THE USE OF COMPACT SURVEILLANCE RADAR TO STUDY POLAR BEARS (*URSUS MARITIMUS*) NEAR CHURCHILL, MANITOBA, CANADA

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Abstract.

Many species of wildlife are currently facing intense competition with people for space and resources, resulting in increasing levels of human-wildlife conflict. In Canada's North, climate change is exacerbating this issue for polar bears (*Ursus maritimus*) and people. Unfortunately, scientific understanding of the factors that influence human-polar bear conflicts is substantially less developed for polar bears compared to other bear species. The majority of movement data on polar bears is accumulated from GPS tracking collars which is female-biased and has insufficient spatial and temporal resolution to document fine-scale movements. To address this shortcoming, my study tested the efficacy of compact surveillance radar (CSR) as a detection method and as a method to study polar bear movement and behaviours. The results showed that the radar currently functions adequately as a detection method, but with future improvements to the technology and customization by the user it has high potential to function as an autonomous detection and alert method. It also provides high-quality data on bears' local movements that can be combined with resource and environmental data specific to the time and location of bear sighting. Though improvements are needed, CSR is a viable new technology to be integrated into polar bear management and ecological studies.

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Chapter 1.

Introduction.

1.1. Background.

Conflicts arise between species when they share a limited resource (Ngene & Omondi, 2008, p. 77). Today, many species of wildlife are facing intense competition with people for space and resources, resulting in increasing levels of human-wildlife conflict (Pimm et al. 1995; Balmford et al. 2001). Climate change can reduce resources for wildlife and exacerbate these conflicts. By significantly altering the habitat of many species (Durner et al. 2009; Dirnböck et al. 2011), climate change has been observed to change the distributions of wildlife populations (Chen et al. 2011). As species adjust to these changing environmental conditions, they are using new areas within their existing ranges (Melin et al. 2014) which can lead to increased levels of human-wildlife conflict (Baruch-Mordo et al. 2014). In Canada's North, these changes are intensifying conflict between polar bears (*Ursus maritimus*) and people (Stirling & Derocher 1993; Stirling, Lunn, & Iacozza 1999; Stirling and Parkinson 2006).

By delaying winter sea ice formation in the fall and causing earlier break up in the spring, warming of the Arctic is shortening bears' hunting season and lengthening the terrestrial fasting period (Cherry et al. 2013; Gleason & Rode 2009; Rode et al. 2015; Schliebe et al. 2008). Polar bears are specialized predators of seals (Derocher, Lunn, & Stirling 2004), primarily ringed seals (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) (Stirling & Archibald 1977; Smith 1980). Requiring sea ice as a platform to hunt, polar bears generally do not hunt during the summer months when much of the seasonal sea ice melts. During these ice free periods, polar bears rely on the fat reserves developed during the hunting period to sustain them (Stirling & Derocher 1993). The warming of the climate is reducing the amount of time bears have to accumulate the fat stores needed to survive the now extended summer months (Derocher, Lunn, & Stirling 2004). Declines in sea ice have been linked to significant, negative effects on polar bear body condition (Stirling, Lunn, & Iacozza 1999) and declines in survival (Stirling & Derocher, 1993). Polar bear body condition deteriorates during the terrestrial period while they rely on finite stores of body fat (Cherry et al. 2013; Rode et al. 2010; Stirling et al.1999). Extended fasting periods and increased nutritional stress have also been attributed to infanticide, cannibalism, and even starvation in some polar bear populations (Lunn & Stenhouse 1985; Derocher & Wiig 1999; Amstrup et al. 2006; Stirling et al. 2008).

The lengthened terrestrial periods coupled with increased human activity into polar bears' ranges expand opportunities for overlap and conflicts (Derocher, Lunn, & Stirling 2004; Stirling & Derocher 1993; Stirling & Parkinson 2006). Compounding increased proximity is the fact that nutritionally stressed bears may be more motivated to take risks to obtain food, including interacting with humans (Derocher, Lunn, & Stirling 2004; Mattson 1990; Peacock et al. 2010; Regehr et al. 2007; Stirling and Derocher 1993; Stirling and Parkinson 2006 Stirling, Lunn, & Iacozza 1999; Towns et al. 2009). As such, it is predicted that the frequency of human-polar bear interactions and conflicts will likely increase as climate change progresses (Dyck 2006; Peacock et al. 2010; Regehr et al. 2007; Stirling et al. 1999).

Currently, most management programs rely on visual reports of polar bears in and around areas of human activity. Bears are then driven out of the area through various methods, including aerosol boat horns, thunderflashes, teleshot flares, gunshots, and the roaring of car engines (Woolridge 1983). Unfortunately, in comparison to other bear species, information on the biophysical factors influencing human-polar bear conflict is substantially less developed and insufficient to guide management (Clark 2003; Clark, van Beest, & Brook 2012). This means that mitigation efforts cannot be designed around the underlying factors that drive human-polar bear conflict; the lack of which is known to be detrimental to wildlife management programs (Knight, J. 2001).

Identifying and understanding factors that affect animal distributions is important for predicting responses to changing environmental conditions (Mills and Gorman 1997; Musiega et al. 2006; Sutherland 2006). Given the threats climate change poses to polar bear health and human-polar bear conflict, it is important to develop our understanding of fine-scale polar bear movement in areas of human activity to better inform management practices. Technology that could collect data on specific populations of bears as well as send early alerts to managers would provide the tools necessary to design sustainable management efforts. While current technologies used to study behaviour and habitat use may not provide this opportunity, the use of compact surveillance radar has great potential to meet both needs – both alerting managers before bears enter areas of human settlement and the ability to study the underlying reasons for conflict. This study examined the efficacy of compact surveillance radar to do both.

1.2. Telemetry & Compact Surveillance Radar

GPS satellite telemetry allows the remote tracking of animal positions and movement (Cagnacci et al. 2010). Researchers can collect large quantities of continuous location data, monitor and map animal movements, model habitat and movement patterns, and evaluate wildlife movements and space use all with a high degree of precision and accuracy, 24 hours a day (Gavrilov et al. 2015; Cagnacci et al. 2010; Lewis et al. 2007). GPS is especially useful for animals like polar bears that are not easily observed in person, such as those with large home ranges or marine animals (Hebblewhite & Haydon 2010). If properly applied, GPS telemetry can be used to improve habitat modeling and conservation, study mechanisms of migration, understand basic ecology of wide-ranging species, positively impact conservation, and even project the impacts of climate change (Hebblewhite & Haydon 2010). This technology has been adapted worldwide to study the ecology and distribution of both terrestrial and marine species (Hebblewhite & Haydon 2010).

