# THE EFFECTS OF THE RED 003 FIRE ON WOODLAND CARIBOU (*Rangifer tarandus caribou)* HABITAT IN THE SYDNEY RANGE

by

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April 2018

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An Undergraduate Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 2018

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|---|---|
| Major Advisor | Second Reader |
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# ABSTRACT

Silva, J. 2018. The effects of the Red 003 Fire on woodland caribou (*Rangifer tarandus caribou*) habitat in the Sydney Range. 92 pp.

Keywords: fire, habitat, image classification, lichen, residuals, Resource Selection Function, woodland caribou.

Disturbances, including forest fires, are considered a primary driver of population decline in boreal woodland caribou populations across Canada. The Sydney Range in northwestern Ontario has been assessed as not self-sustaining due to a low population estimate and extensive anthropogenic and natural disturbances. In 2016, the Red 003 Fire burned most of the northwest corner of the Sydney Range, which contained the highest habitat value and likelihood of occupancy for the Sydney caribou. Managers are concerned the Red 003 Fire could cause decline in the Sydney caribou population.

Telemetry data was used to create a set of models in a Resource Selection Function to explain how caribou used habitat prior to the Red 003 Fire. The telemetry data indicated the importance of the area that burned in the Red 003 Fire as winter habitat for the Sydney caribou. The Resource Selection Function indicated that caribou displayed differing levels of avoidance of recent burns across seasons. Due to the large size of the Red 003 burn and the high percentage of post-fire residuals, it is likely caribou will continue to use habitat within and around the Red 003 burn. However, the persistence of the Sydney caribou population likely hinges on the ability of remaining suitable habitat and the regenerating habitat in 1980s burns to compensate for the areas affected by the Red 003 Fire.

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# ACKNOWLEDGEMENTS

Thank-you to Dr. Brian McLaren, my thesis supervisor, for all your assistance with this project and dedication to all your thesis students. Tomislav Sapic provided invaluable GIS and Python assistance, without which the project would not have been possible. Eric Searle assisted in constructing and interpreting the Resource Selection Function. Several people at the MNRF were involved in creating the Sensitive Data Use License Agreement, especially Almos Mei. Jevon Hagens provided the burn severity map, which was used for field data collection and post-fire habitat assessment. Thank-you to Dr. Ulf Runesson for supporting the field visit to Woodland Caribou Provincial Park. My greatest thanks to all the staff at Woodland Caribou Provincial Park, especially Park Biologist Christine Hague.

# INTRODUCTION

Forest-dwelling woodland caribou (*Rangifer tarandus caribou*) have experienced population decline and range recession across Canada since the beginning of the 20th century (Bergerud 1974). As a result, the species is listed as Threatened under both the federal *Species at Risk Act* (2002) and Ontario's *Endangered Species Act* (2007). Caribou are a challenging species to manage due to their habitat requirements and sensitivity to disturbance. As a landscape-level species, caribou select habitat at a broad scale to provide refuge from predators and at a fine scale to access forage (Rettie and Messier 2000). Caribou tend to occupy large, contiguous tracts of mature conifer forest and peatland where herbaceous and deciduous browse is less abundant (Hornseth and Rempel 2016). This reduces the density of moose (*Alces alces*) and subsequently wolves (*Canus lupus*), providing refuge from predation (Skatter et al. 2017). Within their home range, caribou show preference for terrestrial lichens as forage, especially in winter (Thompson et al. 2015). In some regions, caribou also demonstrate preference for lakes and islands, which provide important refuge and escape habitat (Kansas et al. 2016). Caribou tend to avoid areas with habitat and sensory disturbance including roads, forest harvesting and oil and gas development (Hornseth and Rempel 2016). In some areas, caribou also demonstrate avoidance of recent burns; it is thought that forest fires may contribute to population decline (Courtois et al. 2007; Schaefer and Pruitt 1991).

Despite the contention that fires may negatively affect woodland caribou, caribou inhabit areas with frequent, aggressive forest fires across the central boreal forest. Caribou have adapted to survive the effects of forest fires by occupying a large home range and utilizing undisturbed areas when a fire comes through (Dalerum et al. 2007). It is not uncommon for large portions of the home ranges of some individuals to be affected by forest fires (Skatter et al. 2017). In cases where fire disturbance is prevalent on the home range, the animal may display selection for residual patches of forest within the burn perimeter (Moreau et al. 2012). These residuals may provide adequate forage and refuge to sustain caribou in a landscape with high fire disturbance (Kansas et al. 2016).

The Sydney Range caribou population, located in northwestern Ontario, is classified as not self-sustaining due to a small population, low recruitment rate and high rate of range disturbance (MNRF 2014a). The northwest portion of the Sydney Range, which is largely protected by Woodland Caribou Provincial Park (WCPP), contains most of the area that has high habitat value and likelihood of occupancy for the Sydney caribou. The population is largely restricted to the northwest portion of the Sydney Range due to extensive anthropogenic disturbance including mines, roads and forest harvesting in the central and eastern portions of the Sydney Range.

In May 2016, a forest fire was ignited by a lightning strike in Manitoba. Fueled by strong winds, the Red 003 Fire crossed the Manitoba/Ontario border and burned into WCPP, advancing 22 km in a 24-hour period. Due to heavy fuel-loading and high fire indices, the Red 003 Fire exhibited extreme fire behavior, challenging suppression crews to keep it under control. By the time the fire was declared out on August 9, 2016, over 80,000 ha had burned in the southern half of the park (MNRF 2017a).

Natural resource managers recognize the importance of fire as an intrinsic process in the boreal forest and many government agencies strive to limit fire suppression to promote ecological integrity (Van Sleeuwen 2006; Pyne 2007). WCPP experiences an aggressive fire regime promoted by a dry, prairie-influenced climate (MNRF 2014a). Park managers employ a zoned approach to fire response that allows some fires to burn on the landscape with little or no suppression to promote ecological integrity. The Red 003 Fire burned large parts of the park identified as important habitat for the Sydney caribou (MNRF 2016). Although much of the area that burned was slated to receive fire suppression to protect caribou habitat values, the Red 003 Fire was simply to large and rapid to be suppressed. Fire crews focused on evacuating visitors from the park, preventing the fire from spreading to neighbouring Forest Management Units and protecting structures such as outpost cabins (MNRF 2017a).

Due to the large size of the Red 003 Fire and the extensive disturbance on the Sydney Range, park managers are now concerned that the Red 003 Fire could cause decline in the Sydney caribou population.

## OBJECTIVES

The general objective of this thesis was to identify how the Red 003 Fire will have affected caribou habitat and habitat use on the Sydney Range. The three main methods employed to answer this question were: 1) to classify the available habitat before the fire; 2) to find a Resource Selection Function (RSF) that best explains how caribou used that habitat; and 3) to infer how caribou habitat selection may have changed as a result of the Red 003 Fire.

The first specific objective of this thesis was to create a caribou habitat map for the study area. The study area in this project was restricted to the area that burned in the Red 003 Fire (hereafter referred to as ‘the Red 003 area’). A pre-fire Landsat 8 image was classified into five land cover types relevant to woodland caribou. The five land cover types in the caribou habitat map were mixedwood, upland conifer, sparse forest, treed peatland and open peatland. Accuracy assessments were conducted on the image using ground-truthed data and high-resolution imagery.

In the second specific objective, collaring data was used to construct RSF models for eleven female caribou on the Sydney Range to identify patterns in pre-fire habitat use in the Red 003 area. The RSF was based on a set of hypotheses for how caribou would use habitat on the Sydney Range and incorporated land cover type, disturbance and distance to water. Trends in selection were described using selection coefficients and descriptive statistics. Models were compared using Akaike Information Criterion (AIC) scores.

To satisfy the third specific objective, a literature review of caribou and fire ecology was conducted to determine how caribou alter their habitat selection patterns following forest fires. The results of the RSF and collar analysis were used to put the findings of other studies into the context of the Red 003 Fire. Post-fire habitat within the perimeter of the Red 003 burn was determined by combining a burn severity raster and the caribou habitat map. The ultimate specific objective of this project was to provide park managers with information on caribou habitat use prior to the Red 003 Fire. This information can be used to infer how the fire may affect caribou and their habitat on the Sydney Range, helping to guide management decisions including updating the park's Vegetation Management Plan.

## HYPOTHESES

A set of hypotheses was developed to describe patterns in caribou habitat selection. The hypotheses resulted in six models to compare to identify the best RSF (Table 1). A "browse hypothesis" predicted that caribou selected areas with a high potential to contain their preferred browse. Caribou rely on ground lichens as a major part of their diet, especially in winter (MNRF 2013). Ground-truth observations demonstrated that ground lichens were most abundant in sparse forest and upland conifer. The browse hypothesis predicted caribou would select for upland conifer and sparse forest due to the lichen forage in these forest types.

A “first refuge hypothesis” predicted that caribou selected areas close to lakes. This hypothesis was based on observations in the park and the tendency of caribou to use lakes as refuge and escape habitat (Kansas et al. 2016). A “second refuge hypothesis” predicted caribou selected areas in or near treed peatland. This hypothesis assumed that caribou use peatland complexes to separate themselves spatially from predators and to forage on arboreal lichens (MNRF 2013). A “natural disturbance hypothesis” predicted that caribou avoid recent burns, based on literature demonstrating that caribou avoid regenerating burned areas (< 36 years old) due to their low habitat value (EC 2012).

Table 1. Summary of models and associated hypotheses tested in the RSF.

| RSF Model Name | Hypothesis |
|---|---|
| Browse | Selection of upland conifer/sparse forest. |
| Refuge 1 | Selection of areas close to lakes. |
| Refuge 2 | Selection of treed peatland. |
| Natural Disturbance | Avoidance of recent burns. |
| Browse-Refuge | Selection of upland conifer/sparse forest close to lakes. |
| Full | Selection of unburned (> 36 years since fire) upland conifer/sparse forest close to lakes. |

Two additional hypotheses consisted of more than one hypothesis and were used to construct two multivariate models. The first multivariate model was the “browse-refuge hypothesis,” which predicted that caribou selected upland conifer and sparse forest close to lakes. These sites might provide the ideal combination of escape/refuge habitat and forage for caribou. The second multivariate model, the “full model,” predicted that caribou selected unburned upland conifer/sparse forest (> 36 years since fire) close to lakes. This model was built on the hypothesis that caribou would select for habitat away from recent burns, within sparse forest/upland conifer for forage, and close to lakes for refuge/escape habitat.

# LITERATURE REVIEW

## POLICY BACKGROUND

### Forest Fires

For much of the last 125 years, Ontario has attempted to achieve total fire suppression in the Area of Undertaking, where commercial forestry values have historically outweighed ecological values. Fire exclusion extended to provincial parks, since fires could spread to adjacent timber supply areas and were also generally considered destructive agents, for example, ruining park aesthetics and putting recreational users at risk (Pyne 2007). Today, the primary objective of planning and management in Ontario provincial parks is maintenance of ecological integrity (S.O. 2006 c.12, s.3). This objective is incompatible with fire exclusion, since fire is a vital natural disturbance in forest ecosystems, maintaining landscape heterogeneity and renewing wildlife habitat (Gallant et al. 2003). Ontario's Wildland Fire Management Strategy (2014) reflects the ecological importance of fire, and today many of Ontario's wilderness-class provincial parks have a modified approach to fire suppression that allow some fires to burn. For example, Woodland Caribou Provincial Park has developed a Fire Response Plan that permits fires to burn in the park while being monitored, with active suppression around values such as outpost cabins or critical habitat for species at risk (MNRF 2016).

### Woodland caribou

The boreal population of woodland caribou (*Rangifer tarandus caribou*) was classified as 'Threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2002 in response to widespread population decline (EC 2012). In Ontario, the southern extent of woodland caribou has retreated several hundred kilometres north over the past century, leading to the loss of some populations and severe decline in others (MNRF 2009). The decline in woodland caribou has been largely attributed to land-use change, specifically resource extraction industries that destroy habitat and increase predation rates (Bergerud 1974). Woodland caribou tend to inhabit large, contiguous tracts of mature pine and spruce forest, making use of uplands to forage for lichens. Lakes, islands and bog complexes are also important habitats for calving and predator avoidance/escape (MNRF 2009; EC 2012). Linear features such as roads and powerlines can increase forest fragmentation and predation rates by wolves (James and Stuart-Smith 2000). Habitat loss from fires and forest harvesting can cause caribou to avoid disturbed portions of their home range (Hornseth and Rempel 2016).

Recognizing the sensitivity of woodland caribou to disturbance, Environment Canada established a disturbance threshold to be used by managers to assess the sustainability of caribou population ranges as part of the federal recovery strategy. It stipulates that if a range is more than 35% disturbed by natural or anthropogenic disturbances, the range will be unable to support a self-sustaining population of woodland caribou. Managers in ranges defined as ‘not self-sustaining’ must prevent loss of critical habitat to promote the recovery of the local caribou population (EC 2012). Several woodland caribou ranges in Canada exceed the 35% disturbance threshold, including the Sydney Range in northwestern Ontario (MNRF 2014a). Policies that allow forest fires to burn in ranges with > 35% disturbance may contravene the federal woodland caribou recovery strategy and lead to further population decline. As a result, natural resource managers tend to consider protection of woodland caribou habitat when developing fire management policies (e.g. MNRF 2016).

## FIRE & CARIBOU

Historically, forest fires were viewed as categorically negative for woodland caribou, mainly due to the loss of mature conifer forests caribou rely upon for lichens (Bergerud 1974). The Aitkens caribou population in southeastern Manitoba grazed residual lichens in unburnt patches of forest heavily in the first four years after a large fire (Schaefer and Pruitt 1991). After these residuals were exhausted, the herd became severely food-limited, resulting in population decline. Woodland caribou in Quebec increased the size of their home range and decreased their fidelity to specific habitat areas in ranges with more disturbance (Courtois et al. 2007). Caribou also tend to move more in burned areas, due to the patchy distribution of residual forest and bog within the burn (Rickbeil et al. 2017).

Forest fires can also result in vigorous regrowth of herbaceous and deciduous plants, the preferred browse for moose. Post-fire population increases in moose can promote increased wolf populations, since moose are a primary prey species of wolves (Robinson et al. 2012). Since moose have a higher reproductive rate, they can persist on landscapes with a relatively high density of wolves. However, caribou, which have very low reproductive and calf survival rates, are very sensitive to wolf predation (Bergerud 1974). Several studies in western Canada have documented increased moose populations and wolf predation on caribou following disturbance, a phenomenon known as apparent competition (James et al. 2004; Robinson et al. 2012).

On the other hand, woodland caribou have evolved in the boreal forest over thousands of years in the presence of fire and have been able to compensate for temporary habitat loss because they occupy large home ranges (Kansas et al. 2016). Three woodland caribou populations in Alberta tracked over six to nine years did not alter the size or placement of their home range after fire, even when up to 76% of the home range was burned (Dalerum et al. 2007). Caribou can apparently compensate for the lost habitat by occupying unburned portions of their range and using residuals within the burn. In northwestern Ontario, caribou appeared to select recently disturbed areas in the Spirit Range, where 20% of the landscape was composed of burns less than thirty years old (Hornseth and Rempel 2016). Residuals within recent burns may include upland forest, bog complexes, lakes and islands. Caribou can employ a functional response to a new landscape after fire, allowing them to alter their habitat selection patterns to use residuals for foraging, travel, calving and predator avoidance/escape (Moreau et al. 2012; Kansas et al. 2016; Dalerum et al. 2007). For example, caribou may select isolated residuals within the burn surrounded by unproductive, burned forest. This behavior can help caribou separate themselves spatially from predators and the burned forest surrounding the residual may improve visibility of incoming predators, increasing the likelihood of escape (Skatter et al. 2017).

The vigorous growth of herbaceous plants and shrubs, although possibly increasing apparent competition with moose and wolves, can improve the nutritional quality of summer forage for woodland caribou (Thompson et al. 2015). Fires are also essential for renewing lichen-producing forests. As succession proceeds, over-mature stands will eventually develop dense canopies and the forest floor will be covered in mosses. Fires open the canopy in mature stands, increasing light penetration to the forest floor and promoting lichen regrowth (Schaefer and Pruitt 1991). In the first few years after the fire, movement through the burn may be improved due to clearing of understory debris and vegetation, allowing caribou to move through the burn easily and make use of residual habitat. These residual patches of habitat may contain high-quality lichen forage and be selected by caribou so long as food remains available (Schaefer and Pruitt 1991). As the burn ages, downed wood will begin to fall, regenerating trees will form dense stands, the energetic cost of moving through the landscape will increase and residual lichen patches will be heavily grazed. The lack of food and higher energetic costs of moving through the burn may result in range abandonment or population decline. The burned portion of the range may not be reoccupied until about 40 years after fire once sufficient lichen resources are renewed and movement through the burn is again easier.

There are several challenges in assessing the effects of forest fires on woodland caribou. The first is that there is a lack on information on how caribou use residual habitat within burn perimeters in part because fire maps used in most woodland caribou studies do not separate lakes, islands and residual bog or forest from burned areas (Kansas et al. 2016). Landsat imagery used to backcast post-fire residuals in northern

Saskatchewan found that 33% of the area within provincial fire polygons was in fact unburned and 25% of the fire polygon area was unburned terrestrial habitat. Therefore, there may be significant residual habitat within burns that must be considered when assessing total caribou habitat.

The second issue in studying post-fie caribou habitat use is temporal scope, as fires have different short-term and long-term effects on woodland caribou. Since most studies only look at the effects of fire over a short period (i.e.one to three years), conclusions about positive or negative effects may only apply to the time frame studied. Also, caribou populations are so low in many study areas that variability between animals and between years is amplified, especially in radio-collar studies, where only a few animals are tracked (Courtois et al. 2007). In addition, researchers should attempt to look at the entire burn area when assessing effects of fire on caribou, due to the erratic nature of forest fires (Schaefer and Pruitt 1991).

A third issue in studying the effects of fire on woodland caribou is local context. Habitat selection and other behaviors in woodland caribou vary considerably across the boreal forest. Some populations are very sedentary, others migrate between ecoregions or to different elevations (Newton et al. 2015; Gustine and Parker 2008). Some populations rely heavily upon lakeshore and island habitats, others occupy bedrock and upland forest complexes, while some populations demonstrate strong preference for bogs (Cumming and Beange 1987; Schaefer and Pruitt 1991; Dalerum et al. 2007). Additionally, each range has various levels and types of disturbances, which will affect post-fire habitat use (Courtois et al. 2007).

