasons. We found movement rates were lowest in Season 3, which coincides with fruit ripening (Munro et al. 2006) and is also when paths were most tortuous in areas of high pipeline density, suggesting foraging activity. Similar declines in movement rates from spring to fall have been observed in other grizzly bear populations, and attributed to greater food abundance later in the year (McLoughlin et al. 1999). Movement rates were highest in Season 1, before fruit resources are available, however, this period also coincides with the mating season (Stenhouse et al. 2005, Graham and Stenhouse 2014). The search for mates by both sexes may contribute to the higher movement rates observed in this period.

Bear movement is also affected by the frequency and type of human activity on linear features, with bears moving more quickly near those that experience higher use (Roever et al. 2010, Ladle et al. 2018). If one assumes a greater level of human activity in areas with increased pipeline densities, we might have expected to detect faster and straighter movements of bears in areas with more pipelines. Our results indicated the opposite response, which implies that foraging opportunities may outweigh the elevated risk of encountering humans in high pipeline density areas.

Increased movement rates in response to linear features has been noted in other wildlife species, however. Wolves in northeastern British Columbia increased their speed and decreased tortuosity in response to rising densities of multiple types of linear features, including pipelines, resulting in the avoidance of areas with greater human disturbance and consequently more risk (Ehlers et al. 2014). Seasonal variation in wolf movement rate and path tortuosity was also observed (Ehlers et al. 2014), as we found with bears. Elsewhere, wolves in west-central Alberta exhibited increased path tortuosity in areas of high trail and road density, possibly to avoid junctions and human contact (Whittington et al. 2004).

Differences in response between grizzly bears and wolves may relate to the ways in which linear features affect their consumer-resource interactions. As grizzly bears are omnivores, linear features themselves provide a food source by supporting vegetation growth (McKay et al. 2014), and bears would likely slow down to forage; for wolves, however, these features facilitate hunting and promote faster movement (Dickie et al. 2017), although further research may reveal that bears also benefit in this sense. The discrepancy in findings among the few studies that exist highlights the need to further explore the effects of linear feature expansion on wildlife movement, to clarify the variation that has been indicated thus far.

Our analysis incorporated hourly locations of bears standardized across years, and this temporal resolution is too coarse to evaluate behaviours on the pipelines themselves, such as whether bears travel along ROWs for an extended period of time. It appears that food availability may be an important driver of grizzly bear movement patterns on and near pipelines, however, finer resolution data and field sampling are necessary to confirm this.

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# Conclusions and Recommendations

The aim of this project was to build upon previous work conducted by the fRI Research Grizzly Bear Program in 2012-2013 where we examined the response of grizzly bears to pipelines in the one study area (Kakwa region) in west-central Alberta (McKay et al. 2014). This earlier work determined grizzly bears used pipelines and roads significantly more than expected based on availability and identified a number of important bear foods that were more common on pipeline ROWs and edges than the surrounding forest habitat. Sexual segregation in the use of pipeline habitat was observed, and it was found that bears were more likely to use younger pipeline ROWs, and use of ROWs increased in areas of lower pipeline and road densities. Given these results, this project aimed to determine if these previous findings were specific to this one study area or if they were consistent across the different ecosystems found within Alberta's grizzly bear range by incorporating another five years of grizzly bear collar location data, and expanding the project scope to include six of Alberta's seven BMAs. Additionally, following work in the Kakwa region, questions remained regarding the role of pipeline ROWs as foraging areas or travel corridors, and the behaviour grizzly bears engage in areas on or adjacent to pipeline ROWs, which could have important implications for assessing the risk of grizzly bear mortality and/or human conflict along these features.

When examining grizzly bear location data from six of Alberta's BMAs, our findings indicate both male and female grizzly bears are using pipeline ROWs and roads more than expected by availability, across all non-denning seasons. The data clearly indicate that grizzly bears are not displaced by or avoid pipelines and ROW's within grizzly bear range in Alberta. On average, female grizzly bears were selecting denning locations closer to pipelines than male grizzly bears. Similar to the findings of McKay et al. (2014), our results show grizzly bears were selecting for younger pipeline ROWs (mean age ~6.5 years). We also found that bears were selecting for wider corridors containing two or more pipelines within the ROW. During Season 1 (May 1$^{st}$ to June 15$^{th}$), sex-age class was also an important predictor of grizzly bear use of pipeline ROWs, with adult females more likely to use these features than other sex-age classes. This season also overlaps with the breeding period and it is possible that mating behaviour may also influence the use of open habitats that are found along pipeline ROW's.