Despite its advantages, GPS telemetry has some setbacks for studying polar bears. Firstly, while it is possible to use GPS ear tags, if researchers are using GPS collars, only adult females are able to fitted. Sub-adults and cubs are unable to be collared as they will continue to grow but the collar will not expand. Additionally, due to the conical shape of the male polar bear head, the collars are unable to stay on (Laidre et al. 2013). Secondly, two types of error are inherent in GPS telemetry and can cause bias data sets: missed locations and location error (Lewis et al. 2007). Combined, these factors can lead to mistaken inferences of animal behaviour, particularly those involving movement paths and habitat selection (Friar et al. 2010). Thirdly, the ability of the GPS system to function is constrained by environmental conditions, such as climate, habitat types, and terrain roughness. It is also constrained by animal behaviour, such as their movement type and the orientation of the collar (Heard, Ciarniello, & Seip 2008). Fully understanding and modeling these types of errors is challenging due to the difficulties of setting up field tests (Heard, Ciarniello, & Seip 2008). A final constraint is that GPS collars are costly, often limiting the number of individuals that can be fitted (Cagnacci et al. 2010). A single collar can range from between USD 2000-8000 (Hebblewhite & Haydon 2010). A review by Lindberg and Walker (2007) concluded that a minimum of 20 animals are necessary to make reliable statistical inferences. This trade-off between cost and sample size has led to the inappropriate use of technology in the acceptance of smaller sample sizes (Hebblewhite & Haydon 2010).

A possible solution to study fine-scale movements of wildlife is radar. Radar requires no physical interaction with the animal, is not sex-specific, has a small range of sight allowing the correction of error, and can alert the user of any object detected in the area with an accompanying visualization. At a basic level, radar is the transmission of a pulse of energy (radio waves), the reflection of a portion of that transmission energy by a target, and the reception of the returned energy by a receiver (Eastwood 1967). The time delay between the transmission and reception is how a radar system determines the range of a given target (Gauthreaux & Schmidt 2013). Soon after its invention, users realized radar could be used to detect and track birds (Lack & Varley 1945).

Different types of radar operate at different spatial scales, mainly in their resolution and extent. As such, they can be used to gather different types of data (Gauthreaux & Schmidt 2013). They can also provide information on origin, timing, extent, and volume of movements of animals (Russell & Gauthreaux 1998). Radar allows a more complete assessment of wildlife movement patterns than visual observations due to its capability to work after sunset (Russell & Gauthreaux 1998; Harmata et al. 1999). Radar technology has been adapted and used to study many species of wildlife. Weather surveillance radar (WSR) has been used to study bird movements and bat roosts since the late 1950s (Gauthreaux & Schmidt 2013; Russell & Gauthreaux 1998), while ground-penetrating radar (GPR) has been used to study European rabbit tunnels in Australia (Stott 1996), provide visualization of pocket gopher burrows (Cortez et al. 2013), and European badger dens (Nichole et al. 2003).

In this study, I tested if Compact Surveillance Radar (CSR) can be used to accurately track polar bears over short distances. Compact surveillance radar is most commonly used in security and surveillance applications. The system used in this study was the SpotterRF C40 D which is capable of detecting multiple objects simultaneously, can alert the user of a detected object, provides visuals and location data, and collects and stores information on the object including speed of movement, heading, displacement, distance traveled, size, and duration (*SpotterRF*). Though not previously used in polar bears studies, CSR technology offers many potential advantages. These include the ability to alert users of any potential threats in the area, no risk of interaction with wildlife, low error probability and higher correction capability, the elimination of sexual or size biases, and the potential for integration of detailed habitat and resource data.

Because the SpotterRF system has the ability to alert users when an object is detected, it has the potential to act as a semi-autonomous polar bear detection method – something neither VHF nor GPS collars are currently able to provide. As the systems consists of panels that send out radio waves, it does not require the tagging of an animal. This removes the potential sex and age biases of collars and protects both the researcher and the bear by eliminating need for contact and proximity. With the CSR system the risk of signal and device errors are lessened and the ability to monitor and correct them is heightened. Due to the use of radio waves rather than light or visual cues, the system is able to work in all weather and lighting conditions. This promises 24-hour detection of the selected area regardless of the climate, something that can affect the reliability GPS signals (Heard, Ciarniello, & Seip 2008). While GPS collars can fail due the habitat type and terrain roughness (Heard, Ciarniello, & Seip 2008), CSR systems are connected to sedentary objects (such as a building) and avoid this risk. While it is possible that the CSR system could have the issues of missed locations or location errors, it is entirely possible to observe the study species at the same time as the technology and identify and correct for these errors. Due to its advantages, CSR technology has the potential to be an asset to polar bear management as an autonomous means of detection and alert as well as a method for data collection. As such, this study sought to examine the performance of the SpotterRF CSR system outside Churchill, Manitoba.

1.3. Research Objectives.

The overall goal of this study was to understand if CSR technology is suitable for use as a detection and alert method and for studying the fine-scale behaviour of polar bears in areas of human activity within the overall context of improving human-polar bear conflict management.

Chapter 2, "The Use of Compact Surveillance Radar (CSR) to Detect & Track Polar Bears in Areas of Human Activity" looks at the efficacy of this technology in light of its potential use as a detection and alert system. Combining data gathered by a human observer and the radar, it examines three components of functionality: (1) the ability of the system to detect free-ranging polar bears, (2) the influence of visibility impediments on detection rates, and (3) the ability of the system to track bears across the landscape. These components allowed me to examine if CSR technology worked efficiently enough at detecting polar bears to be a potential alert system for human-polar bear conflict.