Fire is undoubtedly one of the primary forces affecting woodland caribou habitat in the boreal forest. The scientific community generally highlights the negative aspects of fire for woodland caribou, while suggesting caribou may develop adaptations to deal with these severe changes (Kansas et al. 2016). Developing a better understanding of the effects of fire on woodland caribou is critical, given the emphasis of disturbance thresholds in the federal recovery strategy and potentially conflicting fire management practices in protected areas. Managers must have detailed information about local conditions to make informed decisions that balance the ecological role of fire while protecting woodland caribou populations.

## RESOURCE SELECTION FUNCTIONS

Understanding habitat use is integral to developing suitable conservation and management strategies for wildlife. A common way to assess habitat selection is to use a Resource Selection Function (RSF). In its most basic form, an RSF defines selection using a use-availability matrix. If on average individuals use a habitat element proportionally and significantly greater than its availability on the landscape, it is considered selected. If on average individuals use a habitat element proportionally less than its availability, it is considered not selected (Johnson 1980; hereafter, ‘select’ and ‘selection’ will be used in this sense). Today, RSFs use probabilistic functions that allow for spatially explicit predictions of habitat use and availability. Researchers can use RSFs to test hypotheses about the forces driving habitat selection, providing valuable information when developing management strategies (Hornseth and Rempel 2016). When developing an RSF, the researcher must be aware that their results are largely dependent on how they classify the landscape. This will define the available habitats to the animal, which drives the results of the RSF (Johnson 1980). Therefore, it is critical the researcher has a good understanding of the ecology of the animal of interest to ensure the variables in the RSF are meaningful to habitat selection by the species.

Another important concept in wildlife biology is that habitat selection is hierarchical. By convention, first-order selection defines the location of the population range of the species, driven primarily by geographic and biophysical factors (Johnson 1980). Second-order selection is the location of individual home ranges within the population range. Third-order selection is the selection of habitat patches within the individual home range. The finest scale of selection, fourth-order, is the selection of resources such as forage plants within habitat patches.

As a landscape-level species, woodland caribou demonstrate hierarchical habitat selection, and researchers must choose an appropriate spatial scale or range of spatial scales to assess the various orders of habitat selection. This decision is ultimately driven by the level of detail the researcher is interested in obtaining. For example, to analyse caribou use of post-fire residuals, third-order selection would need to be studied. Scale-integrated RSFs are now being used to study caribou habitat selection at multiple spatial scales simultaneously, allowing a more efficient and complete understanding of habitat selection patterns (DeCesare et al. 2012).

A vital part of creating any Resource Selection Function is accurately depicting the domain of availability for an animal at a given point in time. In theory, the entire home range could be considered ‘available’ for selection. However, since the home ranges of woodland caribou are typically large, and collar locations are transmitted every several hours, it is unreasonable from an energetic perspective to assume all parts of the animal’s home range are equally available between subsequent collar locations (Forester et al. 2009). Researchers now commonly use step length models to more accurately define the domain of availability in RSF studies. A step is simply defined as a straight-line segment between subsequent collar locations (i.e. the distance from Point A to Point B; Fortin et al. 2005). Using step length to define the domain of availability means the available points generated to analyse trends in selection reflect the normal movement patterns of the animal. It is thought to create a more accurate depiction of habitat use than models that do not consider animal movement when determining the domain of availability (Forester et al. 2009).

Woodland caribou show preference for different habitat types throughout the year (Ferguson and Elkie 2004). Females are commonly observed calving in peatland complexes, islands or around lakes to improve refuge from predation. Throughout the summer months, caribou tend to wander throughout their home range, utilizing a mosaic of different habitat types (Rettie and Messier 2000). Fall and spring are considered the travel seasons, where caribou move from their calving/summer range to their winter range and from their winter range to their calving range (Ferguson and Elkie 2004). Winter is considered the most limiting season for caribou, since it is the season that typically dictates survival and successful calving the following spring. In winter, caribou diets are restricted mostly to terrestrial and arboreal lichens (Thompson et al. 2015). Caribou tend to congregate in areas with abundant lichen and low snow cover, moving less frequently than in other seasons (MNRF 2013). Because these trends in selection have been noted, many RSF studies analyse seasonal differences in habitat selection.

## HABITAT CLASSIFICATION

Developing an RSF requires determining what is available to the species as habitat. In forest ecosystems, this requires classifying the vegetation communities in the study area. Ideally, this classification is based on ground-truthed observations that document dominant plant community types (Rettie et al. 1997). Once the ground-truthed data is acquired, the classification is applied to the entire landscape using remote sensing and Geographic Information Systems (GIS). The most commonly used datasets in woodland caribou habitat studies are Landsat satellite imagery and provincial forest resource inventory.

### Landsat Imagery

Over the past 45 years, Landsat satellites have been taking images of every location on the Earth's surface approximately twice a month. In 2008, the United States Geological Survey opened the entire Landsat archive to the public free of charge. Opening the Landsat archive has allowed researchers to ask and answer big questions about our planet. Today, Landsat data is used extensively in many fields of study around the world (Wulder et al. 2012). Landsat images are composed of several bands, each capturing different wavelengths of the electromagnetic spectrum. Each pixel in the resulting Landsat scene represents 30 m x 30 m on the ground (Frazer Sherrit 2014).

Landsat is popular among scientists because it is freely available and represents a long series of observations that can be used to track trends over time (Wulder et al. 2012). One of the disadvantages of Landsat imagery is its relatively coarse spatial resolution. Since each pixel represents 30 m x 30 m on the ground, it can only provide coarse classifications of land cover. Another issue with Landsat is clouds, smoke and haze, with can result in gaps in the classification or confuse the software and cause misclassification. Despite the drawbacks, Landsat has been used quite commonly in caribou habitat studies (Frazer Sherritt 2014). To create a map of caribou habitat, the Landsat image needs to be classified so the habitats can be easily interpreted. Image classification is the process of using the spectral properties of an image to group pixels into meaningful classes for the end user. Features on the Earth's surface such as rock, water and vegetation reflect the various wavelengths of electromagnetic radiation in different ways, creating unique spectral signatures. Computer software can analyse the spectral properties of each pixel and group pixels with similar spectral properties together in the same class (Jensen 2005).

The simplest method of image classification is unsupervised classification, where the user defines the number of classes and the software separates the pixels into different classes based on their spectral properties. The user then assigns the created classes a land cover type, often determined by referencing the original, unclassified image (Jensen 2005). The second method of image classification is supervised classification. In supervised classification, the user takes samples from the image representative of different land cover types they can identify visually or based on field observations. The samples are used to create a spectral signature for the desired land cover types that trains the software to recognize other pixels with similar properties. The software classifies the entire image referencing the signature file (Jensen 2005).

### Accuracy Assessment

All reputable remote sensing studies report classification accuracy. This information is extremely important for resource managers to make informed decisions

(Frazer Sherritt 2014). In all remote sensing exercises some pixels will be misclassified because the software is unable to distinguish between features with similar spectral properties (Jensen 2005). Therefore, it is very important to quantify this misclassification, which can be done using accuracy assessment (Frazer Sherritt 2014). Accuracy assessment involves comparing the classified image to a reference layer which may include the original image, an image with a finer spatial resolution and/or information from ground-truthed data. At least 50 random points are generated within pixels from each class in the classified image. The user assigns each point to a class based on the reference layer. The software then compares the class the user assigned for the pixel to the class the computer assigned the pixel to. The resulting error matrix and accuracy totals provide a quantitative assessment of the agreement between the classified image and the reference layer.

It is suggested that classified images used for habitat studies have an overall accuracy ≥ 85% with no individual class less than 70% accurate (Thomlinson et al. 1999). Despite this general guideline, many habitat studies for woodland caribou have much lower total accuracy or do not report accuracy whatsoever (Frazer Sherritt 2014). Accuracy also depends on the classification rules set by the researcher. For example, for very broad categories such as disturbed and undisturbed or peatland and forest, will likely result in higher classification accuracy due to major differences in spectral properties of these land cover types (Courtois et al. 2007; Dalerum et al. 2008). However, some studies may require a finer classification resolution that may result in lower accuracy (e.g. Lay 2005). Therefore, researchers must decide on the balance between accuracy and classification resolution and communicate this trade-off clearly to the end user.

## Forest Resource Inventory

Provincial forest resource inventory data is commonly used in wildlife habitat studies. In Ontario, a Forest Resource Inventory (FRI) has traditionally been created on a 20-year production cycle by the Ministry of Natural Resources and Forestry (MNRF). High-resolution imagery is captured by fixed-wing aircraft flying systematic gridlines over the Area of Undertaking (AOU), the region where commercial forestry is practiced in Ontario. The most recent imagery was captured by a Lecia ADS 40 image scanner with a pixel resolution of 40 cm x 40 cm. Ground crews visit pre-determined sampling plots to collect detailed soil and vegetation information. Photo interpreters use the ground plot information and other data sources to assist in their delineation of ecosites within each image. The interpreters draw polygons on the aerial images representing discrete ecosites and each polygon is assigned attributes such as tree height and stand age (Frazer Sherrit 2014).

The primary advantage of using FRI data in wildlife studies is the ability to create habitat maps at a finer spatial and classification resolution than most remote sensing technologies (Frazer Sherrit 2014). In addition, since ecosite or vegetation characteristics are already interpreted for each polygon, the researcher does not have to start the classification process from scratch. Often, polygons are grouped into a new classification scheme more relevant to woodland caribou habitat (e.g. Dyke 2008). In addition, using FRI allows for easy incorporation of wildlife habitat objectives in forest management planning through standard habitat models (Elkie et al. 2014).

Despite the positives of FRI, there are several drawbacks to using this type of data in habitat studies. First, due to the long production cycle, FRI does not always reflect current conditions on the forest, especially in very dynamic ecosystems where disturbances are frequent and cause large-scale change (Boan et al. 2013). Also, Hague (pers. comm., September 6, 2017) stated that as a forest management planning tool, active Forest Management Units (FMUs) receive priority for FRI renewal to support decision-making. This means that provincial parks are often last in line to receive FRI, posing a challenge to using the data to direct management activities. Also, Ontario's FRI is only available in the Area of Undertaking, meaning its application in caribou studies is limited since most caribou ranges in the province are north of the Area of Undertaking. It has also been suggested that the ecosite scale is not appropriate for most woodland caribou habitat studies, since habitat selection often takes place at larger scales (e.g. Hornseth and Rempel 2016).

# METHODS & MATERIALS

## STUDY AREA

Woodland Caribou Provincial Park (WCPP) is located in northwestern Ontario, approximately 30 km west of the town of Red Lake and 90 km north of the city of Kenora (Figure 1). WCPP was designated a wilderness-class provincial park at its founding in 1983. Today, the park is one of several protected areas in the region that together encompass over 1 million ha of boreal forest. In addition to preserving boreal forest ecosystems, the park provides excellent recreational opportunities for anglers and canoeists. Many Indigenous cultural values are found within the park and are particularly well-documented along the Bloodvein River (MNRF 2004).

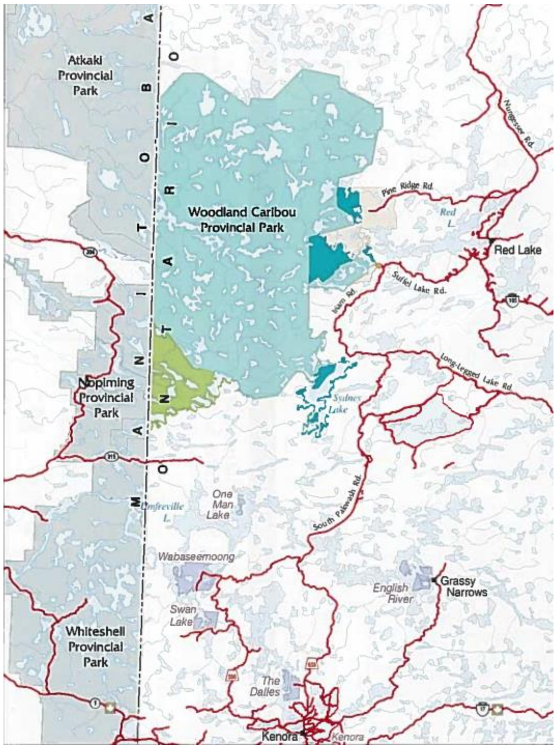


Figure 1. Regional context of Woodland Caribou Provincial Park (MNRF 2004).

Protecting boreal woodland caribou was one of the primary reasons WCPP was established (MNRF 2004). The southern half of the park protects a portion of the Sydney Range, one of Ontario’s 14 woodland caribou ranges (Figure 2). The southern part of the park is dominated by jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) BSP) with extensive areas of exposed bedrock. The area is also characterised by a high density of small lakes with irregular shorelines and numerous islands (MNRF 2014a).

Figure 2. Location of the Sydney Range, outlined in the thick grey line (MNRF 2014a).

Due to its proximity to the Great Plains, WCPP experiences climate conditions similar to the boreal forest of the prairie provinces. The park has one of the shortest fire cycles in Ontario, leading to a very dynamic ecosystem. Park managers insist that “nature still rules” in WCPP, and maintaining ecological integrity, including a role for fire, is top of mind for park managers. The park’s fire regime is dominated by large, stand-replacing fires with a fire cycle of approximately 100 years (MNRF 2004). In 2016, the Red 003 Fire burned a large portion of the southern part of WCPP, including much of the area being used by the Sydney caribou population. The study area for this project is defined as the intersection of the Red 003 Fire and the Sydney Range in Woodland Caribou Provincial Park (Figure 3).

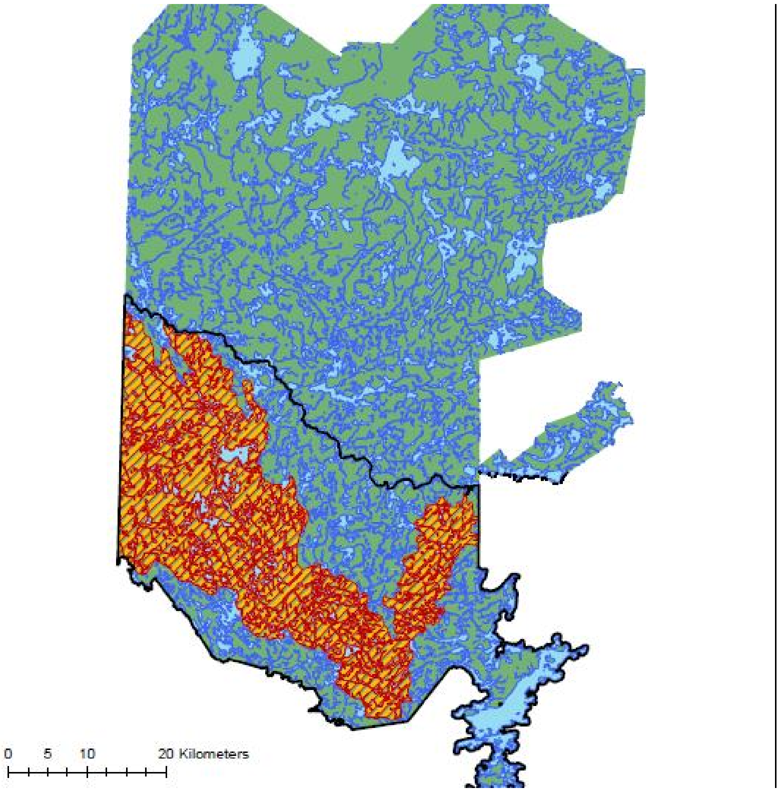


Figure 3. The study area for this project is highlighted in orange. It represents the intersection of the Red 003 Fire and the Sydney Range in Woodland Caribou Provincial Park.

## FIELD SAMPLING

Field sampling for this project was conducted by Joe Silva and Park Biologist Christine Hague from August 30th-September 6th, 2017 in the central portion of the Red 003 burn- the Bulging-Haggart-Broken Arrow lakes system. This area is representative of the Sydney Range and offered the opportunity to visit bog, island, bedrock and forested habitats. This area was also selected due to a diversity of burn severities and known presence of caribou prior to the burn. A floatplane was used to access Bulging Lake, after which canoe was the mode of transportation. The purpose of the field visit was to conduct vegetation sampling to determine suitable habitat classes and to provide a reference layer for an accuracy assessment of the caribou habitat map.

Due to the mode of travel within the park, sampling locations were not selected prior to the field visit. A combination of maps including Landcover 2000, collar locations, burn severity and satellite imagery were used in the field to identify good candidate sites for ground-truthing. At each sampling location, a waypoint was entered for the canoe and a transect was established by taking a compass bearing. Each transect measured 150 m in length and was oriented to bisect the feature(s) of interest identified at the time of selecting the sampling location. A 5.64 m radius plot was established every 50 m on the transect and recorded on the GPS.

The number of stems and species of all trees > 10 cm diameter at breast height (DBH) within the plot were recorded. The DBH of an average stem of each species was measured and recorded to the nearest 0.5 cm. If no trees in the plot exceeded 10 cm DBH, the number of stems in the plot was recorded and the DBH of an average tree was measured to the nearest 0.5 cm. DBH of living trees was recorded preferentially if they were present in the plot. The understory observations consisted of recording the top five tree and shrub species by cover within the plot < 1.3 m in height. An overall percent cover of these understory species within the plot was also recorded.

Ground cover and ground vegetation was assessed in a 1 $m^2$ subplot established by throwing a pen from plot centre. Within this subplot, percent ground cover was visually estimated for the following categories: small dead wood, coarse dead wood, bedrock, stones, mineral soil, conifer, broadleaf and graminoid litter, humus, lichens, feathermoss, sphagnum and other mosses. The presence of all herbaceous plants and bryophytes growing in the 1 $m^2$ plot were recorded. Duff thickness in the centre of the 1 $m^2$ plot was measured using a ruler and a small trowel. Pictures were taken at each plot facing north and south from the 5.64 m radius plot centre. Field data was collected from a total of fifty-seven plots over nineteen transects. A GIS file was created from the ground-truthed data. The information collected in the field was used to assign each plot to one of five land cover classes: mixedwood, upland conifer, sparse forest, open peatland or treed peatland. This data was later used as a reference layer for an accuracy assessment of the caribou habitat map.