While earlier research (McKay et al. 2014) in the Kakwa region found grizzly bear use of pipeline ROWs increased in areas of lower pipeline and road densities, our findings did not show this same pattern of use. The probability of pipeline use increased as pipeline densities increased during Season 1 and 3, with a decrease in use observed in Season 2. Natural resource exploration and extraction has occurred in the Kakwa area for decades, primarily from oil and gas activities and timber harvest. Since 2000, oil and gas well-site development in the region has increased, bringing with it an escalation in the construction of associated roads, pipelines, and industrial infrastructure. Across our wider study area, including BMAs 2, 3, 4, and 7, pipeline density vary. This discrepancy in findings may indicate a possible threshold may exist at which the level of human disturbance, like that seen in the Kakwa region, elicits an avoidance response, despite the attractive foraging potential along these anthropogenic features. It is also possible that the related forest harvesting activities that occur in these shared landscapes is playing a role in these areas and broad habitat features, of which pipelines are a part, are interacting to affect bear behaviour. Further research is required to examine questions of functional response by grizzly bears to changing linear feature densities.

One of the knowledge gaps that remained following our earlier work examining grizzly bear response to pipelines related to questions of grizzly bear behaviour on and adjacent to ROW's and why these features may be selected for. The temporal resolution of hourly GPS collar data is quite coarse to try to evaluate fine-scale behaviour on the pipeline ROWs themselves, and extended sets of consecutive grizzly bear collar locations, consistently falling on narrow linear features, such as pipeline ROWs, are relatively rare in our dataset. However, by evaluating metrics such as movement rate and path straightness in areas of high versus low pipeline density, we were able to gain valuable insight into broad scale movement behaviours by different age-sex classes of grizzly bears across the seasons. Our findings indicate that grizzly bear movement differs between areas of low and high pipeline density, and is influenced by both bear age-sex class and season. In all sex-age classes, bears reduced their speed and moved more tortuously in parts of their habitat with higher densities of pipelines, which is consistent with foraging behaviour. Additionally, in areas of high pipeline density, movement rates were slowest and most tortuous in Season 3, which coincides with berry ripening. There is no evidence in our study that suggests bears are using these features to facilitate faster movement, and results from our movement analyses seem to further support our hypothesis that bears are selecting pipeline ROWs as important foraging areas.

While pipeline ROWs may provide valuable foraging areas for grizzly bears, the potential for these features to facilitate increased human access into otherwise remote grizzly bear habitat is an important consideration. It is well documented that motorized access is associated with an increased risk of human-grizzly bear interaction that results in grizzly bear mortality. Managing motorized access, in the form of both paved/graveled road densities and off-highway vehicle (OHV) traffic, has been identified as a priority in the 2016 Alberta Grizzly Bear Recovery Plan. While maintaining some degree of OHV access on pipelines ROWs may be necessary for monitoring and inspection efforts by industrial staff, efforts to reducing public recreationists use of these features could be achieved through minimizing line-of-sight down pipeline ROWs at the intersection with roads. As suggested by McKay et al. (2014), berms along road intersections and/or encouraging shrub growth within the first 50 m of a road intersection could help to reduce grizzly bear mortality risk on pipelines at road intersections.

Additionally, given grizzly bear selection for these features, specifically younger pipeline ROWs, safety training for pipeline workers should be a high priority. Training in bear safety, awareness, and behaviours should be provided to all field staff working in bear country, with regular re-certification. Grizzly bears selection for pipeline ROWs should be considered in company-specific safety planning, and systems should be in place to report sightings of grizzly bears on site in order to notify other employees working in the area. It is recommended that bear spray be provided to all field workers, with regular training in the effective use of this deterrent.