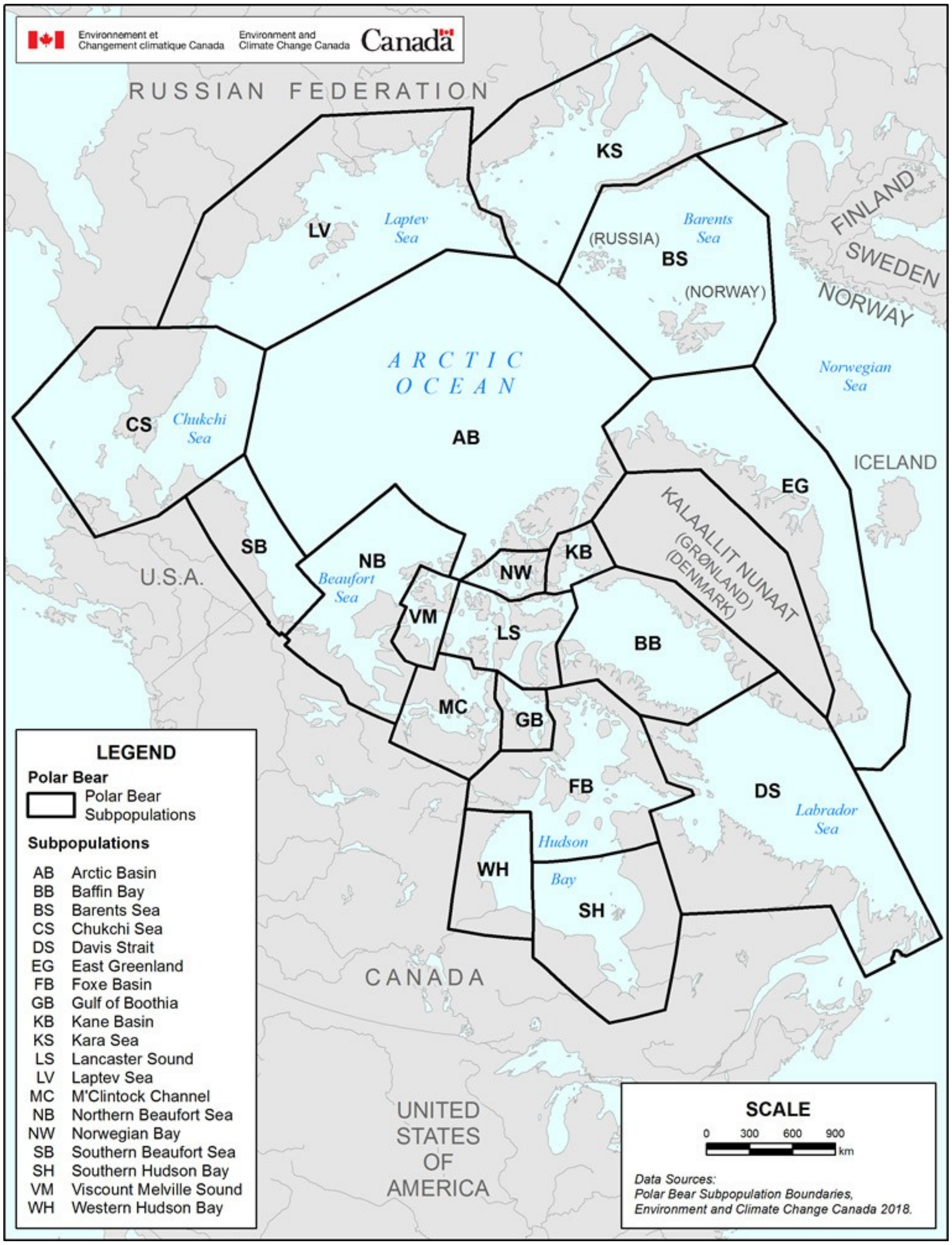
Chapter 3, "The Use of Compact Surveillance Radar to Study Polar Bear Behaviour in an Area of Human Activity" examines the movement data that the system gathers to understand the potential for use in studying polar bear behaviour. I examined movement patterns, the influence of environmental conditions on bear activity, curiosity behaviours, tortuosity of bear movement, and movement modes. These analyses allowed me to determine the potential uses of CSR technology in studying fine-scale polar bear movements and behaviours in light of its potential use for future studies.

Chapter 4, "Conclusions", summarizes the findings, situates them in light of conservation, and makes suggestions for future studies.

Chapter 2.

The Use of Compact Surveillance Radar (CSR) to Detect & Track Polar Bears in Areas of Human Activity.

2.1. Introduction



Data Sources: Polar Bear Subpopulation Boundaries, Environment and Climate Change Canada 2018.

Figure 2.1. MAP OF POLAR BEAR SUBPOPULATIONS. Map showing all the subpopulations of polar bears worldwide. The population in this study was the Western Hudson Bay population (WH) (*Government of Canada*).

Polar bears (*Ursus maritimus*) live throughout the circumpolar Arctic (Aars, Lunn, & Derocher, 2006). They rely on the annual sea ice over the continental shelf and the inter-island archipelagos around the polar basin, as this is where biological productivity is highest (Aars, Lunn, & Derocher 2006) – see Figure 2.1. In Canada, bears can be found through the Arctic Archipelago, the Beaufort Sea, Hudson Bay, James Bay, and Baffin Island (Aars, Lunn, & Derocher 2006). These bears spend part of the summer and fall on land, where they fast during the seasonal melting of sea ice (Jonkel et al. 1976; Stirling & Lunn 1997; Ferguson, Messier, & Taylor 1997). This is because polar bears are specialized predators of seals (Derocher, Lunn, & Stirling 2004), primarily ringed seals (*Pusa hispida*) and bearded seals (*Erignathus barbatus*) (Stirling & Archibald 1977; Smith 1980). During ice free periods, polar bears rely on the fat reserves developed during the hunting period. As such they require successful spring and early summer hunting to accumulate adequate fat stores to survive the summer fasting period (Stirling & Derocher 1993).

Research has shown that climate change in the Arctic is threatening this pattern of hunting and fasting (Derocher, Lunn, & Stirling 2004). By delaying sea ice formation in the fall and causing earlier break up in the spring, warming of the Arctic shortens bears' hunting season and lengthens the terrestrial fasting period (Cherry et al. 2013; Gleason & Rode 2009; Rode et al. 2015; Schliebe et al. 2008). These changes in winter sea ice pose major threats to polar bear survival. As a result of sea ice loss, some populations of polar bears have even experienced declines in abundance (Regehr et al. 2007; Bromaghin, McDonald, & Stirling 2015; Lunn, Servanty, & Regehr 2016; Obbard et al. 2018).

In addition to threatening bear survival, climate change has the potential to exacerbate conflict between polar bears and people (Stirling and Derocher 1993; Stirling et al. 1999; Stirling and Parkinson 2006). When species adjust to changing environmental conditions, they use new areas within their existing ranges (Melin et al. 2014) which can lead to increased levels of human-wildlife conflict (Baruch-Mordo et al. 2014). While it is difficult to directly attribute climate change to individual human-bear incidents (Hulme 2009), the causal chain of reduced Arctic ice, nutritionally stressed bears, and increased conflict with people is supported by considerable empirical evidence (Clark 2003). It is believed that lengthening terrestrial periods of polar bears coupled with extended human activity into polar bears' ranges expand opportunities for overlap and thus conflicts (Derocher, Lunn, & Stirling 2004; Stirling & Derocher 1993; Stirling & Parkinson 2006). Supporting this is the fact most human-polar bear conflicts occur during bears' terrestrial period (Dyck 2006; Fleck and Herrero 1988; Gjertz & Persen 1987; Gjertz & Schie 1998; Gjertz, Aarvik, & Hindrum 1993; Stenhous, Lee, & Poole 1988). Two separate studies found that the majority of polar bears killed in defense of life or property (DLP) occurred during the open water season (Stenhouse et al. 1988; Dyck 2006).

A major anthropogenic factor contributing to human-polar bear conflict is increasing human populations in polar bear ranges by local populations, tourism, oil and gas industries, and scientific personnel (Towns et al., 2009; Hovelsrud et al. 2008; Wooldridge, 1983). This trend is significant, as human-polar bear conflict is considered to be a function of both polar bear and human population densities and behaviour (Clark 2003; Herrero & Fleck 1990). Throughout Nunavut, interviews with Inuit communities demonstrate this trend toward increased overlap as they report increasing polar bear sightings in close proximity to their communities (Tyrrell 2006; Dowsley & Taylor 2006; Dowsley & Wenzel 2008). For example, interviews in three northern communities in Canada (Pond Inlet, Clyde River, and Qikiqtarjuag), showed the majority of community members believed there to be an increase in polar bears entering the community over the 10-15 years before the survey. While some believed there to be no change in the frequency, no respondents believed there to be a decrease (Dowsley & Wenzel 2008).