## CARIBOU HABITAT CLASSIFICATION

To make an informed decision about which data source to use to classify caribou habitat, a review of several woodland caribou habitat studies was conducted. Most studies used either forest resource inventory or Landsat to classify woodland caribou habitat (Table 2). Many of the studies that used forest resource inventory data were designed to create Habitat Suitability Indices or used in other applications less relevant to this thesis. Because FRI polygons for WCPP are still being produced and will not be available until the spring or summer of 2018, Landsat was used to create the caribou habitat map in this thesis to match the approach of most of the studies reviewed here.

Table 2. Summary of data sources used to classify habitat in woodland caribou studies.

| Study | Habitat Classification | | |
|---|---|---|---|
| | Landsat | Forest Resource Inventory | Other |
| Dyke 2008 | | x | |
| Frazer Sherritt 2014 | x | x | |
| Hornseth and Rempel 2016 | x | | |
| Curtois et al. 2007 | x | | |
| Moreau et al. 2012 | x | | |
| Rettie and Messier 1997 | | x | |
| Gustine et al. 2006 | x | | |
| Dalerum et al. 2007 | | | x |
| Schaefer and Pruitt 1991 | | | x |
| Rickbiel et al. 2017 | x | | |
| Kliskey et al. 1999 | | x | |
| Johnson et al. 2004 | | x | |
| Bechtel et al. 2004 | x | | |
| Rettie and Messier 2000 | | x | |
| Boan et al. 2013 | | x | |
| Lay 2002 | x | | |
| Johnson et al. 2003 | x | | |
| Schindler and Lidgett 2006 | | x | |
| Gustine and Parker 2008 | x | | |
| Total | 10 | 8 | 2 |

Since the RSF is based on pre-fire collar locations, a Landsat 8 image from July 31$^{st}$, 2014 was selected to classify pre-fire land cover types. All image processing and classification was conducted using the ERDAS IMAGINE remote sensing software. Because many studies that use Landsat data to classify forests use the red, near infrared (NIR) and short-wave infrared (SWIR) bands (e.g. Wolter et al. 1995), Landsat 8 bands 6,5,4 were stacked to create a multispectral image for classification.

Once the multispectral image was created, the Red 003 burn polygon was used to subset the image to the study area. Prior to subsetting the image, the Red 003 burn polygon was buffered by 2100 m to account for the reported 100 m accuracy of the polygon and the maximum distance available points generated for the RSF were expected to be from the burn. Once the multispectral image was subset to the study area, pixels representing water were masked out of the image with a supervised classification of just two classes: water and land. This classified image was recoded and used as a mask layer to remove the pixels representing water from the original multispectral image. Removing these pixels increased the efficiency of classifying terrestrial habitats.

The multispectral image was classified into five land cover types relevant to woodland caribou: open peatland, treed peatland, mixedwood, upland conifer and sparse forest. Since ground-truthing of land cover types was limited to a small area during field data collection, 25 km$^2$ FRI ortho tiles (40 cm resolution) in false colour were used to identify suitable training sites for a signature file. Instead of sampling the entire burn, which consisted of fifty-two ortho tiles, samples were taken from eight tiles. Tiles were selected to be spread evenly throughout the burn and to contain diverse land cover types as identified in Landcover 2000.

Five training sites were selected per cover type in each tile, for a total of 200 training sites. An additional ten training sites were added for mixedwood and upland conifer to improve separation of these cover types. Additional training sites were added for open peatland, due to misclassification in early classified images. Areas that appeared to be affected by recent disturbances or areas not supporting a distinct land cover type were also included in the open peatland class since these areas, like open peatland, were not expected to be used significantly by caribou (Figure 4). These adjustments led to a total of 251 training sites in the final signature file. The signature file was used to run a supervised classification on the multispectral image (Figure 5).

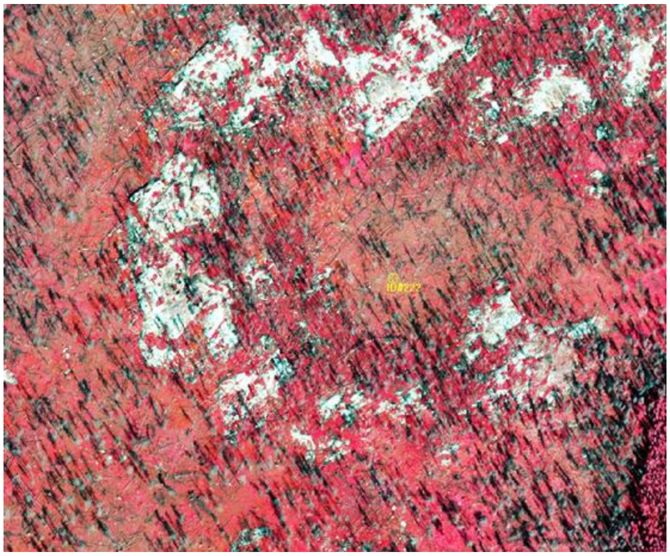


Figure 4. A part of the study area that appears recently disturbed. Such areas were included in the open peatland class.

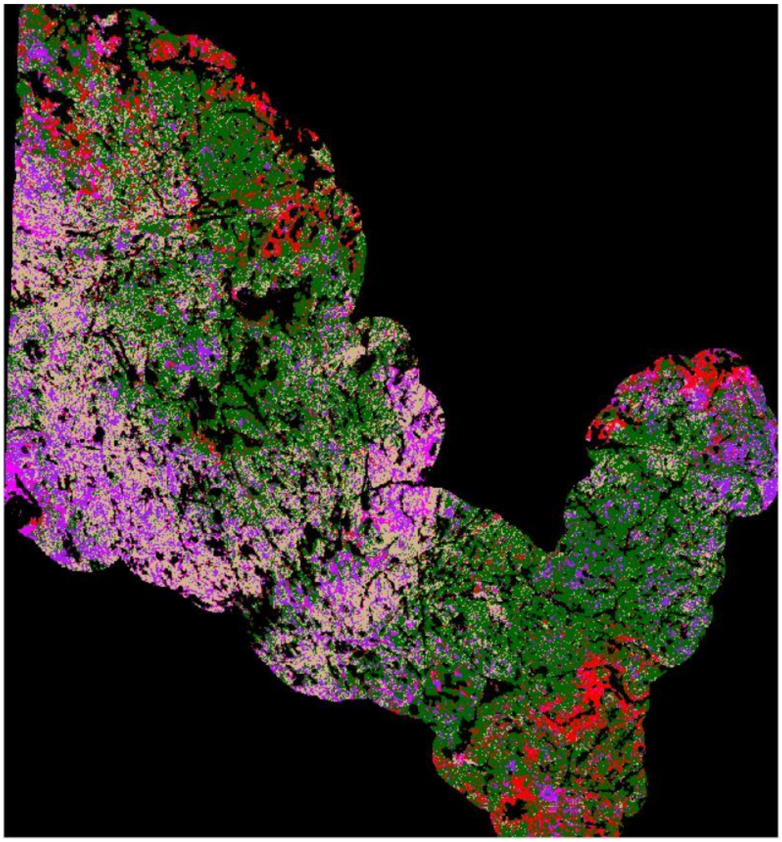


Figure 5. Caribou habitat map for the Red 003 area. Green = upland conifer, tan = sparse forest, red = mixedwood, purple = treed peatland, pink = open peatland.

The classified image was recoded and subset to the extent of the ortho tile coverage for the accuracy assessment. The accuracy assessment tool was used to generate 50 random points in each cover type. The FRI ortho tiles were used as the reference layer for a formal accuracy assessment. In addition to the formal accuracy assessment conducted in ERDAS, the field data GIS file was used as a reference layer to perform an informal accuracy assessment to determine if the classified image agreed with the ground-truthed observations. The final caribou habitat map was converted to a polygon file for the RSF. The geometry of the resulting polygon file was simplified to reduce the incidence of unnatural shapes and increase minimum patch size to ≥ 0.5 ha.

## PRELIMINARY COLLAR ANALYSIS

The collaring dataset used in this investigation is from the Integrated Range Assessment collaring project. This dataset provides the most recent information on pre-fire caribou habitat use in and around the Red 003 area. Twelve adult female caribou inhabiting the Sydney Range were fitted with Argos GPS collars (Telonics Inc.) on February 9, 2012. The dataset was restricted to eleven animals since one animal died early in the study. All other study animals retained their collar for two to three years, for a minimum of 1,670 points and a maximum of 3,243 points during the study period.

The Red 003 Fire polygon was buffered by 110 m and this boundary was used to determine if collar locations were in or out of the Red 003 area. The 110 m buffer accounts for the positional accuracies reported for the burn polygon and the collar locations. One of five seasons was assigned to each point according to scientific observations of seasonal caribou habitat use: winter (December 1st-March 31st), spring (April 1st-April 30th), calving (May 1st-July 14th), summer (July 15th-Spetember 15th) and fall (September 16th-November 30th; MNRF 2013; Ferguson and Elkie 2004). A preliminary analysis of the collar data was undertaken to determine the time spent by each animal in the Red 003 area as a proportion of the study period. The seasonality of use in the Red 003 area was also summarized. A Python script written by Tomislav Sapic was used for this analysis and is included in Appendix I.

For the purposes of the RSF, more data cleaning of the collaring dataset was necessary. The collars used in this study reported two types of locations: GPS locations and Argos locations, resulting in irregular location transmissions including some days when no messages were received and other days when several messages were received. This phenomenon is common in collaring studies and can cause bias since more points may be collected in open habitats or on days with clear weather. Some researchers attempt to deal with this issue by randomly selecting a single point per day per animal (e.g. Hornseth and Rempel) or by applying other mathematical techniques (e.g. Aarts et al. 2008). In this study, the collaring dataset was restricted to only include GPS locations since GPS locations are transmitted at more regular intervals and have greater positional accuracy than Argos locations (Argos 2016). MNRF staff indicated the Sydney GPS collar locations have a positional accuracy of ± 20 m. To address bias in telemetry fix rate, points selected for inclusion in the RSF had consistent elapse time of five hours since the last location, restricting the RSF to the programing of the collars during their first year (2012-02-09 to 2013-03-31).

## RESOURCE SELECTION FUNCTION

In this study, step length was used to define the domain of availability for all caribou between subsequent collar transmissions. Each step involved a point pair, where an animal moved from Point A to Point B. Point B in the point pair is considered ‘selected’ and hereafter will be referred to as the used point. A Python script was used to identify point pairs with points five hours apart and both points in the Red 003 area (Appendix I). This dataset was further restricted so that only records representing used points were retained, which resulted in a final set of 4,096 point pairs.

Step length was calculated for each point pair in the resulting dataset using a simple script in the Field Calculator (Appendix I). The mean step length was then to be used to define the domain of availability. However, all animals in the study demonstrated an exponential distribution for step length. The arithmetic mean is not the best measure of central tendency for data that is not normally distributed. To derive a more accurate average step length, geometric means needed to be calculated. This required transforming the data using log base 10, taking the arithmetic mean of the log transformed data and taking the anti-log of the arithmetic mean (Appendix I). This resulted in a geometric mean step length for each animal. The mean step length for the population was calculated by taking the average of the geometric mean step lengths (Table 3).

Table 3. Geometric mean step length (of log-transformed data) and maximum step length for 11 female caribou in the Sydney Range. Step lengths are for 5-hour intervals spanning 2012-02-09 to 2013-03-31.

| Animal Number | Mean Step Length (m) | Maximum Step Length (m) |
|---|---|---|
| C241 | 198 | 13144 |
| C243 | 262 | 16391 |
| C246 | 235 | 7510 |
| C253 | 296 | 14398 |
| C256 | 363 | 15079 |
| C257 | 336 | 9511 |
| C264 | 285 | 9363 |
| C265 | 251 | 11671 |
| C275 | 224 | 22292 |
| C277 | 265 | 7766 |
| C278 | 279 | 13622 |
| Totals | **272** | **22292** |

Each animal displays different movement characteristics with respect to step length (Table 3). Animal C241 had the lowest geometric mean step length at 198 m. Animal C256 had the highest geometric mean step length at 363 m. The maximum step length observed over a 5-hour period was 22,292 m traveled by C275 on March 23/24, 2012 (late winter). The mean step length for the population was 272 m.

Step length acted as the parameter in an exponential distribution used to generate a set of thirty available points for each used point. Three times the observed mean step length (816 m) was used as the parameter for the exponential distribution. This distance was larger than 80% of the observed step lengths and was chosen by the convention of Forester et al. (2009), who used two times the observed mean step length to make the domain of availability more realistic. Generating the available points consisted of three steps: 1) draw a random step length from the exponential distribution centred on Point

A; 2) draw a random bearing travelled from Point A (0-360°); 3) derive the x-coordinate and y-coordinate of the available point.

The step length for each available point was drawn from the exponential distribution:

$$\Phi_p (r_p) = \lambda_p \exp(-\lambda_p d_p)$$

Where $\Phi_p (r_p)$ = step length drawn from the exponential distribution

$\lambda_p = 1/816$

$d_p = 816$

A random bearing (0-360°) was paired with each step length and x and y-coordinates for each available point were generated according to the following equations:

$$p_x = a_x + r_p \cos(u_p)$$

$$p_y = a_y + r_p \sin(u_p)$$

Where $p_x$ and $p_y$ are the x and y coordinates of the available point

$a_x$ and $a_y$ = the x and y coordinates of Point A

$r_p$ = step length drawn from the exponential distribution

$u_p$ = random bearing drawn from 0-360°

This procedure was repeated thirty times for each point pair, resulting in a new dataset with a total of 134,580 available points. The script used for this procedure was written by Tomislav Sapic and is attached in Appendix I.

Once the set of available points was generated, a binary variable was added to the available point and point pair datasets to indicate whether each point was used (1) or available (0). Environmental variables were attached to each used and available point to compare trends in habitat selection through the RSF (Figure 6). In this study, the three habitat variables tested were land cover, distance to water and disturbance. Spatial joining was used to assign a land cover value from the caribou habitat map to each used and available point. Spatial joining was also used to assign each point as either in or out of disturbance. Disturbances in this study were defined as areas that had burned in a forest fire in the last 36 years. The data used for this variable was produced by the MNRF in 2012 as an output from the Caribou Screening Tool. Distance to water was calculated for each point using the Near tool in ArcMap and the OHN_WATERBODY shapefile as the lakes layer.

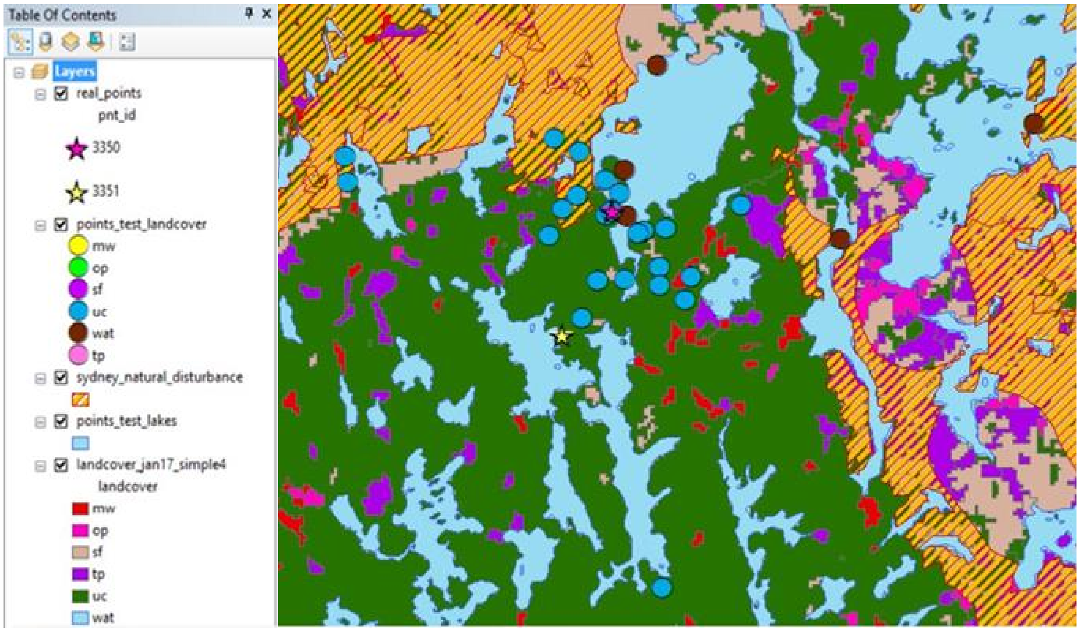
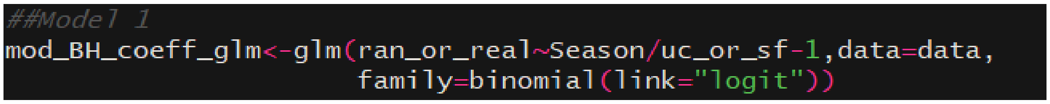


Figure 6. Example point pair with available points. In this example the pink star is Point A and the yellow star is the used point. The large circles are the available points for the point pair coloured by land cover type.

Once the environmental variables were attached, the used and available points datasets were exported from ArcMap as a .csv file. Both datasets were brought into SPSS and a series of binary variables were added to facilitate testing of the hypotheses in the RSF. The first binary variable denoted whether a point was in (1) or out (0) of disturbance. The second denoted whether a point was in upland conifer or sparse forest or in another cover type. The third denoted whether a point was in treed peatland (1) or in another cover type (0).

R Version 3.4.3 was used to run the generalized linear models for the Resource Selection Functions (RSFs). Initially, the RSFs were run as generalized linear mixed effects models using the ‘glmer’ function. A random effect for animal number was set to determine if there were differences in selection between individual animals. The variance for the random effect of animal number was consistently very close to zero for all hypotheses, meaning there was no discernible difference in selection among individuals. The RSFs were also run using ‘glmer’ with a random effect for both animal number and point number to see if differences in the set of available points affected selection. The variance for a random effect of point number was consistently close to zero, meaning there is no discernable difference in selection with respect to the set of available points.

Based on these preliminary results, to improve model parsimony all six RSFs were run using the generalized linear model or ‘glm’ function. The ‘glm’ function used binomial logistic regression to derive selection coefficients for each variable by season (Figure 7).



```
##Model 1
mod_BH_coeff_glm<-glm(ran_or_real~Season/uc_or_sf-1,data=data,
                      family=binomial(link="logit"))
```

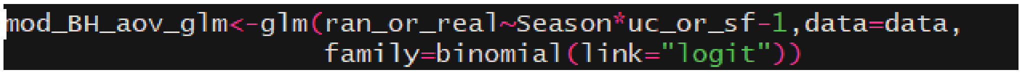
Figure 7. Code used in R to derive the selection coefficients for the Browse Hypothesis model.

The dependent variable in the generalized linear model was whether the point was used (1) or available (0). Each model contained a fixed effect for season and a fixed effect for the variable(s) of interest (Table 4).

Table 4. Model set and data structure for the generalized linear models tested in the Resource Selection Function.

| Model Name | Fixed Effects |
|---|---|
| Browse Hypothesis | Upland conifer/Sparse forest<br>Season |
| Refuge Hypothesis 1 | Distance to water<br>Season |
| Refuge Hypothesis 2 | Treed peatland<br>Season |
| Natural Disturbance Hypothesis | Disturbance<br>Season |
| Browse-Refuge Hypothesis | Upland conifer/sparse forest<br>Distance to water<br>Season |
| Full | Upland conifer/sparse forest<br>Distance to water<br>Disturbance<br>Season |

The selection coefficients for each hypothesis by season were graphed using the ‘ggplot’ function. Each model was run a second time to derive an interaction effect between season and the variable(s) of interest, enabling an ANOVA table and AIC score to be calculated (Figure 8).



```
mod_BH_aov_glm<-glm(ran_or_real~Season*uc_or_sf-1,data=data,
                    family=binomial(link="logit"))
```

Figure 8. Code used in R to derive the ANOVA table and AIC score for the browse hypothesis model.

An Akaike Information Criterion (AIC) table was used to compare models and to determine which model best explained caribou habitat selection (Wagenmakers and Farrell 2004).

## DESCRIPTIVE STATISTICS

SPSS Statistics was used to summarize the used and available point datasets to help interpret the results of the RSF. To facilitate the calculation of descriptive statistics, a single dataset containing the values for the used point and its associated available points was generated in ArcMap. The count of points in each land cover type and in disturbance for each set of available points was generated using the Summary Statistics tool. The tables generated by the Summary Statistics tool were linked to the associated used point in the point pairs dataset using a table join function. The resulting table was exported to Excel and columns were added to indicate the proportion of available points in each land cover type and in disturbance. Cross-tabs was used to compare the proportion of used and available points in each land cover type and disturbance class.

Following the convention of Hebblewhite and Merrill (2008), the mean distance to water of used points was compared to mean distance to water for the available points. Due to the high density of lakes in the study area, both used and available points demonstrated an exponential distribution for distance to water. This required transforming the data using log base 10, taking the arithmetic mean of the log transformed data and taking the anti-log of the arithmetic mean. For the available points, this procedure was conducted using a Python script (Appendix I). The mean distances to water for the available points still displayed an exponential distribution. As a result, they were transformed in SPSS as described above, as was distance to water for the used points. Points in lakes (distance to water = 0 m) were included in the analysis and were converted to 0.1 m from water since log base 10 of zero is a math error.

## POST-FIRE HABITAT

Jevon Hagens, a Research Forester at the MNRF Centre for Northern Forest Ecosystem Research, produced a burn severity map of the Red 003 Fire. Jevon used a differenced Normalized Burn Ratio (dNBR) to classify burned and unburned land within the Red 003 Fire perimeter. The dNBR values were used to classify the burn into low, moderate and high severity burn classes (Kansas et al. 2016).

The fire severity map and land cover map were clipped to the same extent using the polygon Jevon generated for the burn. To easily interpret which land cover types burned, the raster values for the land cover map were multiplied by 100. The burn severity raster values were reclassified so that NoData (unburned) pixels had a value of 4. Then the fire severity and land cover rasters were added using the Raster Calculator to create one raster that indicated the area of each landcover class that burned or remained unburned after the Red 003 Fire. This raster also indicated the area of each land cover type affected by each burn severity. The total number of unburned pixels for each land cover type was used to determine the area and percentage of the Red 003 Fire polygon that was residual habitat.

To estimate how much area of the home ranges of individual animals the Red 003 Fire affected, the fire severity raster was converted to a polygon file. Minimum Convex Polygons were generated using the Minimum Bounding Geometry Tool to represent the home range of each animal. The fire severity polygon and the home range polygons were then intersected to determine the area of each home range that burned in the Red 003 Fire.

# RESULTS

## FORMAL ACCURACY ASSESSMENT

The formal accuracy assessment conducted on the final classified image provides quantitative accuracy information for each class and the overall image, allowing for the appraisal of the quality of the classification, the identification of common errors and the caveats of using the classified image in further analyses. The formal accuracy assessment was conducted for the entire study area using FRI ortho tiles as a reference layer. The formal accuracy assessment indicated that the habitat map had an overall classification accuracy of 75% (Table 5). This accuracy is comparable to the habitat layers used in other studies and is acceptable for use in this project.

Table 5. Accuracy totals for the caribou habitat map. UNCL= unclassified, OP = open peatland, TP = treed peatland, MW = mixedwood, UC = upland conifer and SPF = sparse forest.

| Landcover Type | Reference Totals | Classified Totals | # Correct | Producer's Accuracy % | User's Accuracy % | Mean Accuracy % |
|---|---|---|---|---|---|---|
| UNCL | 5 | 50 | N/A | N/A | N/A | N/A |
| OP | 35 | 50 | 30 | 86 | 60 | 73 |
| TP | 45 | 50 | 35 | 78 | 70 | 74 |
| MW | 48 | 50 | 39 | 81 | 78 | 80 |
| UC | 54 | 50 | 39 | 72 | 78 | 75 |
| SPF | 63 | 50 | 44 | 70 | 88 | 79 |
| Totals | 250 | 250 | 187 | | | |

Overall Classification Accuracy: 75%

Producer’s accuracy compares the number of reference pixels in each class to the number of correctly classified pixels in each class. For example, treed peatland has a producer’s accuracy of 78% (Table 5). This means that 35 of the 45 pixels identified as treed peatland during the accuracy assessment were classified by the software as treed peatland. User's accuracy compares the number of pixels correctly classified to the number of pixels sampled in each class (in this case 50 pixels sampled/class). Treed peatland had a user's accuracy of 70% (Table 5). This means that 35 of the 50 treed peatland pixels in the accuracy assessment were correctly classified as treed peatland. Most of classes in the image had producer's and user's accuracies around 70-80%, which is the recommended minimum accuracy for use in wildlife habitat studies (Thomlinson et al. 1999). However, as in any classified image, errors are present. Understanding these errors can help the user further appraise the quality of the classified image and decide whether it is suitable for a task.

Open peatland had the lowest mean accuracy of all classes at 73% (Table 5). Based on the error matrix, 30 of the 50 pixels sampled in the accuracy assessment were correctly classified as open peatland (Table 6). Open peatland was commonly confused with all other classes. This likely indicates that there is not enough spectral separation between open peatland and the other land cover classes. The relatively low accuracy of open peatland was identified in early classified images. Attempts were made to improve the accuracy of this class including masking out the water. Most open peatland in the FRI ortho tiles were close to open water. This resulted in lakeshore forest being misclassified as open peatland in earlier classified images.

Table 6. Error matrix for the caribou habitat map. UNCL = unclassified, OP = open peatland, TP = treed peatland, MW = mixedwood, UC = upland conifer and SPF = sparse forest.

| Landcover Type | UNCL | OP | TP | MW | UC | SPF | Row Total |
|---|---|---|---|---|---|---|---|
| UNCL | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OP | 2 | 30 | 4 | 3 | 5 | 6 | 50 |
| TP | 0 | 4 | 35 | 0 | 5 | 6 | 50 |
| MW | 0 | 1 | 5 | 39 | 2 | 3 | 50 |
| UC | 3 | 0 | 0 | 4 | 39 | 4 | 50 |
| SPF | 0 | 0 | 1 | 2 | 3 | 44 | 50 |
| Column Total | 5 | 35 | 45 | 48 | 54 | 63 | 250 |

Treed peatland had a mean classification accuracy of 74% (Table 5). Treed peatland was commonly confused with open peatland and upland conifer (Table 6). Confusion with open peatland may have been caused by a similar spectral signature between treed peatland and the disturbed areas included in the open peatland class. Confusion of treed peatland and upland conifer is likely caused by different spectral conditions across the image, since in some parts of the image, low-lying upland conifer was misclassified as treed peatland. Treed peatland was also often confused with sparse forest. This region is characterized by an abundance of exposed bedrock, even adjacent to and within bog complexes. Therefore, confusion between sparse forest and treed peatland is most likely caused by the presence of both cover types in the same pixel.

Mixedwood had a mean classification accuracy of 80% (Table 5). Mixedwood was most often confused with treed peatland (Table 6), probably because of alder in some treed peatlands. More samples of alder-containing treed peatlands would be required to rectify this issue. Upland conifer had a mean classification accuracy of 75% (Table 5). Upland conifer was most commonly confused with mixedwood and sparse forest due to similarities in the spectral signatures of these classes (Table 6). Sparse forest had a mean classification accuracy of 79% (Table 5). Sparse forest had the highest user's accuracy of all classes at 88%, indicating the software was quite effective at picking out the spectral signature of sparse forest from the image. However, the producer's accuracy for sparse forest was substantially lower at 70%. This was caused by the high number of pixels in the accuracy assessment (63) identified as sparse forest, of which only 44 were classified as sparse forest by the software. Sparse forest was most commonly confused with upland conifer (Table 6). This misclassification was likely caused by a lack of spectral separation between sparse forest and upland conifer.

## INFORMAL ACCURACY ASSESSMENT

In addition to the formal accuracy assessment, an informal accuracy assessment was conducted using the field data GIS file as a reference layer. Of the 57 field plots, the classified landcover agreed with the reference landcover for 41 plots, for an overall accuracy of 72%. The overall accuracy from the informal accuracy assessment is similar to the formal accuracy assessment score of 75% (Table 5). Most of the reference plots (37 of 57 plots) were established in upland conifer or sparse forest due to the prevalence of these landcover types in the Bulging/Haggart/Broken Arrow lakes system. Like the formal accuracy assessment, the informal accuracy assessment revealed confusion between upland conifer and sparse forest (5 of 16 errors). The informal accuracy assessment also revealed misclassification between treed peatland and sparse forest (9 of 16 errors). The source of the treed peatland classification errors was investigated by overlaying the classified image on the ortho tiles. Two theories for were hypothesized to explain misclassification of treed peatland: edge effects and pixel values.

As previously mentioned, WCPP is characterized by abundant exposed bedrock. As a result, many bog complexes are bordered by and interspersed with exposed bedrock. For the pixels in the informal accuracy assessment, it appears that in cases when a pixel contained both treed peatland and sparse forest, it was usually classified as sparse forest, even when the plot data clearly reflected treed peatland. Therefore, either the method of field data collection was not appropriate given the scale of Landsat data or the sparse forest spectral properties are preferentially selected by the image classifier.

Misclassification of pixels where the entire pixel appears to be treed peatland are more troubling. These errors likely arose due to limitations in the image classifier or under-sampling of treed peatland when creating the signature file. It should be noted that the misclassification of treed peatland and sparse forest is not uniformly distributed throughout the image and may have been highlighted in the informal accuracy assessment due to poor separation of these land cover types in the area visited for field sampling. Thus, the formal accuracy assessment is a better indicator of the reliability of separation between these two landcover types.

## PRELIMINARY COLLAR ANALYSIS

Preliminary analysis of the collar data provided an overview of how woodland caribou in the Sydney Range were using the Red 003 area prior to the fire in 2016. All the animals included in this study retained the collar for a minimum of two years and a maximum of three years (Table 7). Only three animals spent more than 50% of their time in Red 003 area: animals C243, C256, and C265. Animal C243 spent the greatest percentage of time in the Red 003 area at 83%. On average, each animal spent 35% of its time in the Red 003 area, with a median of 24%.

Table 7. Length of study and overall use of the Red 003 area prior to the fire for 11 female caribou in the Sydney Range.

| Animal # | Start Date | End Date | Total Days | Days in Red 003 | Days in Red 003 (%) |
|---|---|---|---|---|---|
| C241 | 2012-02-09 | 2014-08-13 | 918 | 220 | 24 |
| C243 | 2012-02-09 | 2014-07-06 | 660 | 546 | 83 |
| C246 | 2012-02-09 | 2014-04-05 | 770 | 215 | 28 |
| C253 | 2012-02-09 | 2015-03-19 | 1121 | 160 | 14 |
| C256 | 2012-02-09 | 2015-03-11 | 1115 | 802 | 72 |
| C257 | 2012-02-09 | 2015-03-01 | 1108 | 144 | 13 |
| C264 | 2012-02-09 | 2014-07-24 | 896 | 166 | 19 |
| C265 | 2012-02-09 | 2014-12-16 | 1034 | 561 | 54 |
| C275 | 2012-02-09 | 2015-03-01 | 1078 | 368 | 34 |
| C277 | 2012-02-09 | 2015-03-01 | 1104 | 208 | 19 |
| C278 | 2012-02-09 | 2015-03-01 | 984 | 202 | 21 |
| | | | | Average | 35 |
| | | | | Median | 24 |
| | | | | Variance | 0.058 |
| | | | | STDEV | 0.242 |

The summary of overall use in the Red 003 area indicated that six animals spent less than 25% of their time in the Red 003 area (Table 7). However, even these animals displayed greater use of the Red 003 area in certain seasons. Overall, the animals in this study used the Red 003 area most frequently during the winter (Table 8). Although no individual spent more than 65% of its winter days in the Red 003 area, the animals spent an average of 48% of their winter days in the Red 003 area, indicating its importance as winter habitat. In the calving and summer seasons, most animals dispersed from the Red 003 area to other parts of the range, except for animals C243, C256 and C265. It is possible these three animals used the Red 003 area for calving. The study animals spent the least amount of time in the Red 003 area during fall at an average of 20% of days.

Table 8. Seasonal use of the Red 003 area prior to the fire by 11 female caribou in the Sydney Range.

| Animal Number | % of Days in Burn | | | | |
|---|---|---|---|---|---|
| | Winter | Spring | Calving | Summer | Fall |
| C241 | 65 | 33 | 0 | 0 | 1 |
| C243 | 58 | 87 | 84 | 96 | 99 |
| C246 | 30 | 3 | 24 | 45 | 24 |
| C253 | 36 | 18 | 0 | 0 | 1 |
| C256 | 56 | 78 | 100 | 99 | 47 |
| C257 | 28 | 37 | 1 | 0 | 1 |
| C264 | 44 | 41 | 0 | 0 | 0 |
| C265 | 51 | 42 | 79 | 82 | 17 |
| C275 | 61 | 56 | 12 | 33 | 3 |
| C277 | 47 | 30 | 0 | 0 | 3 |
| C278 | 47 | 29 | 0 | 0 | 23 |
| Average | 48 | 41 | 27 | 32 | 20 |
| Median | 47 | 37 | 1 | 0 | 3 |
| Variance | 0.01 | 0.06 | 0.16 | 0.17 | 0.09 |
| STDEV | 0.12 | 0.24 | 0.40 | 0.42 | 0.30 |

## RESOURCE SLECTION FUNCTIONS & DESCRIPTIVE STATISTICS

The results of each model in the Resource Selection Function are presented here in sequence. Each model has a summary graph, which displays trends in habitat selection across the defined seasons. If the selection coefficient is greater than 0 (above the dotted line), caribou were selecting for the habitat variable. If the selection coefficient is less than zero (below the dotted line), caribou were avoiding the habitat variable. The error bars indicate if the selection or avoidance is significant ($\alpha = 0.05$). If the error bar crosses the dotted line, the selection or avoidance is not statistically significant.

The browse hypothesis was not rejected because caribou selected for upland conifer and sparse forest in all seasons (Figure 9). Selection for upland conifer and sparse forest was significant (α = 0.05) in all seasons except spring (Figure 9). The highest selection coefficient value was during the calving season, indicating the importance of this cover type during the calving season.

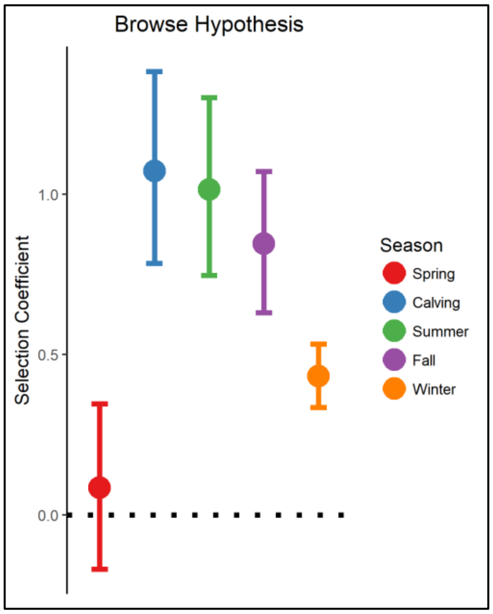


Figure 9. Selection coefficients for the browse hypothesis.

The first refuge hypothesis, which predicted that caribou selected areas close to lakes, was rejected because caribou selected points further from lakes than the geometric mean distance to water for the set of available points (Figure 10). This selection was significant (α = 0.05) across all seasons. Available points that fell within lakes were included in the model, since caribou are known to use lakes to escape predators or to travel to

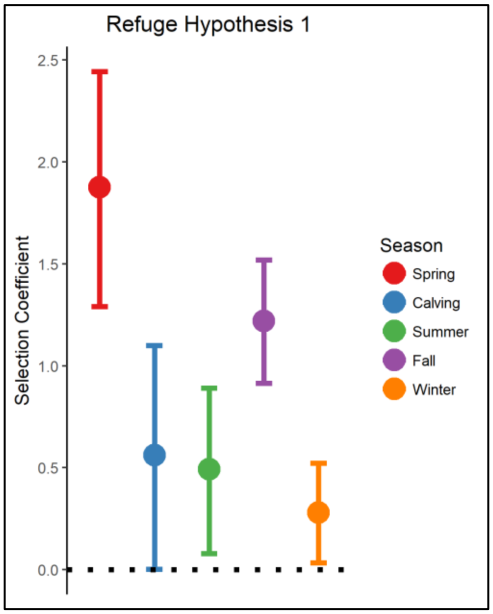


Figure 10. Selection coefficients for Refuge Hypothesis 1.

islands. Due to the high density of lakes in the study area, many available points fell within lakes and thus had a distance to water of zero. This resulted in consistently low geometric mean distance to water for each set of available points, which likely caused the observed trend in selection.