Compounding increased proximity is the fact that nutritionally stressed bears may be more motivated to take risks to obtain food, including interacting with humans (Derocher, Lunn, & Stirling 2004; Mattson 1990; Peacock et al. 2010; Regehr et al. 2007; Stirling and Derocher 1993; Stirling and Parkinson 2006 Stirling, Lunn, & Iacozza 1999; Towns et al. 2009). Studies have found that human interaction with many species of bears can result from their searching for alternative food sources (Rajpurohit and Krausman 2000; Gunther et al. 2004; Oka et al. 2004). This is can be exacerbated when primary food sources become limited (McDonald & Fuller 2005). A recent study by Wilder et al. (2017) showed that nutritionally stressed adult male polar bears were the most likely to pose threats to human safety. Attacks by adult females were rare and mostly attributed to the defense of cub(s) (Wilder et al. 2017). A study by Towns et al. (2009) had similar results wherein sub-adult male bears were found to the be most common group of bears to interact with people and become problems. They suggested that the high energetic demands of sub-adults may make them more prone to nutritional stress and therefore increases the likelihood of interacting with people to obtain food (Towns et al. 2009).

Conflict with polar bears is not simply a safety concern for northern communities, it also disrupts recreational, subsistence, and industrial activities (Wilson et al. 2017). DLP-killed (defense of life and property) polar bears are often deducted from communities' hunting quotas. In Canada, Inuit and Inuit-guided sports hunters can legally harvest polar bears through a quota system designed around the maximum sustainable yield. While DLP kills previously had the option to be excluded from these quotas, new co-management agreements in 1995 between the Government of the Northwest Territories and the HTO/Regional Wildlife Organizations made it mandatory to include all human-caused bear mortalities in these quotas in an attempt to minimize overexploitation (Dyck 2006). The threat of conflict also impacts recreational activities. In a 2006 study of Inuit knowledge on polar bears, local community members stated that the number of bears in the area was increasing and that this was interrupting their summer activities, such as berry picking, wherein they had to be more diligent and carry weapons (Dowsley & Taylor 2006). Polar bears can also cause significant property damage, which is reported to be increasing in recent years. In a study in Baffin Bay, 27 of 29 local Inuit interviewed reported that they believe bears are causing more damage now than 15 years ago. The same study reported that in Baffin Bay, Pond Inlet, and Clyde River, all three communities reported destruction of meat caches by polar bears (Dowsley & Wenzel 2008).

While human-polar bear conflict has rarely led to the death or injury to humans, it is often fatal for the bear (Dyck 2006). Two separate studies in the 1980s on the mortality rate of polar bears in conflict with people revealed a 61% mortality rate (Fleck & Herrero 1988) and a 92% mortality rate (Gjertz & Persen 1987). Additionally, polar bear attacks on humans often result in negative public reaction, which can be detrimental to polar bear conservation. In some cases, negative views of bears following attacks have been seen to last for decades, resulting in less social tolerance and increased defense kills (Löe and Röskaft 2004). As such, effective management of human-polar bear conflict is considered an essential precondition to the coexistence of polar bears and people (Madden 2004) and important for both parties.

Currently there exists no technology that can autonomously and remotely alert communities to the potential threat of polar bears entering the community. Most management programs rely on visual reports of polar bears in and around areas of human activity. Bears are then driven out of the area through various methods, including aerosol boat horns, light flashes, flares, gunshots, and the roaring of car engines (Woolridge 1983). The advent of a technology that would allow communities to detect bears remotely before they enter the community would allow early intervention that would protect both people and bears.

Radar technologies have the potential to detect all bears in an area and alert managers of their presence. Compact surveillance radar (CSR) specifically is most commonly used in security and surveillance applications. CSR systems are comprised of a series of radar panels connected to an NiO system that processes and stores data. The system can also be linked to video cameras that record moving objects. Using radio waves as opposed to heat- or visual-based technology allows CSR systems to work 24-hours a day to detect and track multiple moving objects regardless of light and weather conditions. This is particularly useful in areas where constant human presence is not feasible, as it can work both autonomously and semi-autonomously.

This system offers potential to mitigate human-bear conflict. A major advantage of CSR technology is the ability to detect any movement within the radar zone and alert the user of that movement immediately (via email, text, or call). An alert tells the user the system-assigned track ID of the object, the exact location, and gives a visual image of the object. The user can remotely log onto the system to determine if the detected object needs intervention, follow its movements, and watch it on the camera live (*Spotter*RF). There is thus potential to aid management programs by allowing communities to monitor for polar bears remotely and take action before they enter areas of human activity.

Due to its detection and alert capabilities, this study sought to examine the efficacy of CSR technology as a potential management tool in reducing human-polar bear conflict. Specifically, I examined the potential use of CSR as a detection and alert system. Combining data gathered by a human observer and the radar, I examined three components of functionality: (1) the radar detection ability, (2) the influence of visibility impediments on the ability of the radar to detect bears, and (3) the ability of the system to successfully track bears. These components allowed me to examine if CSR technology worked efficiently enough at detecting and tracking polar bears to be a potential alert system for human-polar bear conflict.

2.2. Methods

2.2.1. Study Site

This study took place on the shore of Hudson Bay outside Churchill, Manitoba, Canada. Often referred to as "the polar bear capital of the world", the Churchill area boasts a high number of summering polar bears. These bears are part of Western Hudson Bay subpopulation (Regehr et al. 2007) – see Figure 2.1. When winter sea ice thaws in the spring, polar bears come ashore and spend the next ~4 months on land. In the fall, bears congregate along the shore of the bay awaiting sea ice freeze up (Regehr et al. 2007). As such, this is an ideal location to test the equipment, given the large number of bears and proximity to town.

Both radar and direct data collection took place at the Tundra Buggy Lodge. The Tundra Buggy Lodge is a semi-permanent tourist lodge owned and operated by Frontiers North Adventures. The lodge operates for the entirety of the polar bear season – approximately mid-October to late November. The lodge is driven out to "Polar Bear Point" each fall – an area on the shores of

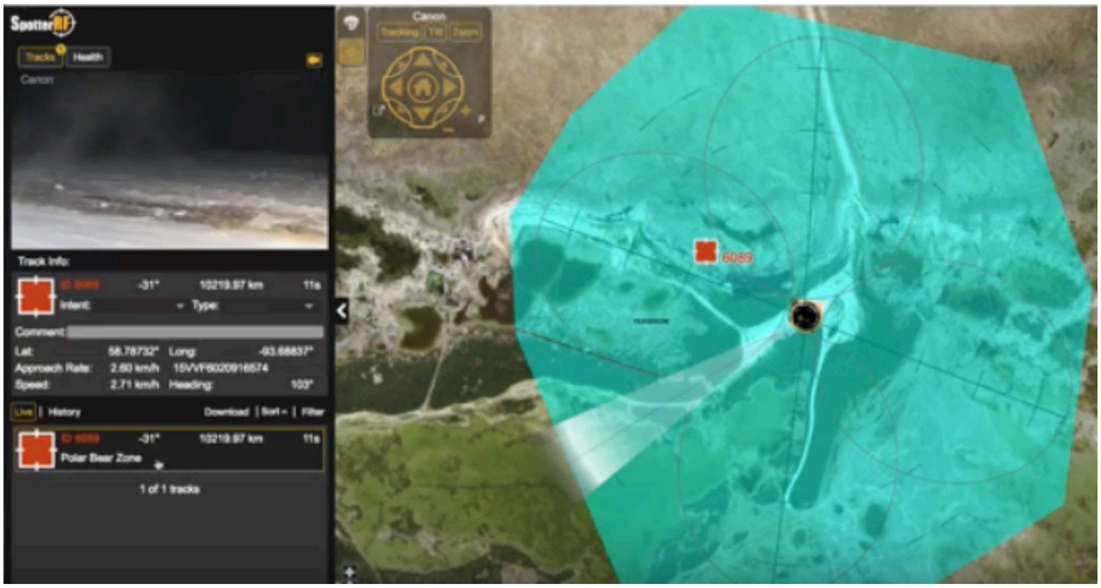
Hudson Bay, approximately 30 km east of Churchill. The exact location of the lodge during this study was North 58.786356, West 93.685747.