The browse-refuge hypothesis was partially rejected. As predicted, caribou selected for upland conifer and sparse forest. However, caribou selected points further from lakes than the geometric mean distance to water for the set of available points (Figure 11). Unlike the first refuge hypothesis, only two of the five seasons showed significant ($\alpha = 0.05$) selection for points further from water. In calving, summer and winter, used point distance to water was not significantly different than the geometric mean distance to water for the set of available points. The second refuge hypothesis was not rejected, since caribou selected for treed peatland in all seasons except fall. Selection for treed peatland was only significant in spring (Figure 12).

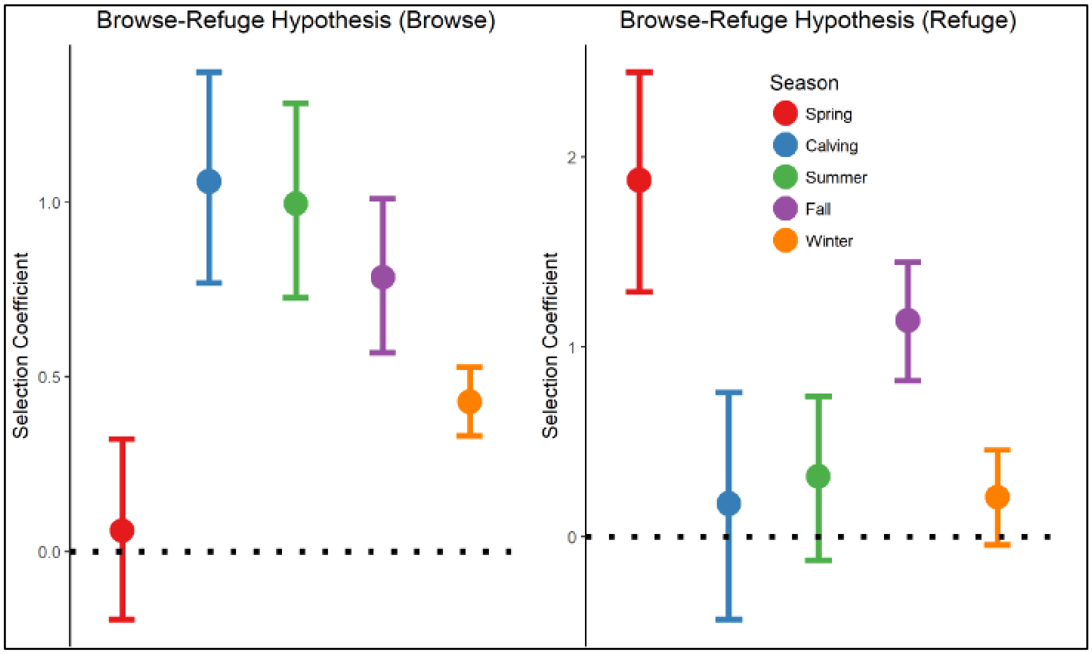


Figure 11. Selection coefficients for upland conifer/sparse forest (left) and distance to water (right) from the Browse-Refuge Hypothesis model.

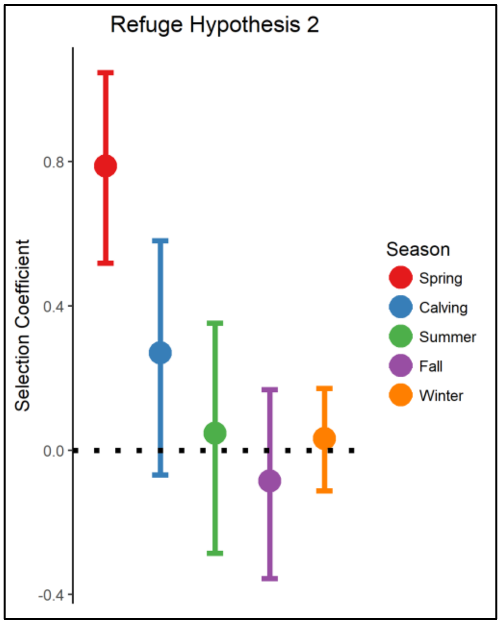


Figure 12. Selection coefficients for Refuge Hypothesis 2.

The Natural Disturbance Hypothesis was not rejected, since caribou avoided disturbance in all seasons (Figure 13). Despite demonstrating avoidance of disturbance, caribou only significantly avoided disturbance (α = 0.05) in spring, fall and winter. Avoidance of disturbance was not significant during the calving season or during the summer (Figure 13).

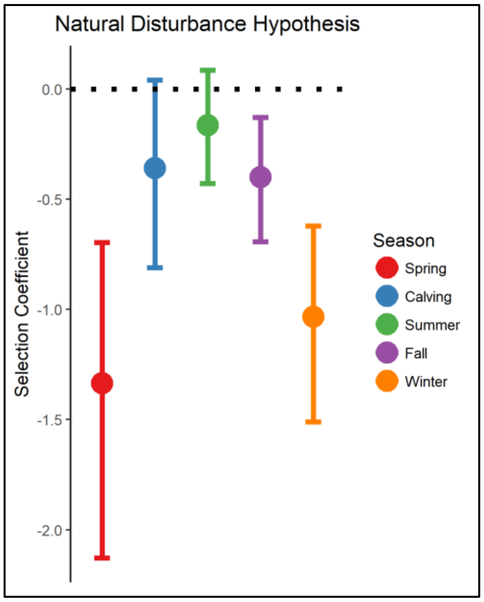


Figure 13. Selection coefficients for the Natural Disturbance Hypothesis.

Further demonstrating that caribou avoided disturbance, a greater proportion of available points were found to be in disturbance compared to used points (Figure 14). During the calving and winter seasons, caribou selected for portions of their home range with a lower proportion of disturbance, especially in winter. During summer, caribou occupied portions of their home range with a greater proportion of disturbance and selected disturbed areas more in summer than in any other season.

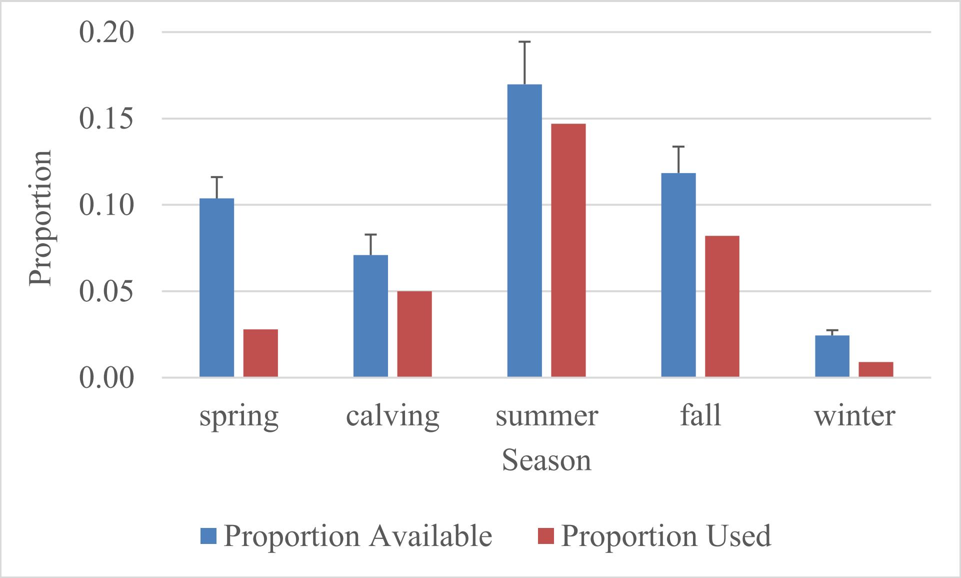


Figure 14. Proportion of available points in disturbance vs. proportion of used points in disturbance by season.

The full model was partially rejected. As predicted, caribou demonstrated selection for upland conifer and sparse forest and avoidance of disturbance. However, caribou selected points further from water than the geometric mean distance to water for the set of available points (Figure 15). The full model was the best of the six models tested at explaining caribou habitat selection (Table 9).

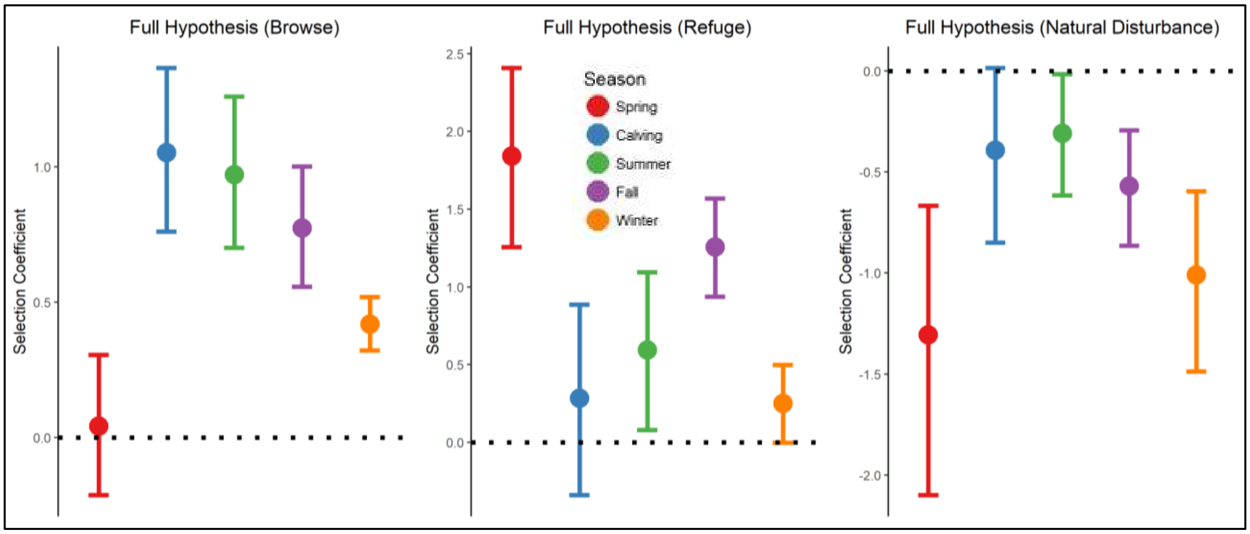


Figure 15. Selection coefficients for the variables in the full model: upland conifer/sparse forest (left), distance to water (centre) and disturbance (right).

Table 9. AIC scores for the six models tested in the RSF. *K* indicates the number of fixed effects in the model.

| Hypothesis | *K* | AIC | Δ AIC |
|---|---|---|---|
| Full | 4 | 36521 | 0 |
| Browse-refuge | 3 | 36584 | 64 |
| Browse | 2 | 36663 | 142 |
| Refuge 1 | 2 | 36832 | 312 |
| Natural disturbance | 2 | 36877 | 356 |
| Refuge 2 | 2 | 36907 | 387 |

The browse hypothesis was much closer to the full model than any of the other univariate models, lending support to the conclusion that upland conifer and sparse forest are particularly important in predicting caribou habitat selection. The multivariate models (full and browse-refuge) had the lowest AIC values, indicating that multiple variables were better at predicting habitat selection than any single variable.

## POST-FIRE HABITAT

To evaluate how the Red 003 Fire affected caribou habitat on the Sydney Range, a post-fire habitat raster was created (Figure 16).

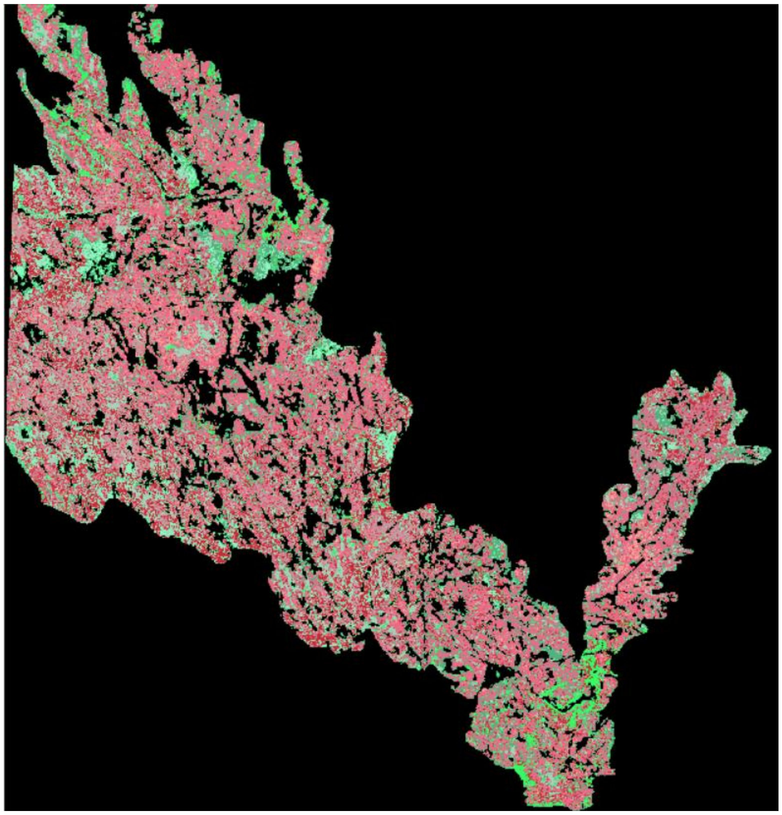


Figure 16. Post-fire habitat raster. Red areas burned in the Red 003 Fire, green areas did not burn in Red 003 Fire.

The post-fire habitat raster was used to determine the area of each land cover type that burned or remained unburned within the perimeter of the Red 003 Fire (Table 10). The total area of the Red 003 burn within the study area was approximately 79,265 ha. However, within the burn perimeter, 33% of the land remained unburned. In addition to unburned land, there are numerous lakes within the burn perimeter, some of which contain islands that escaped the flames.

Table 10. Area of each landcover type (ha) in the Red 003 area before and after the Red 003 Fire.

| Landcover | Pre-Fire Area | Residual Area |
|---|---|---|
| Open peatland | 3521 | 2594 |
| Treed peatland | 9677 | 6580 |
| Mixedwood | 5826 | 4378 |
| Upland conifer | 38774 | 8558 |
| Sparse forest | 21466 | 3930 |
| Total | 79265 | 26038 |
| % Residuals | 33% | |

There is a considerable amount of residual forest and peatland left within the Red 003 burn that may serve as habitat for woodland caribou. This includes 8,558 ha of upland conifer and 3,930 ha of sparse forest, which caribou selected according to the RSF (Figure 9). Despite the sizable area of post-fire residuals of these two land cover types, the area of upland conifer and sparse forest were greatly reduced from their pre-fire extent. The large reduction in these cover types will have a disproportionate effect on post-fire use in the Red 003 area due to the importance of upland conifer and sparse forest as caribou habitat.

The fire severity raster was also used to determine the percentage of the home range of each animal that burned in the Red 003 Fire (Figure 17). 35% of animal C243's home range burned in the Red 003 Fire, the highest percentage of any animal. The home ranges of animals C256 and C278 also experienced sizable loss of habitat, with 25% and 22% burned respectively. The percentages of the home range burned in the Red 003 Fire are an addition to the disturbance on each animal's home range. Since many animals already have some old burns and/or forest harvesting in their home range, adding the

Red 003 Fire significantly reduces the undisturbed portion of the home range, leading to lower habitat availability.

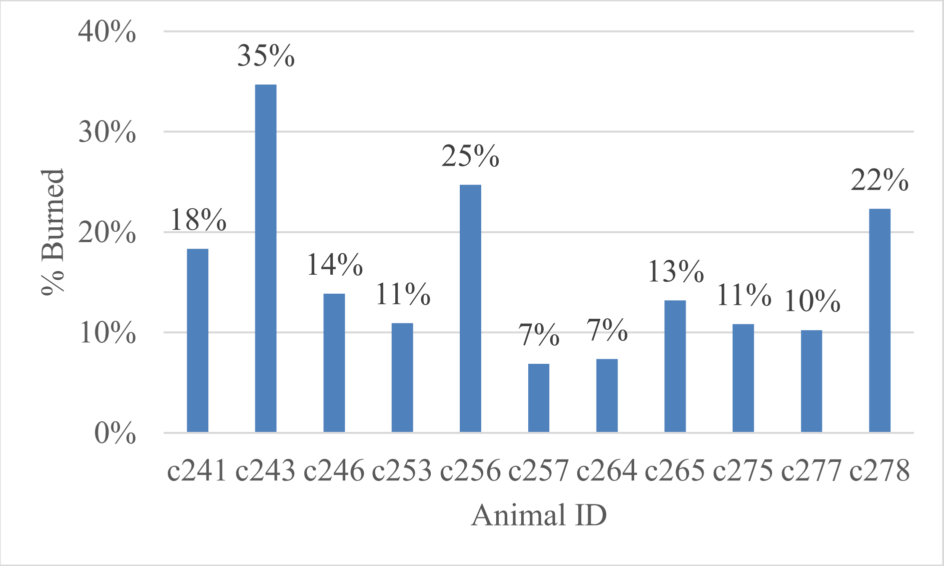


Figure 17. Fraction (%) of the home range of each animal that burned in the Red 003 Fire.

# DISCUSSION

## UNDER SEIGE

The MNRF conducted an Integrated Range Assessment (IRA) for the Sydney Range in 2014 as part of Ontario’s Woodland Caribou Range Management Policy. The Sydney caribou population was assessed at a minimum of 55 individuals with a calving rate of 14-18 calves/100 females. Due to the small population estimate and low calving rate, the population was assessed as possibly being in decline. The Sydney Range was assessed as being heavily disturbed, mostly due to timber harvesting, roads and mining development in the central and eastern portions of the range. When anthropogenic and natural disturbances were combined, 63% of the Sydney Range was considered disturbed, leading to the conclusion that the Sydney Range is in insufficient condition to support a self-sustaining population of caribou (MNRF 2014a).

For the last 30 years, the northwest portion of the Sydney range has acted as a stronghold for the Sydney caribou as anthropogenic disturbance and large fires from the 1980s restricted use of other portions of the range. The northwest corner of the range is protected by WCPP and contains minimal anthropogenic disturbance. During the IRA, the northwestern portion of the Sydney Range was identified as having the highest habitat quality in the Sydney Range and the highest likelihood of caribou occupancy (Figure 18). The area was a patchwork of young, intermediate and old forest with comparatively smaller burned areas than other portions of the range. The risk to the Sydney caribou population was rated as high since a very small portion of the range was actively being used and the area was at high risk to burn in the near future due to the aggressive local fire regime (MNRF 2014a).