2.2.2. Radar: Installation, Data Collection, & Data Cleaning

The radar system used in this study was the SpotterRF C40 D©, produced by the SpotterRF company based in Utah, USA. This system consisted of four radar panels and one pan-tilt-zoom (PTZ) camera. The radar panels used radio waves to detect moving objects and recorded data on these. Each panel had an ellipse of sight, the farthest point of which is 400m from the panel itself. When turned on, the radar panels continuously scanned for movement by sending out pulses of radio waves. The system was designed to detect moving objects – sedentary objects are not recorded. Upon detection of a moving object, the radar triggers the PTZ camera to centre on and follow the moving object (see Figure 2.2). The system is capable of recording multiple moving objects simultaneously. The amount of time an object must be sedentary before tracking stops is customizable. It will follow and record the object for as long the panels detect its movement. If the panels detect more than one object at a time, the PTZ camera will switch between objects, the specifics of which are adjustable (*SpotterRF*).

Figure 2.2. PAN-TILT-ZOOM CAMERA & RADAR PANEL. The pan-tilt-zoom camera (left) located in the centre of the radar panels. One of four C-40 D radar panels (right).

The PTZ camera and radar panels were connected to an NiO system, the main user interface for the technology (see Figure 2.3). The NiO system recorded all the information recorded by the radar panels on all tracked objects. This includes, but is not limited to, the displacement, the speed of movement, duration of the sighting, latitude and longitude, and the relative size of the object. This system also recorded the movement of objects on a satellite map of the area. Each sighted object is recorded as a "track" and given a unique ID number. This information could be accessed in real time and retroactively (*SpotterRF*). The PTZ camera was connected to a Networked Video Recorder, Blue Iris©. All footage collected by the PTZ camera was stored on this application, which could be accessed in real time and retroactively.



Track Info:
ID 6089 -31° 10219.97 km 11s
Intent: Type:
Comment:
Lat: 58.78732° Long: -93.68837°
Approach Rate: 2.60 km/h 15VVF6020916574
Speed: 2.71 km/h Heading: 103°

Live | History Download | Sort | Filter
ID 6089 -31° 10219.97 km 11s
Polar Bear Zone
1 of 1 tracks

Figure 2.3. SCREEN CAPTURE OF THE ONLINE INTERFACE FOR SPOTTER RF. The online user interface shows the position of the radars, their individual ranges, and an adjustable real-time or historical log showing both geolocation of tracked objects and the camera recording.

The Spotter RF system was installed on October 3, 2019 on Frontiers North's Tundra Buggy Lodge. The four panels were installed on the outside of the lodge, on a raised section of the roof (see Figure 2.4). One panel was installed on each corner, facing North, South, East, and West, allowing a 360-degree view of the surrounding area. The PTZ camera was installed in the centre of the platform, in the middle of the panels. This allowed the camera visual access to the same area the panels could scan. The panels were set to pulse 4 times per second. Each radar panel was set to have a pitch of -2.27 and a roll of-1.02 on the recommendation of SpotterRF. This allowed the panels their largest frame of view, based on the height they were installed at (~4.5 metres off the ground). Other presets were not adjusted, and no filters or exclusion zones were turned on.

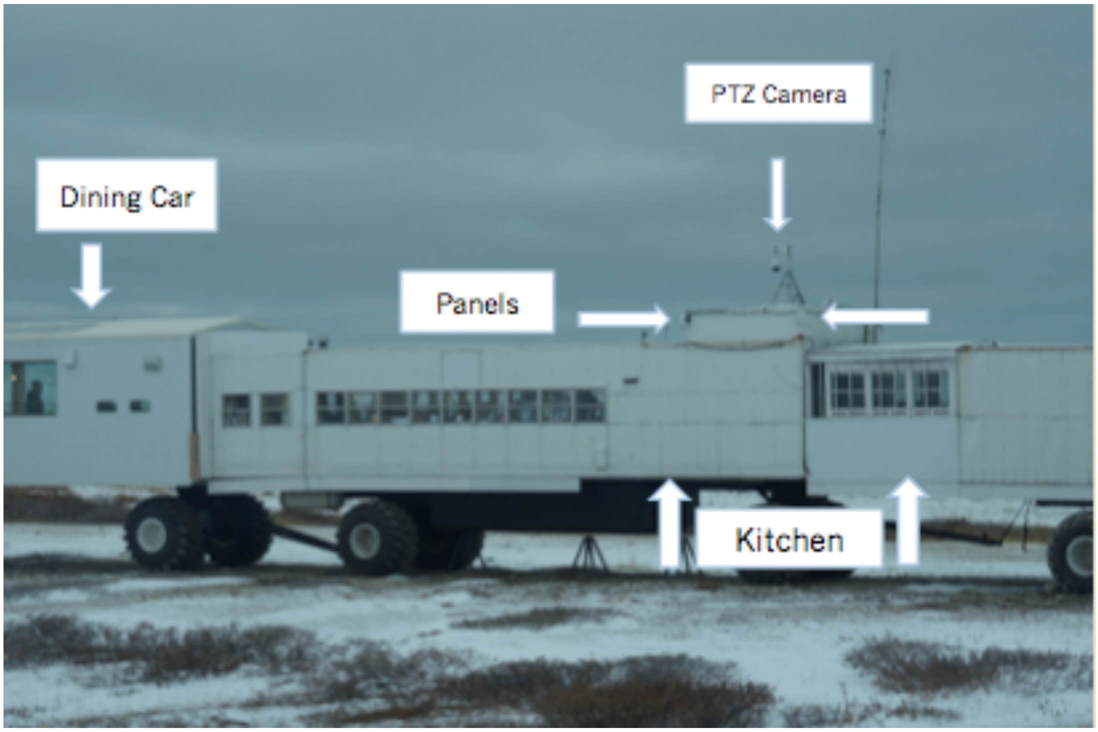
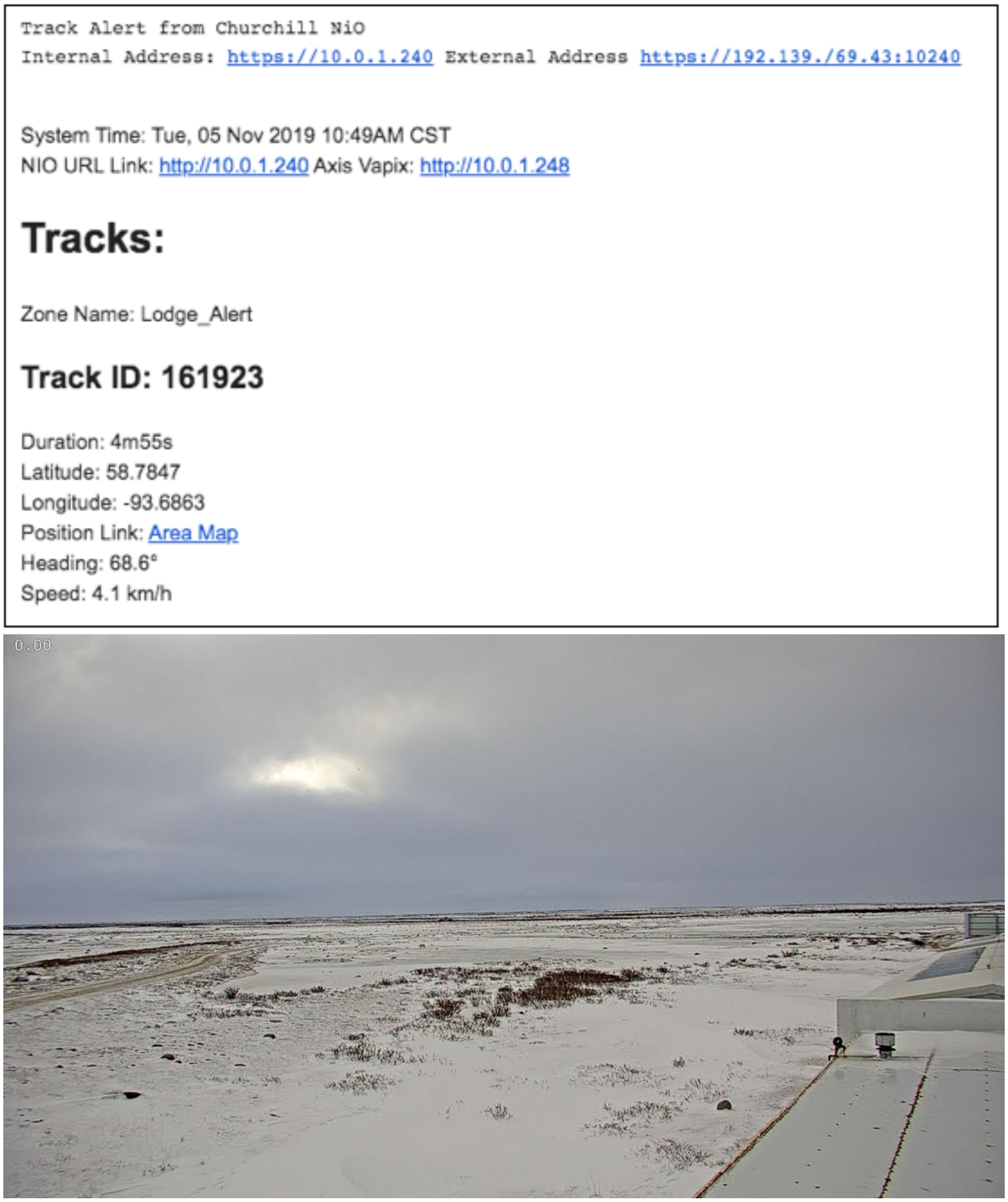


Figure 2.4. PLACEMENT OF RADAR SYSTEM. Frontier North's Tundra Buggy Lodge shown here with the CSR system installed. One C-40 D panel was installed on each corner of the raised platform, with the PTZ camera installed in the centre of the panels, on the top of the platform.

The system was set to send an email alert upon detection of a track. This email included the track ID, duration of the track, latitude and longitude, heading, speed, and photo(s) of the object. If multiple tracks were being recorded simultaneously, all tracks were included in the same email (see Figure 2.5).

The system was active for two periods in fall 2019: October 25-31 and November 4-13. The data for the field season were downloaded from the NiO system in csv format. There were two versions of data: summary and full files. Summary files reduced each sighting to one data entry and averaged the data collected for that sighting. The full files included the data recorded at every pulse the object was recorded.



Track Alert from Churchill NiO
Internal Address: https://10.0.1.240 External Address https://192.139./69.43:10240

System Time: Tue, 05 Nov 2019 10:49AM CST
NIO URL Link: http://10.0.1.240 Axis Vapix: http://10.0.1.248

Tracks:

Zone Name: Lodge_Alert

Track ID: 161923

Duration: 4m55s
Latitude: 58.7847
Longitude: -93.6863
Position Link: Area Map
Heading: 68.6°
Speed: 4.1 km/h

Figure 2.5. SCREEN CAPTURE OF AN EMAIL ALERT. The top panel shows an example of the information included for a track, the bottom panel shows an example of an attached image for a track.

Due to the sensitivity of the system, there was an average of 1810 ±1459 (SD) sightings per day. These sightings included vehicles, arctic foxes (*Vulpes lagopus*), arctic hares (*Lepus arcticus*), birds, foliage, and waves. As such, it was necessary to identify which tracks were polar bears. To extract these data, the email alerts were used as they provided both a visual of the object and the track number (see Figure 2.5). When a photo was included in the email, that photo has a label printed on it. Some of these photos are labelled with the ID of the track it is recording. Unfortunately, not all photos were named with a track ID. A large portion of the photos were named "preset-Axis Vapix". This meant if a photo had a polar bear but no track ID, I was unable to identify the track ID for that bear to obtain retrieve any movement information for that individual.

An additional problem was that during direct observations it was noted that the radar would occasionally assign multiple tracks to a single bear. To combine tracks that were the same bear, the PTZ camera footage contained in the email alerts was used. All tracks that were within 20 minutes of one another were examined to determine if they were the same bear. To be considered the same bear, two criteria had to be met: have two tracks within 20 minutes of one another and a photo of the bears in a position that was relatively the same (i.e. probable that the bear had been able to travel there within the time frame). This process continued for all tracks within the 20-minute threshold. This process continued until all possible tracks were grouped per bear.

For bears with multiple tracks, all the track IDs were recorded and data extracted and combined. Average speed was the mean of all tracks, while total displacement, duration, and distance was the sum of all tracks. The number of tracks per bear and the average time between tracks was also included.

2.2.3. Direct Observations: Data Collection & Cleaning

Direct (human) observation data collection took place over two periods: October 12-20 and November 7-13, 2019. There were two observers total, one working the first period and one the second. The observer was equipped with a watch (synced to the exact time on the NiO system), binoculars, and a range finder. Data were recorded on paper maps mirroring the NiO map (see Figure 2.6). The exact centre of the direction data map indicates the outdoor observation deck on the top of the lodge. This is the only outdoor position where the observer could see the entire range of the radar. Four increasingly large circles show the position of four 100 m zones from the position of the observer on the observation deck. Eight lines (four red and four black) indicate the directions of the compass. One blue vertical line indicates the North West-South East directions from the PTZ camera. This is noted as the radar was installed 45m South West of the observation deck.