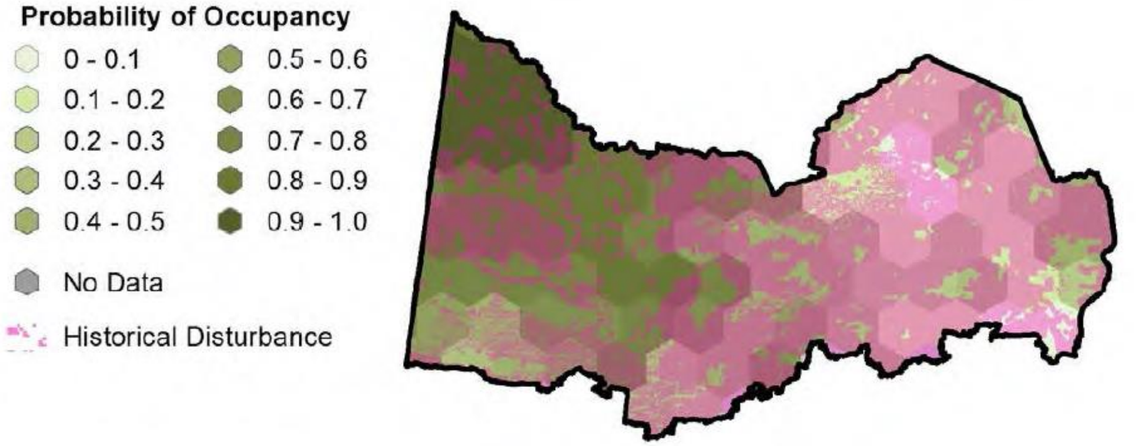


Figure 18. Probability of caribou occupancy in the Sydney Range in the context of regional disturbances (MNRF 2014a).

The northwest portion of the Sydney Range began a drastic transition in October 2012, when heavy, wet snow combined with strong winds snapped and bent trees over a large area, increasing the amount of dead wood in the forest. In the years following the so-called snow-down event, the abundant dead wood provided ideal conditions for white-spotted sawyer beetles, which experienced a population explosion. The beetles added to the existing fuel load as the adults fed on the shoots of adjacent trees in large numbers, causing whole-tree mortality over entire stands (MNRF 2017b). Together, the snow-down event and white-spotted sawyer beetle outbreak increased the fuel load in the northwest portion of the Sydney Range significantly.

In early May 2016, lightning ignited a fire in Manitoba. Promoted by strong winds, dry conditions and abundant fuel, the fire quickly crossed the border into WCPP. The Red 003 Fire quickly moved through the northwest portion of the Sydney Range, burning much of the habitat deemed as critical to the population's persistence during the IRA (MNRF 2014a). Based on the importance of this part of the range to the Sydney caribou, it is difficult to dispute that the fire will have significant and likely negative implications for caribou in the Sydney Range.

## STUDY LIMITATIONS

### Caribou Habitat Map

All wildlife habitat studies should quantify the accuracy of the habitat classifications, since errors are unavoidable. Photo interpreters delineating a forest inventory make mistakes, as do algorithms that classify Landsat imagery based on the spectral properties of the pixels. In this study, an overall accuracy of 75% was reported for the caribou habitat map. This accuracy is on par with other Masters theses and published papers (Frazer Sherritt 2014; Thomlinson et al. 1999). An informal accuracy assessment indicated that treed peatland was not reliably classified correctly in the habitat map, as 9 of the 16 errors were misclassification of treed peatland. Treed peatland also had the second lowest overall accuracy of the five land cover types at 74%. Initially, the second refuge hypothesis was intended to look at distance to treed peatland as refuge habitat, instead locations in treed peatland. The decision to omit distance to treed peatland as a variable reflected a lack of confidence in the classification of this cover type and may mean selection for this cover type is not accurately reflected in the results.

A second limitation of this study is that distance to water was used as an indication of refuge habitat, but all lakes were included regardless of their size. There is likely a minimum surface area and/or shoreline configuration that makes a lake suitable refuge habitat. Since the lakes in the distance to water model were not screened to reflect refuge characteristics, the results of the RSF may be a poor indication of how refuge habitat around lakes is selected.

### Resource Selection Function

There were several limitations imposed by the collar data in this study. First, collar locations were restricted to the first year of observations (2012-02-09 to 2013-03-31) for a consistent 5-hour interval between location transmissions. Inspection of the collar data indicated that after 2013-03-31, the collars in the Sydney study were programmed to switch to locations transmissions every ten hours. The choice of the five-hour interval follows the convention of other studies which utilize shorter time intervals to obtain finer-scale selection information for ungulates (Avgar et al. 2015; Forester et al. 2009; Fortin et al. 2005; Potts et al. 2014). However, the additional temporal extent in the collar dataset could have shown inter-annual variation in habitat selection. This could include abnormal habitat selection due to the snow-down event that occurred in October 2012, which was captured in the extent studied but not compared to subsequent years.

Caribou, like other ungulates, show different movement patterns depending on time of day and season (Forester et al. 2009). This study utilized a single parameter to derive step length of available points. Ideally, the step length parameter would have been adjusted to reflect changes in caribou movement throughout the day and in different seasons. Trends in seasonal habitat selection could also have been misrepresented in this study since length of daylight changes by season and this was not accounted for in the RSF. Another restriction imposed by this study was focusing on habitat use only within the Red 003 area. The decision to restrict the analysis to the Red 003 area was made to reduce interpretations of habitat use to the burn to maximize insights about post-fire implications. Restricting the dataset to the Red 003 area meant that in certain seasons (e.g. calving, summer) the habitat use trends were determined by only a few individuals that stayed in the Red 003 area during that time of the year. This means that the results of the RSF may not apply to the Sydney Range as a whole, which limits the transferability of the study.

### Post-Fire Habitat

The conclusions that can be made about the effects of the Red 003 Fire were limited by the assumption that the Sydney Range would act in isolation from the neighbouring Owl-Flinstone Range in Manitoba. It is likely that the options for the Sydney caribou to adapt to the Red 003 Fire do not stop at the Manitoba border (MNRF 2014a). The likelihood that Manitoba habitat will be used by Sydney caribou depends on habitat status in Manitoba and whether animals can access those areas, especially the animals with home ranges on the eastern side of WCPP, some 50 km from the Manitoba border. The post-fire home range analysis could have been improved by using more accurate methods to delineate home ranges. Seasonal ranges should also have been delineated, since the preliminary collar analysis indicated caribou used the Red 003 area in different proportions throughout the year. It would be useful to look at the proportion of the winter range for each animal that burned, since this is the season where the Red 003 area was used most heavily.

It has been suggested that moose densities may increase after the Red 003 Fire. By extension, it is anticipated this will lead to higher wolf densities and higher predation rates on woodland caribou. Wolf observations for WCPP are mostly incidental and not detailed enough to determine predation rates nor infer how the fire will change wolf/caribou dynamics. The northwest portion of the Sydney Range generally contains low productivity forests with minimal amounts mixedwood or hardwood stands. It is likely the Red 003 Fire will perpetuate the conifer-dominated, lichen-rich stands that were present in the area prior to the burn. It is not anticipated that the fire will increase the abundance of herbaceous and deciduous browse to the point that apparent competition with moose and wolves becomes an issue, but this future research on this subject is warranted.

Perhaps the greatest limitation to drawing conclusions about the effects of the Red 003 Fire on woodland caribou in the Sydney Range is a lack of post-fire caribou observations. Collaring data would be the best method to determine post-fire habitat use, however there are no post-fire telemetry locations for the Sydney Range, nor is their any plan for a telemetry project in the near future. In the absence of post-fire telemetry data or other direct observations, habitat classifications could be used to identify areas the Sydney caribou may use as seasonal habitat. Standard habitat models such as the Ontario Landscape Tool may be used to identify the amount of habitat burned and unburned after the Red 003 Fire, providing more insight into post-fire habitat selection. This should be a focus of future research for the park. The future trends in habitat selection presented in this thesis are speculative based on the results of the RSF and descriptive statistics, a review of the relevant literature and considering range condition in the area surrounding the Red 003 burn.

## HOMESICK

The Red 003 Fire burned part of the home range of all eleven caribou included in the study. Although for most animals the Red 003 Fire burned less than 20% of the home range, for three animals Red 003 affected more than 20% of the home range, with the greatest being animal C243 at 35%. It is important to recognize that this analysis was conducted with the burn severity map, and therefore excludes residuals from the burn percentage calculation. Therefore, if you were to consider the entire area inside the burn perimeter as disturbed, as is the case in Environment Canada’s recovery strategy, the percentage of the home range affected would be much greater. In addition, the method used to calculate the home range generated the smallest convex polygon that covered all locations for each animal over the study period. In many caribou studies, the home range is delineated using a 95% Minimum Convex Polygon or other methods that reduce the effect of outlier points inflating the size of the home range (Dalerum et al. 2007; Skatter et al. 2017). Since the home range polygons were generated using all locations, they predict an area larger than what each animal reasonably uses as its home range.

These considerations make the results of the home range analysis more troubling, since the percentage of the home range burned in the Red 003 Fire is likely higher than what has been reported. Because the Sydney Range is already heavily disturbed, the Red 003 Fire only adds to the problem. For example, several study animals occupied home ranges in the eastern portion of WCPP and eastward to Medicine Stone Lake. This remnant occupied area is bound by forest harvesting to the north and a 1980s burn to the south (MNRF 2014a). These animals only overwintered in the Red 003 area and thus the percentage of their home range burned was low. However, with limited suitable habitat around their home range, and loss of wintering habitat from the Red 003 Fire, these animals may experience greater impacts than the home range analysis suggests.

## WINTER BLUES

Perhaps the most significant finding of the preliminary collar analysis was that winter was the season with the highest use of the Red 003 area. On average, caribou spent 48% of their winter days in the Red 003 area. Most of the collar observations during the winter were in the eastern portions of the park in the Jake Lake area. This area was identified in Woodland Caribou Provincial Park's Vegetation Management Plan as high-quality caribou habitat and is recognized as a Caribou Winter Activity Area (MNRF 2016). Although slated for full suppression under the Vegetation Management Plan, large potions of this area burned in the Red 003 Fire. An aerial survey of this Winter Activity Area was conducted by Christine Hague on January 17, 2018. Fourteen caribou were observed west of the former Winter Activity Area near Mexican Hat Lake. There was sign of caribou use in the high-quality habitat that was spared on either side of the burn and caribou appeared to be crossing from one side of the burn to the other through the skinniest point (Hague pers. comm. January 19, 2018).

In winter, caribou forage for lichens, especially ground lichens. Typically, Winter Activity Areas are characterized by abundant ground lichens and low snow depths. Since these types of habitats may be relatively rare on the landscape, it is not uncommon to observe caribou grouping together in winter, such as what was observed at Mexican Hat Lake (MNRF 2013). Although lichen can provide a source of forage during winter, caribou, like other cervids, experience a negative energy balance during winter (Bergerud 1974). Thus, winter is a critical season for determining survival and successful calving the following year. In Manitoba, a large fire in 1980 burned portions of the Aitkens caribou range and the herd became severely food-limited in subsequent winters due to lack of lichen forage, resulting in population decline (Schaefer and Pruitt 1991). It is possible that the Red 003 Fire eliminated a large enough portion of the winter range for the Sydney caribou that similar results could be experienced.

In this investigation, caribou were avoiding disturbance in all seasons, but this avoidance was especially pronounced in winter. Based on post-fire winter observations made by Christine Hague, if the RSF was conducted on post-fire collar locations, caribou would likely have a much higher proportion of available points in disturbance, since caribou are still using the Winter Activity Area in the eastern portion of WCPP which is now bisected by the Red 003 Fire. It is unknown whether the remaining winter habitat will be sufficient to sustain the Sydney caribou, as the IRA indicated that prior to the Red 003 Fire, the Sydney Range already contained less winter habitat than predicted by the Natural Range of Variation (MNRF 2014a).

## A MOTHER KNOWS BEST

From the preliminary collar analysis, it should be noted that three animals (C243, C256 and C265) spent the majority of the calving season within the Red 003 area. Although this study did not look at collar movement patterns to identify calving events (e.g. Skatter et al. 2017), it is not unreasonable to conclude that some portions of the Red 003 area may have been used for calving. Caribou in the Sydney Range show high fidelity to calve at specific lakes, where shoreline features and islands are chosen to provide forage and refuge from predators (MNRF 2014a). Several calving sites were known the exist within the area that burned in the Red 003 Fire (MNRF 2016).

In this analysis, caribou were selecting for upland conifer and sparse forest most strongly during the calving season. The post-fire habitat analysis indicates that 16% of the land within the burn perimeter is upland conifer or sparse forest residuals. Much of the peatland complexes within the burn perimeter also remained unburned, and caribou displayed selection for treed peatland. Post-fire residuals are known to be used by caribou during the calving season in areas with extensive fire disturbance (Skatter et al. 2017). Post-fire residuals may provide the critical combination of refuge form predators, adequate forage and increased visibility of needed for calving habitat. Within burn perimeters, caribou generally display preference for calving within fen or bog complexes. Thus, residuals may provide suitable calving habitat for caribou in the Sydney Range, especially for animals that spent the calving season in the Red 003 area prior to the burn.

## SUMMER TRAVELS

In this analysis, caribou demonstrated greater use of burns and occupied portions of their home range with a greater proportion of burns during summer. During the summer months, caribou tend to wander over wider areas, since their diet is less restricted (Thompson et al. 2015). Thus, it is likely that caribou will move through the Red 003 burn and use post-fire residuals throughout the summer months. Use of residuals within the burn was observed on several accounts during the field visit to WCPP. Fresh tracks were observed on Haggart Lake and browse and scat within the Haggart Bog Complex, indicating caribou were still moving through that portion of the burn. A group of 3-4 animals was also observed on two occasions on Broken Arrow Lake. The group appeared to be using two unburned, lichen-rich islands within the burn perimeter as refuge and forage habitat. In addition, a single caribou was also observed swimming in the main body of Broken Arrow Lake, a large area within the burn perimeter that was spared by the Red 003 Fire.

Despite the field observations of post-fire habitat use, it is important to put the possible use of post-fire residuals within the Red 003 burn into context. First, upland conifer and sparse forest was the best single variable for predicting habitat use in the Red 003 area. 78% of the upland conifer and 82% of the sparse forest was burned in Red 003. Thus, even though significant amounts of residual habitat remain within the burn, it is unclear whether these patches of upland conifer and sparse forest will provide meaningful habitat or if they are too small and/or isolated to be suitable for caribou (Skatter et al. 2017). By comparison, only 33% of the treed peatland cover type burned in the Red 003 Fire, so there are still abundant residuals of this cover type within the burn perimeter. Treed peatland residuals may function as refuge habitat and make occupation of the Red 003 burn more viable or attractive to Sydney caribou. Due to the large size of the Red 003 burn and its central position in the occupied portion of the Sydney Range, it is predicted animals will continue to move through the burn and make use of residuals, especially those animals with a greater percentage of their home range within the Red 003 area.

## AN UNCERTAIN FUTURE

Although animals may show preference for certain land cover types or forest conditions, they will make use of what is available to them. This adaptability is reflected in the diversity of habitat strategies used by caribou across Canada, which varies in part due to different disturbance regimes (Gustine and Parker 2008; Dalerum et al. 2007; Skatter et al. 2017; Ferguson and Elkie 2004). In the Sydney Range, caribou have adapted to a landscape with an aggressive fire regime. Caribou can adapt to post-fire conditions by exhibiting functional habitat use that takes advantage of residual habitats within the burn (Moreau et al. 2012). Evidence suggests that caribou can tolerate high levels of fire disturbance without a decline in population (Dalerum et al. 2007; Skatter et al. 2017).

Royd Lake, which is currently used as a calving area, may take on greater importance after the Red 003 Fire. A large area unaffected by the Red 003 Fire includes Mexican Hat/Burnt Rock/Aegean Lake, which had pre-fire use and has post-fire winter observations. Caribou will also likely continue to use habitat west of Bunny Lake up to the burn perimeter. The area immediately south of the park boundary (Dowswell Lake) was used by collared animals and may be used more extensively in the future. Caribou may also move to portions of the neighbouring Owl-Flinstone range in Manitoba, although consideration of this option is beyond the scope of this investigation.

There are also several old burns caribou may recolonize to compensate for habitat lost in Red 003. The area south of the park boundary contains Kenora 73, a large fire that burned in 1983. This fire has resulted in a continuous patch of conifer forest with high likelihood to provide suitable winter habitat and refuge in the future (MNRF 2014a). It will be vital to monitor for caribou in this area since it is outside of WCPP and is likely slated for future harvest as it falls within the Kenora FMU. The study animals with eastern home ranges border Red 149, a 27,000 ha fire that burned in 1983. This area has a high potential to be used by caribou displaced by Red 003 since it is close to existing home ranges and has a high potential to become suitable habitat (MNRF 2014a). A third fire burned on the Sydney Range in 1983, the Irregular Lake Fire (Red 166) which affected 36,000 ha. Much of the basis for establishing WCPP was to protect the population of caribou known to frequent the Irregular Lake area (MNRF 2014a). The Irregular Lake area was previously used by caribou in summer and winter and is adjacent to Eagle-Snowshoe Conservation Reserve where historic calving lakes are located. It is also relatively isolated from anthropogenic disturbances. Despite the potential for caribou to recolonize the Irregular Lake area, observations indicate that regeneration of the burn is slow, with limited lichen regrowth noted to date (Hague, pers. comm. April 5, 2018). Caribou may start to utilize parts of the Red 031 burn, a 54,000 ha area that burned in 1974. This burn is expected to develop into a large tract of suitable caribou habitat in the near future. Its proximity to Royd Lake, an area actively used by Sydney caribou for calving, and the eastern home ranges of some Sydney individuals may make this area more attractive. In addition, since this burn is over 40 years old, it may have better lichen regeneration than many of the 1980s burns on the Sydney Range (Figure 19).