Active surveys took place solely during daylight hours. Surveys were not limited to a specific schedule, rather the observer was to be looking for bears as continuously as possible during daylight hours. Only bears that were observed to be mobile within the 400m threshold were recorded. Sedentary bears were noted but not recorded as sightings until they moved. Bears outside the 400m range were also noted, but not recorded until they entered the 400m range. Mobility included active traveling as well as movement in one place, such as eating or shifting in place. During the hours without sunlight, the observer was to record any opportunistically sighted bears. This system was used because the lighting on the lodge only allowed visibility up to 50m from the lodge, and as such the observer could not see the entire 400m range that the radar was able to

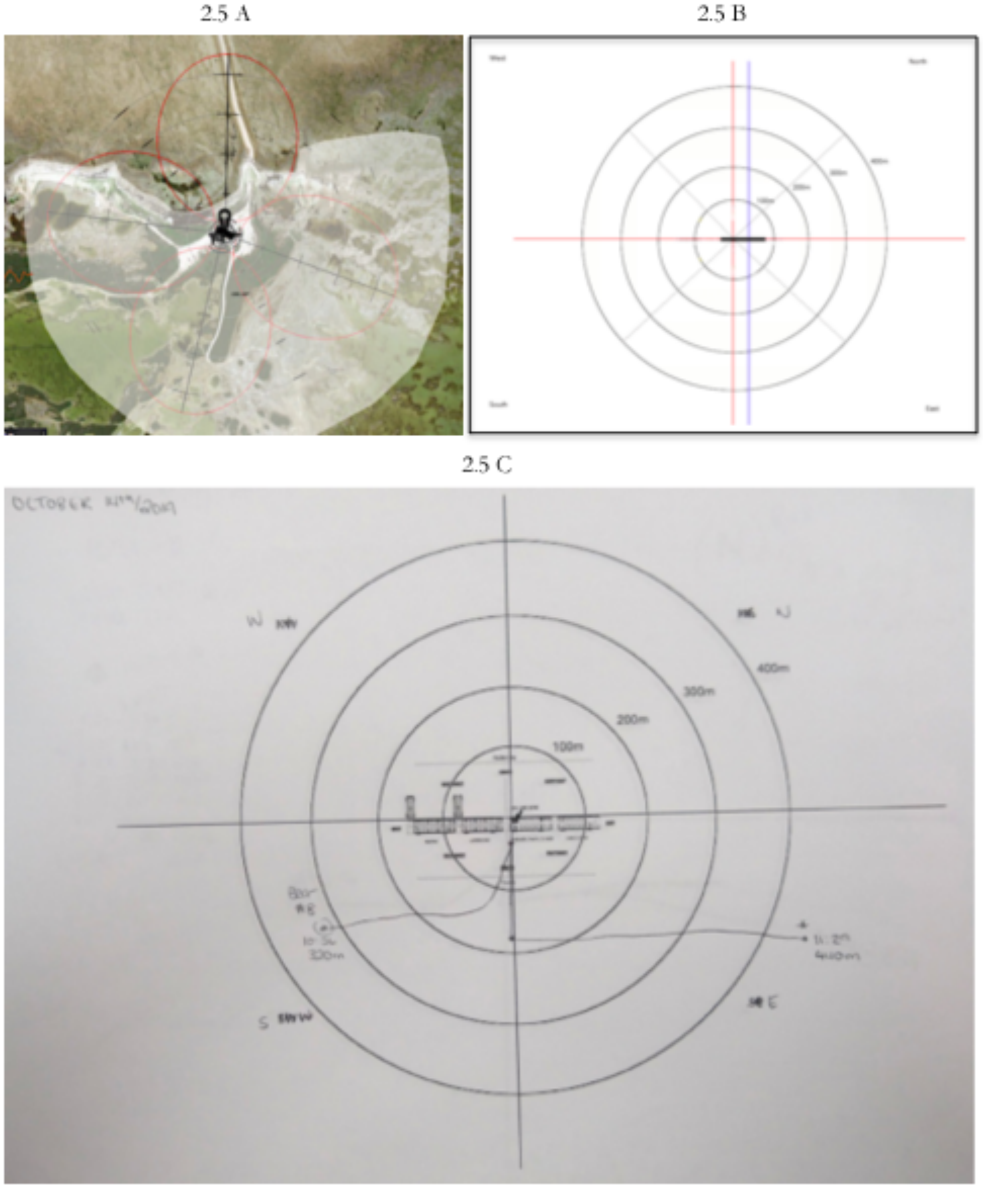


Figure 2.6. OBSERVATION & RADAR MAPS. (A) shows the radar's map, (B) shows the data collection map, and (C) shows a completed data collection sheet. Lines show the quadrats the radar panel will see within, while the circles show each 100m radius.

Upon detection of a moving polar bear within the 400m range, the observer began a sighting. The initial location of the bear was marked on the map and indicated as the start point using a dot within a circle. The time (in 24 format) was recorded, as well as the distance in metres from the observer, obtained using the rangefinder. While the sighting was active, the observer recorded the position of the bear approximately every minute, noting the time and the distance from observer. These location points were connected with a line to show the trajectory of the bear. Once a bear was sedentary, the sighting was ended and a note was made on the map of the final location point, including time and distance (see Figure 2.6). A sighting was considered active until the bear either a) left the 400m range zone, or b) was sedentary or out of view for 5+ minutes. The 5-minute rule was implemented so as to not over-record bear sightings. The radar has an adjustable threshold of how long a track must be sedentary or out of view before it is terminated. Often, a bear that is out of view or sedentary for a moment will not be ended by the radar. To account for this, if a bear came back into view within 5 minutes the sighting was not ended. The sighting then continued from the point where it came back into view. If a bear was either sedentary or out of view for over 5 minutes, the sighting was terminated. If that same bear became active again, it was recorded as a new sighting.

2.2.4. Data Analyses

2.2.4.A. Radar Detection Rate

The radar detection rate was calculated to determine the number of directly observed bears that were seen by the radar. Data from the period of November 7, 2019 – November 12, 2019 inclusively were used for this calculation, as this was the only period of time when there was a direct observer and the radar was recording bears simultaneously. Direct observations were considered confirmed bears. The detection rate was calculated as the percentage of these directly observed bears that were also detected by the radar. To verify the radar detected the same bear, two criteria had to be met: (1) a photo of the bear on the PTZ camera, and (2) this bear in the same position at the same time as the observer saw it. A 15-minute threshold was used before and after to examine the radar bears. For example, if a manual sighting was recorded between 10:00 and 10:05, radar tracks were checked that began between 9:45 and 10:20. This threshold allowed for the earlier detection and longer tracking of the bears, to account for observer biases (e.g. missed bear coming into the zone, weather affecting visual ability, etc.). For this analysis, the presence of a track ID on the photo was not necessary for a positive detection by the radar. Rather, in the event the system recorded a photo of a bear that was in the correct time frame and location, these were considered detected by the radar. This was done to ensure that we determined the actual radar detection rate, and not the ability of the system to label the photograph with a bear ID number. If there were no confirmed radar bear tracks during this time, the bear was considered not detected by the radar.