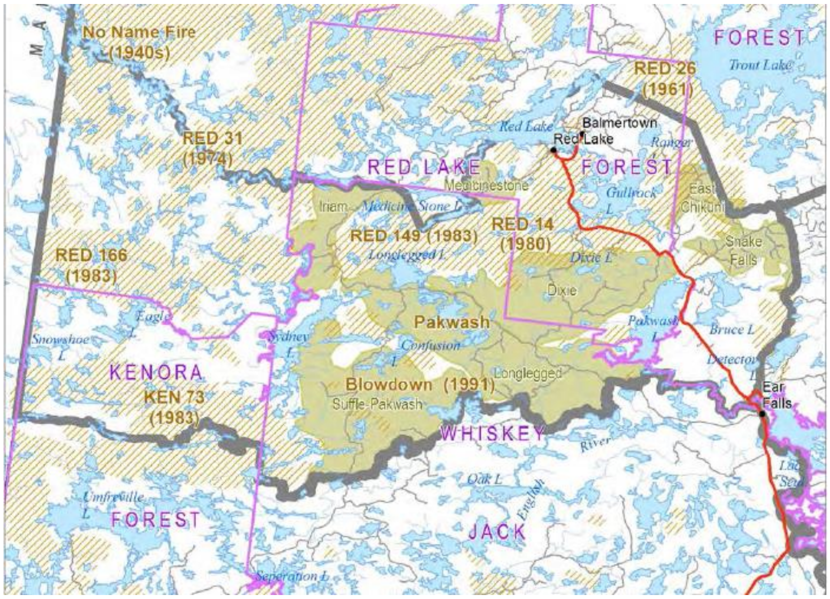


Figure 19. Map of historical fire disturbance (hatch areas) and forest harvesting (solid brown areas) in the Sydney Range (MNRF 2014a).

The situation after the Red 003 Fire provides researchers with an excellent opportunity to study post-fire recovery of caribou habitat. The Sydney caribou are limited in the areas of the landscape they can occupy due to anthropogenic disturbance. This increases the likelihood that Sydney caribou will use residuals within the Red 003 burn. However, the ability of residuals to provide suitable habitat is questionable and thus the future success of caribou in the Sydney Range seems to hinge on the ability for the regenerating burns to provide suitable habitat in the near future. If a 40-year recovery period is assumed, the 1970s and 1980s burns within and surrounding WCPP will soon be considered suitable. Some studies have questioned the contention that post-fire habitat recovery is linear, and that caribou will not use more recent burns (Skatter et al. 2014), but WCPP is characterized by shallow soils, which may slow succession and thus recovery of caribou habitat. Thus, there is a need to study post-fire lichen recovery across a continuum of stands with different time since fire to determine when, from a lichen forage perspective, the old burns in the Sydney Range will become suitable habitat for the caribou displaced by the Red 003 Fire. Studying post-fire caribou response and lichen recovery on the Sydney Range will help improve our understanding of the ecology of caribou and fire.

## CONCLUSION

Woodland caribou on the Sydney Range are faced with an abundance of challenges in the aftermath of the Red 003 Fire. Although WCPP's Vegetation Management Plan called for fire suppression in most of the Red 003 area to protect caribou habitat values, the Red 003 Fire was too intense to be suppressed. In areas where an aggressive fire regime is experienced, there is little managers can do to prevent the loss of habitat in large fire events. Due to the importance of the northwest portion of the Sydney Range, the Red 003 Fire will have negative consequences for the Sydney caribou, especially during the winter. This study indicates that caribou were avoiding portions of the landscape with disturbance during the winter and that the Red 003 area was used most in winter. Since the Red 003 Fire burned portions of high-value winter habitat, it is predicted to have negative impacts on caribou wintering success. This investigation also revealed that a high percentage of some home ranges have been affected by the Red 003 Fire, which may add stress to a population with limited habitat availability in other portions of the Sydney Range.

Despite the concerns raised about the stability of the Sydney caribou population, the Sydney caribou will probably be able to adapt to the new post-fire reality. A large proportion of the area inside the burn perimeter comprises unburned residuals that may provide caribou with important habitat during the summer and calving seasons. Caribou will likely exhibit a complex pattern of habitat use that includes burned and unburned portions of their range similar to the way caribou have adapted to frequent forest fires in northern Saskatchewan (Skatter et al. 2017). It is also likely that caribou will begin to reoccupy 1970s and 1980s burns in the western portion of the Sydney Range as habitat conditions begin to become more suitable. Due to relatively limited anthropogenic disturbance in the western portion of the Sydney Range, the cumulative effects of the Red 003 Fire and anthropogenic disturbance are likely to be limited, increasing the likelihood that caribou will persist in the area.

Future research should focus on natural regeneration in old burns and determine whether these areas are in fact being reoccupied by the Sydney caribou. This research could have policy implications including how ranges with extensive fire disturbance are managed. In addition, it will be important for managers at WCPP to work with adjacent land-users namely timber harvesting on the Kenora and Red Lake FMUs where many large, contiguous tracts of fire-origin conifer forest are expected to become suitable caribou habitat in the near future but may also be in the future timber harvest areas. Due to the large changes the Red 003 Fire is anticipated to have on the Sydney caribou, it is recommended that WCPP revisit the Vegetation Management Plan and take a holistic approach to maintain the viability of woodland caribou on the Sydney Range.

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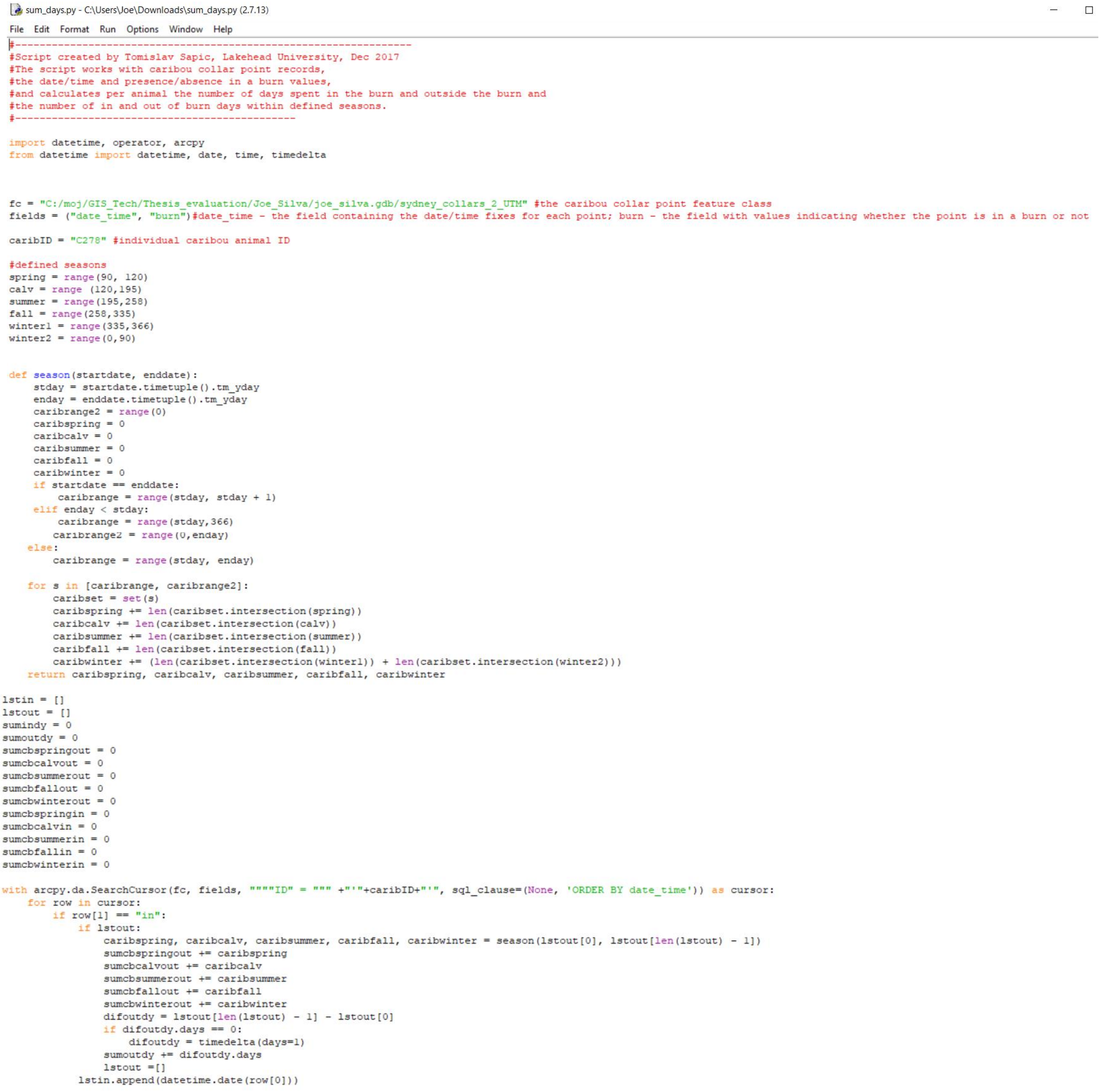
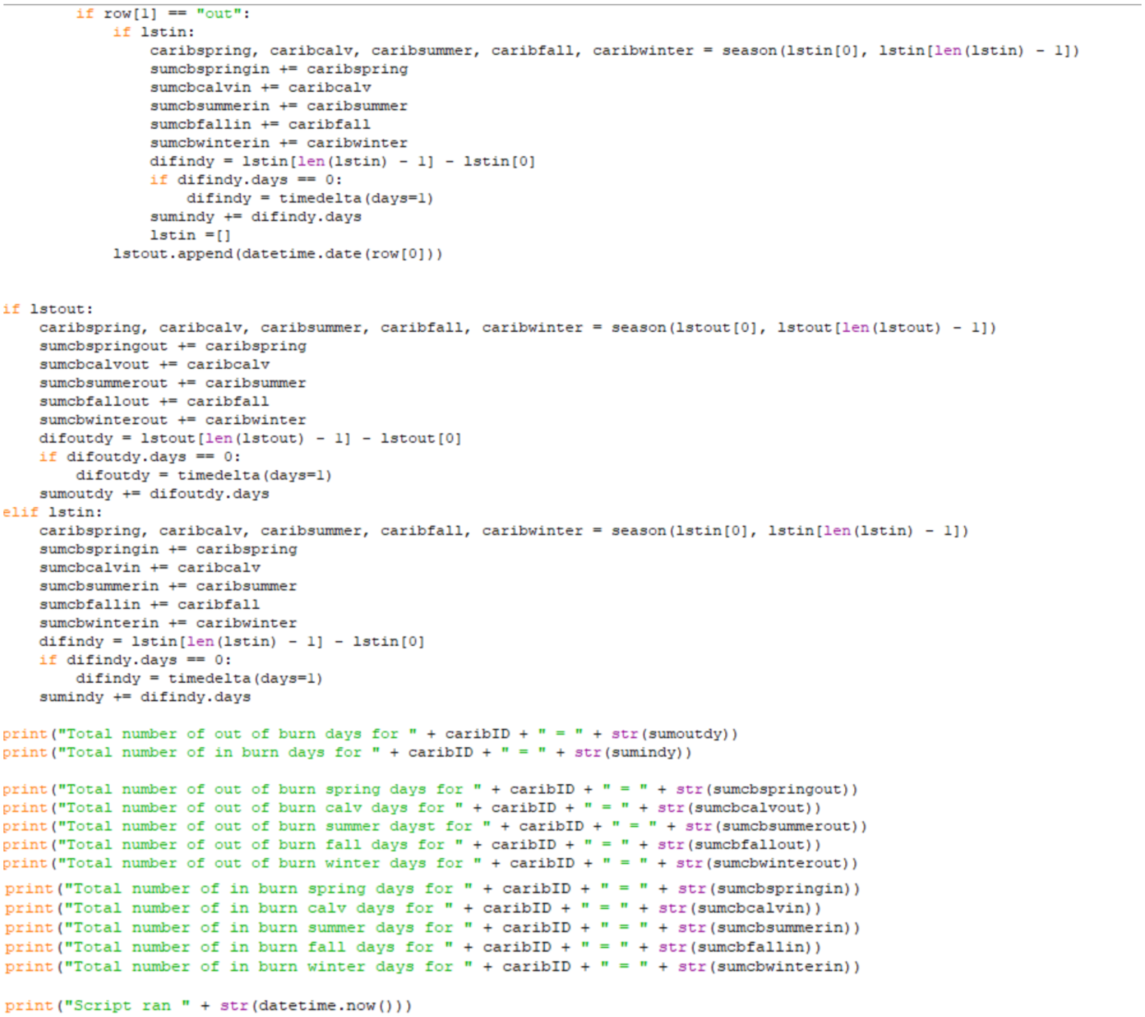
# APPENDICES

# APPENDIX I

## i. Script for the number of days each animal spent in the Red 003 area



```
 #-----------------------------------------------------------------
 #Script created by Tomislav Sapic, Lakehead University, Dec 2017
 #The script works with caribou collar point records,
 #the date/time and presence/absence in a burn values,
 #and calculates per animal the number of days spent in the burn and outside the burn and
 #the number of in and out of burn days within defined seasons.
 #-----------------------------------------------

 import datetime, operator, arcpy
 from datetime import datetime, date, time, timedelta



 fc = "C:/moj/GIS_Tech/Thesis_evaluation/Joe_Silva/joe_silva.gdb/sydney_collars_2_UTM" #the caribou collar point feature class
 fields = ("date_time", "burn")#date_time - the field containing the date/time fixes for each point; burn - the field with values indicating whether the point is in a burn or not

 caribID = "C278" #individual caribou animal ID

 #defined seasons
 spring = range(90, 120)
 calv = range (120,195)
 summer = range(195,258)
 fall = range(258,335)
 winter1 = range(335,366)
 winter2 = range(0,90)


 def season(startdate, enddate):
     stday = startdate.timetuple().tm_yday
     enday = enddate.timetuple().tm_yday
     caribrange2 = range(0)
     caribspring = 0
     caribcalv = 0
     caribsummer = 0
     caribfall = 0
     caribwinter = 0
     if startdate == enddate:
         caribrange = range(stday, stday + 1)
     elif enday < stday:
         caribrange = range(stday,366)
        caribrange2 = range(0,enday)
    else:
        caribrange = range(stday, enday)

    for s in [caribrange, caribrange2]:
        caribset = set(s)
        caribspring += len(caribset.intersection(spring))
        caribcalv += len(caribset.intersection(calv))
        caribsummer += len(caribset.intersection(summer))
        caribfall += len(caribset.intersection(fall))
        caribwinter += (len(caribset.intersection(winter1)) + len(caribset.intersection(winter2)))
    return caribspring, caribcalv, caribsummer, caribfall, caribwinter

lstin = []
lstout = []
sumindy = 0
sumoutdy = 0
sumcbspringout = 0
sumcbcalvout = 0
sumcbsummerout = 0
sumcbfallout = 0
sumcbwinterout = 0
sumcbspringin = 0
sumcbcalvin = 0
sumcbsummerin = 0
sumcbfallin = 0
sumcbwinterin = 0

with arcpy.da.SearchCursor(fc, fields, """"ID" = """ +"'"+caribID+"'", sql_clause=(None, 'ORDER BY date_time')) as cursor:
    for row in cursor:
        if row[1] == "in":
            if lstout:
                caribspring, caribcalv, caribsummer, caribfall, caribwinter = season(lstout[0], lstout[len(lstout) - 1])
                sumcbspringout += caribspring
                sumcbcalvout += caribcalv
                sumcbsummerout += caribsummer
                sumcbfallout += caribfall
                sumcbwinterout += caribwinter
                difoutdy = lstout[len(lstout) - 1] - lstout[0]
                if difoutdy.days == 0:
                    difoutdy = timedelta(days=1)
                sumoutdy += difoutdy.days
                lstout =[]
            lstin.append(datetime.date(row[0]))
```



```
        if row[1] == "out":
            if lstin:
                caribspring, caribcalv, caribsummer, caribfall, caribwinter = season(lstin[0], lstin[len(lstin) - 1])
                sumcbspringin += caribspring
                sumcbcalvin += caribcalv
                sumcbsummerin += caribsummer
                sumcbfallin += caribfall
                sumcbwinterin += caribwinter
                difindy = lstin[len(lstin) - 1] - lstin[0]
                if difindy.days == 0:
                    difindy = timedelta(days=1)
                sumindy += difindy.days
                lstin =[]
            lstout.append(datetime.date(row[0]))


if lstout:
    caribspring, caribcalv, caribsummer, caribfall, caribwinter = season(lstout[0], lstout[len(lstout) - 1])
    sumcbspringout += caribspring
    sumcbcalvout += caribcalv
    sumcbsummerout += caribsummer
    sumcbfallout += caribfall
    sumcbwinterout += caribwinter
    difoutdy = lstout[len(lstout) - 1] - lstout[0]
    if difoutdy.days == 0:
        difoutdy = timedelta(days=1)
    sumoutdy += difoutdy.days
elif lstin:
    caribspring, caribcalv, caribsummer, caribfall, caribwinter = season(lstin[0], lstin[len(lstin) - 1])
    sumcbspringin += caribspring
    sumcbcalvin += caribcalv
    sumcbsummerin += caribsummer
    sumcbfallin += caribfall
    sumcbwinterin += caribwinter
    difindy = lstin[len(lstin) - 1] - lstin[0]
    if difindy.days == 0:
        difindy = timedelta(days=1)
    sumindy += difindy.days

print("Total number of out of burn days for " + caribID + " = " + str(sumoutdy))
print("Total number of in burn days for " + caribID + " = " + str(sumindy))

print("Total number of out of burn spring days for " + caribID + " = " + str(sumcbspringout))
print("Total number of out of burn calv days for " + caribID + " = " + str(sumcbcalvout))
print("Total number of out of burn summer dayst for " + caribID + " = " + str(sumcbsummerout))
print("Total number of out of burn fall days for " + caribID + " = " + str(sumcbfallout))
print("Total number of out of burn winter days for " + caribID + " = " + str(sumcbwinterout))
print("Total number of in burn spring days for " + caribID + " = " + str(sumcbspringin))
print("Total number of in burn calv days for " + caribID + " = " + str(sumcbcalvin))
print("Total number of in burn summer days for " + caribID + " = " + str(sumcbsummerin))
print("Total number of in burn fall days for " + caribID + " = " + str(sumcbfallin))
print("Total number of in burn winter days for " + caribID + " = " + str(sumcbwinterin))

print("Script ran " + str(datetime.now()))
```

ii. Script for step length:

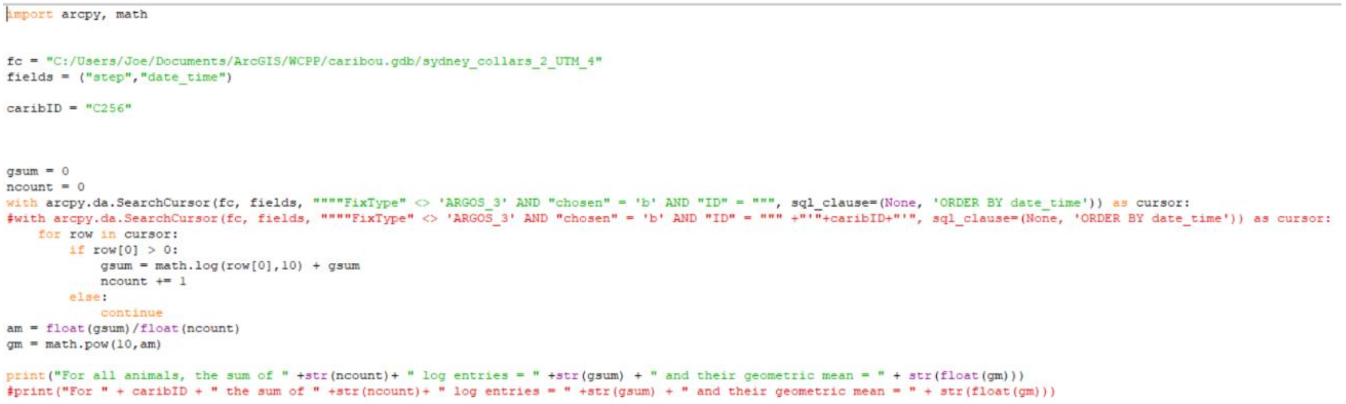
Field Calculator Code Block (Python parser):

```
count = 0
def dist(shape):
    global prev
    global count
    point = arcpy.PointGeometry(shape.getPart(0))
    if count > 0:
        distance = point.distanceTo(prev)
    else:
        distance = 0
    prev = point
    count = count+1
    return distance
Field Calculator expression: dist( !Shape! )
```

## iii. Script for elapse time:

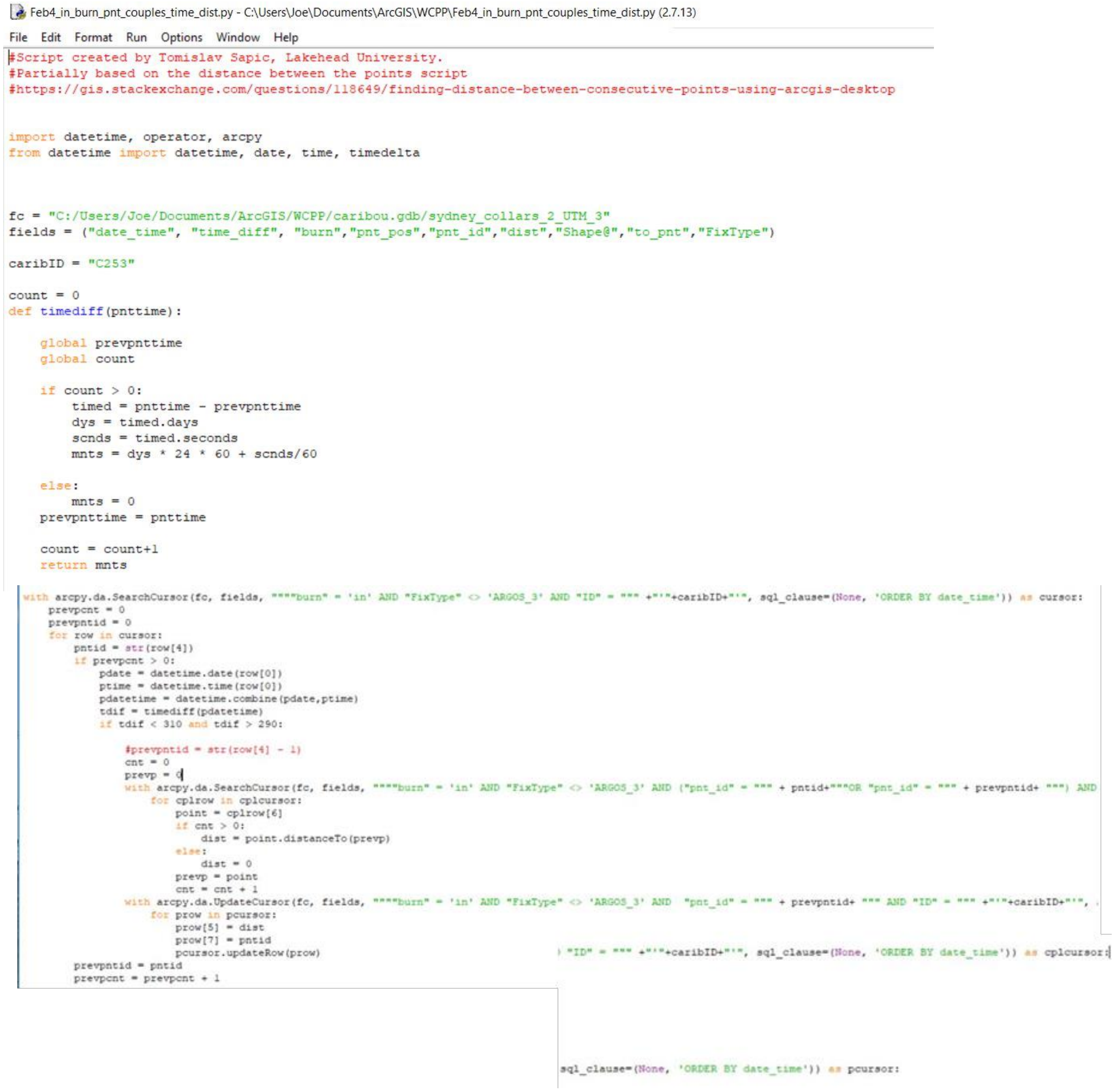
```
fc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/sydney_collars_2_UTM_1"
fields = ("date_time", "time_diff")

caribID = "C253"

count = 0
def timediff(pnttime):

    global prevpnttime
    global count

    if count > 0:
        timed = pnttime - prevpnttime
        dys = timed.days
        scnds = timed.seconds
        mnts = dys * 24 * 60 + scnds/60
##        print("pnttime")
##        print(pnttime)
##        print("prevpnttime")
##        print(prevpnttime)
##        print("minutes")
##        print(mnts)
    else:
        mnts = 0
    prevpnttime = pnttime

    count = count+1
    return mnts


with arcpy.da.UpdateCursor(fc, fields, """"ID" = """ +"'"+caribID+"'", sql_clause=(None, 'ORDER BY date_time')) as cursor:
    for row in cursor:
        pdate = datetime.date(row[0])
        ptime = datetime.time(row[0])
        pdatetime = datetime.combine(pdate,ptime)
        tdif = timediff(pdatetime)
##        print("tdif")
##        print(tdif)
        row[1] = tdif
        cursor.updateRow(row)
```

## iv. Script for anti-log of arithmetic mean of log-transformed step lengths.



```
import arcpy, math


fc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/sydney_collars_2_UTM_4"
fields = ("step","date_time")

caribID = "C256"



gsum = 0
ncount = 0
with arcpy.da.SearchCursor(fc, fields, """"FixType" <> 'ARGOS_3' AND "chosen" = 'b' AND "ID" = """, sql_clause=(None, 'ORDER BY date_time')) as cursor:
#with arcpy.da.SearchCursor(fc, fields, """"FixType" <> 'ARGOS_3' AND "chosen" = 'b' AND "ID" = """ +"'"+caribID+"'", sql_clause=(None, 'ORDER BY date_time')) as cursor:
    for row in cursor:
        if row[0] > 0:
            gsum = math.log(row[0],10) + gsum
            ncount += 1
        else:
            continue
am = float(gsum)/float(ncount)
gm = math.pow(10,am)

print("For all animals, the sum of " +str(ncount)+ " log entries = " +str(gsum) + " and their geometric mean = " + str(float(gm)))
#print("For " + caribID + " the sum of " +str(ncount)+ " log entries = " +str(gsum) + " and their geometric mean = " + str(float(gm)))
```

## v. Point pairs script

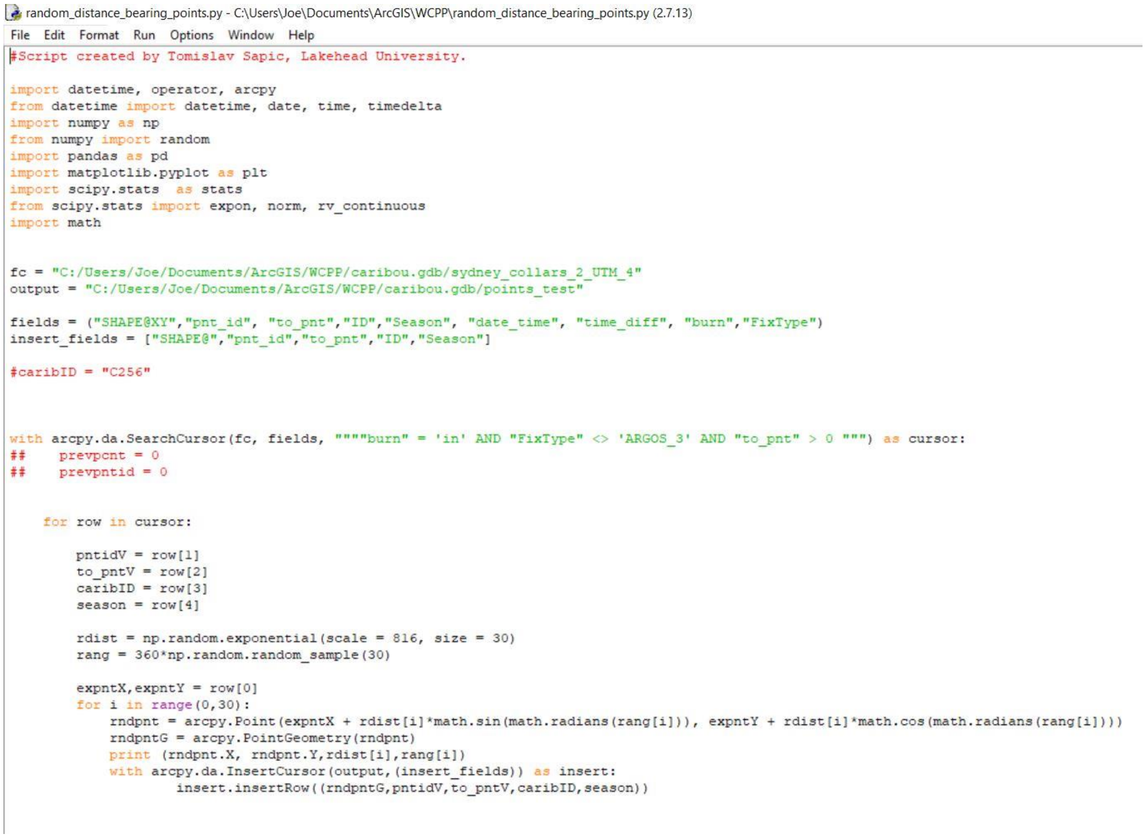


```
#Script created by Tomislav Sapic, Lakehead University.
#Partially based on the distance between the points script
#https://gis.stackexchange.com/questions/118649/finding-distance-between-consecutive-points-using-arcgis-desktop


import datetime, operator, arcpy
from datetime import datetime, date, time, timedelta



fc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/sydney_collars_2_UTM_3"
fields = ("date_time", "time_diff", "burn","pnt_pos","pnt_id","dist","Shape@","to_pnt","FixType")

caribID = "C253"

count = 0
def timediff(pnttime):

    global prevpnttime
    global count

    if count > 0:
        timed = pnttime - prevpnttime
        dys = timed.days
        scnds = timed.seconds
        mnts = dys * 24 * 60 + scnds/60

    else:
        mnts = 0
    prevpnttime = pnttime

    count = count+1
    return mnts
with arcpy.da.SearchCursor(fc, fields, """"burn" = 'in' AND "FixType" <> 'ARGOS_3' AND "ID" = """ +"'"+caribID+"'", sql_clause=(None, 'ORDER BY date_time')) as cursor:
    prevpcnt = 0
    prevpntid = 0
    for row in cursor:
        pntid = str(row[4])
        if prevpcnt > 0:
            pdate = datetime.date(row[0])
            ptime = datetime.time(row[0])
            pdatetime = datetime.combine(pdate,ptime)
            tdif = timediff(pdatetime)
            if tdif < 310 and tdif > 290:

                #prevpntid = str(row[4] - 1)
                cnt = 0
                prevp = 0
                with arcpy.da.SearchCursor(fc, fields, """"burn" = 'in' AND "FixType" <> 'ARGOS_3' AND ("pnt_id" = """ + pntid+"""OR "pnt_id" = """ + prevpntid+ """) AND
                    for cplrow in cplcursor:
                        point = cplrow[6]
                        if cnt > 0:
                            dist = point.distanceTo(prevp)
                        else:
                            dist = 0
                        prevp = point
                        cnt = cnt + 1
                with arcpy.da.UpdateCursor(fc, fields, """"burn" = 'in' AND "FixType" <> 'ARGOS_3' AND  "pnt_id" = """ + prevpntid+ """ AND "ID" = """ +"'"+caribID+"'", 
                    for prow in pcursor:
                        prow[5] = dist
                        prow[7] = pntid
                        pcursor.updateRow(prow)
        prevpntid = pntid
        prevpcnt = prevpcnt + 1
```

```
) "ID" = """ +"'"+caribID+"'", sql_clause=(None, 'ORDER BY date_time')) as cplcursor:
```

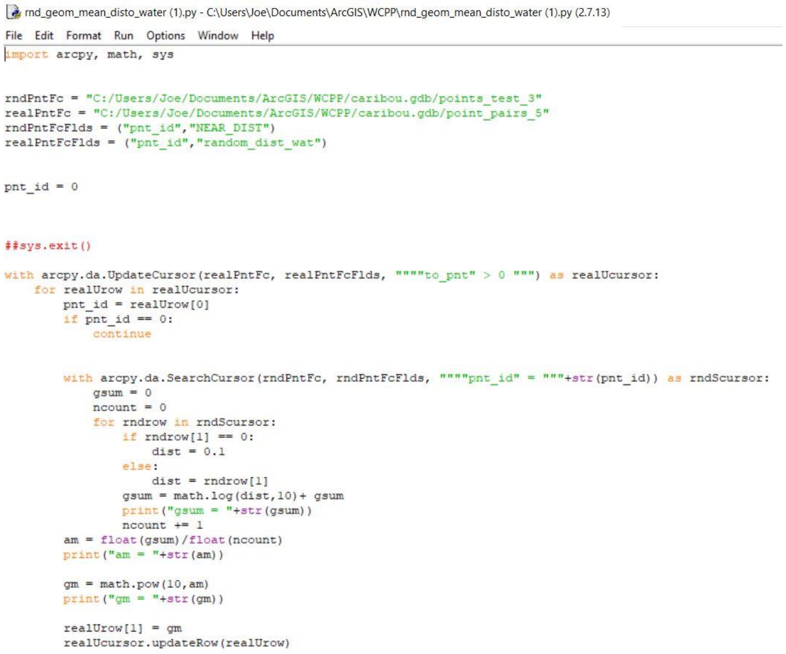
```
sql_clause=(None, 'ORDER BY date_time')) as pcursor:
```

vi. Script used to generate random points for each point pair.



```
#Script created by Tomislav Sapic, Lakehead University.

import datetime, operator, arcpy
from datetime import datetime, date, time, timedelta
import numpy as np
from numpy import random
import pandas as pd
import matplotlib.pyplot as plt
import scipy.stats  as stats
from scipy.stats import expon, norm, rv_continuous
import math


fc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/sydney_collars_2_UTM_4"
output = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/points_test"

fields = ("SHAPE@XY","pnt_id", "to_pnt","ID","Season", "date_time", "time_diff", "burn","FixType")
insert_fields = ["SHAPE@","pnt_id","to_pnt","ID","Season"]

#caribID = "C256"



with arcpy.da.SearchCursor(fc, fields, """"burn" = 'in' AND "FixType" <> 'ARGOS_3' AND "to_pnt" > 0 """) as cursor:
##    prevpcnt = 0
##    prevpntid = 0


    for row in cursor:

        pntidV = row[1]
        to_pntV = row[2]
        caribID = row[3]
        season = row[4]

        rdist = np.random.exponential(scale = 816, size = 30)
        rang = 360*np.random.random_sample(30)

        expntX,expntY = row[0]
        for i in range(0,30):
            rndpnt = arcpy.Point(expntX + rdist[i]*math.sin(math.radians(rang[i])), expntY + rdist[i]*math.cos(math.radians(rang[i])))
            rndpntG = arcpy.PointGeometry(rndpnt)
            print (rndpnt.X, rndpnt.Y,rdist[i],rang[i])
            with arcpy.da.InsertCursor(output,(insert_fields)) as insert:
                    insert.insertRow((rndpntG,pntidV,to_pntV,caribID,season))
```

vii. Random point mean distance to water script



```
import arcpy, math, sys


rndPntFc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/points_test_3"
realPntFc = "C:/Users/Joe/Documents/ArcGIS/WCPP/caribou.gdb/point_pairs_5"
rndPntFcFlds = ("pnt_id","NEAR_DIST")
realPntFcFlds = ("pnt_id","random_dist_wat")


pnt_id = 0



##sys.exit()

with arcpy.da.UpdateCursor(realPntFc, realPntFcFlds, """"to_pnt" > 0 """) as realUcursor:
    for realUrow in realUcursor:
        pnt_id = realUrow[0]
        if pnt_id == 0:
            continue


        with arcpy.da.SearchCursor(rndPntFc, rndPntFcFlds, """"pnt_id" = """+str(pnt_id)) as rndScursor:
            gsum = 0
            ncount = 0
            for rndrow in rndScursor:
                if rndrow[1] == 0:
                    dist = 0.1
                else:
                    dist = rndrow[1]
                gsum = math.log(dist,10)+ gsum
                print("gsum = "+str(gsum))
                ncount += 1
        am = float(gsum)/float(ncount)
        print("am = "+str(am))

        gm = math.pow(10,am)
        print("gm = "+str(gm))

        realUrow[1] = gm
        realUcursor.updateRow(realUrow)
```