Further analyses were performed on the detection data (i.e. the directly sighted bears and the yes/no detection by the radar) to determine if any factors affected the detection rate. Time of day, weather, wind speed, and duration of sighting were tested. Time of day was binned into three categories: (1) 06:00-13:59, (2) 14:00-21:59, (3) 22:00-5:59. Weather was binned into three categories: (1) sunny and partial sun, (2) cloud and rain, and (3) snow. Wind speed was left as a continuous variable and the exact speed at the time of sighting was used. Duration of sighting in minutes was left as a continuous variable. Separate logistic regressions were run on each variable to determine if they affected if a bear was or was not detected by the radar. I also recorded the number of tracks per bear detected by the radar as described in section 2.2.2. To understand if the direct observer and the radar had differences in their observations of the same bear, the data from both data sets were compared to calculate the differences between in start time, end time, and total sighting duration between the direct observer and the radar.

I also calculated the number of additional bears the radar detected that the human observer did not. This allowed an analysis of the detection method for all bears seen during the observation period. Separate Fisher's analyses were used to test whether time of day, weather, and wind speed affected the detection method. Time of day and weather condition were categorized into bins in the same manner as above. Wind speed was binned into three categories based on the Beaufort scale of wind speed classification. Each category had a span of 14km/h, closely resembling the classifications of calm winds, gentle winds, and strong winds. Categories were: (1) 0-14km/, (2) 15-29km/h, and (3) 30-44km/h. Detection methods were classified as (1) only radar detection, (2) only direct observer detection, and (3) detection by both the radar and direct observer.

2.2.4.B. *Effect of Visibility Impediments on the Number of Bears Detected*

The effect of visibility was examined using three environmental factors that were determine may affect detection ability: (1) the time of day was used to examine the effect of the presence or absence of daylight; (2) the weather, which can affect visibility via rain and snow; and (3) the wind speed, which can significantly impede visibility when blowing ground snow.

Time was binned into two categories for analysis: day and night hours. The exact time of sunrise and sunset was determined from data retrieved from timeanddate.com (*Past Weather in Churchill,* 2019). These were recorded for both radar and direct observations. The number of bears seen by each observation method was plotted onto individual circular plots. This allowed visualization of sightings on a circular axis, as time is not linear (Pewsey, Neuhäuser, & Ruxton 2013). A Kuiper test of uniformity was performed to test if the distribution of bear sightings were uniform across 24-hour periods. (Pewsey, Neuhäuser, & Ruxton 2013). A chi square analysis was run to determine if the presence or absence of daylight affected the number of bears detected by the radar and direct observation, as well as the differences between the detection methods. A Bonferroni post-hoc test was performed on significant results to further understand the results and adjust the p-value to account for the multiple tests run in the Chi Square analysis.

Weather was classified as (1) sun or partial sun, (2) overcast and rain, and (3) snow. The data for weather were retrieved from timeanddate.com (*Past Weather in Churchill*) and recorded for each individual bear based on the exact time of the sighting. This was done for both radar and direct observations. A chi square analysis was run to determine the effect of weather on each method of detection and the differences between the detection methods. A Bonferroni post-hoc test was performed to determine the specific variables that deviated from their expected values and thus may have more significantly affected the detection ability of the radar or human observer.

Wind speed in kilometres per hour (km/h) was retrieved from timeanddate.com (*Past Weather in Churchill*) and recorded for each individual bear based on the exact time of the sighting. This was done for both the radar and direct observations. Separate linear regressions were run on the radar and direct data. Pearson's correlation values were used to further test the relationship between the wind speed and the number of bears detected.

2.2.4.C. Radar Tracking Ability

To examine how well the radar followed a bear (the tracking ability), radar data were examined and analyzed to understand how many tracks were recorded per individual bear and what may have determined the number of tracks. These data were collected during the periods of October 25-31, 2019 and November 4-13 inclusively.

There was a total of 77 individual bears recorded during this time. Of these, 24 bears had two or more tracks. Linear regression analyses were run for these 24 bears to determine if any independent variables affected the number of tracks recorded. These variables were: time of day, weather, wind speed, temperature, speed of bear movement, and the duration of the sighting. Time of day and weather were binned into the same categories as in 2.2.4.A. Wind speed and temperature used their exact values. The speed of bear movement was calculated as the mean speed of all tracks recorded for an individual bear. Duration of sighting was calculated as the sum of the durations for all tracks recorded for an individual bear. Multiple regression analyses were run to determine if the combination of variables affected the number of tracks recorded. These regressions were performed on all possible combinations of 2, 3, 4, and 5 variables. All statistical analyses were performed in SPSS with significance set at $\alpha = 0.05$.

2.3. Results

2.3.1. General Observations

Over the two periods of direct observation, a total of 58 bear sightings were observed. The mean per day was 3.87 ± 3.5 (SD) bears, with a range of 0-12 per day. The average duration of a sighting was 14.79 ± 13.54 (range 2-54) minutes. Over the two periods of radar observation, a total of 77 bear sightings were observed. The mean per day was 4.53 bears ± 6.28 (SD), ranging from 0-19 bears. The average duration of a sighting was 7.12 minutes ± 6.53 (SD) and ranged between 10 seconds and 34.66 minutes.

2.3.2. Radar Detection Ability

2.3.2.A. Detection Rate

Table 2.1. DETECTION RATE DATA. This table outlines the time and date of direct sightings 7-12 Nov 2019 and if the radar detected these bears. For some radar detections, the track ID was not known and so movement data could not be retrieved.

Date	Sighting Number	Time of Sighting	Duration of Sighting (min)	Radar Detection (Y/N)	Number of Tracks
07.11.19	1	13:00-13:07	7	Y	2
07.11.19	2	13:34-13:36	2	Y	0
07.11.19	3	13:56-14:06	10	Y	1
07.11.19	4	14:46-14:50	4	Y	3
07.11.19	5	14:58-15:09	11	Y	1
08.11.19	6	10:48-10:51	3	N	-
08.11.19	7	11:45-11:49	4	N	-
08.11.19	8	12:33-12:38	5	Y	0
10.11.19	9	14:43-14:45	2	N	-
10.11.19	10	15:21-15:26	5	N	-
12.11.19	11	12:54-12:59	5	Y	0
12.11.19	12	13:55-14:05	10	Y	3

For the period 7-12 Nov 2019, when observations and radar were simultaneously operating, detection rate of the radar was calculated as 66.6% (8/12) of all direct bear sightings (Table 2.1).

2.3.2.B. Variables Affecting Detection

The results of the logistic regressions showed that radar sightings were not affected by the time of day, wind speed, weather condition, or the duration of a sighting.

Table 2.2. INFLUENCE OF VARIABLES ON DETECTION BY RADAR. This table outlines the results of the logistic regressions run to determine if any external variables affected if a manual sighting was detected by the radar.

Variable	Nagelkerke Statistic	P-value
Time of Day	0.082	0.395
Wind Speed	0.108	0.337
Weather	0.250	1.0
Duration of Sighting	0.128	0.573

2.3.2.C. Number of Tracks Recorded per Bear

Of the 8 bears detected by the radar for the detection rate, only two were recorded with a single track. Three of the bears did not have any tracks – their presence was detected on the emailed photos and counted as detected by the bear, but photos had no corresponding track number. One bear was recorded with 2 tracks, and two bears were recorded with 3 tracks. This is summarized in Figure 2.7.

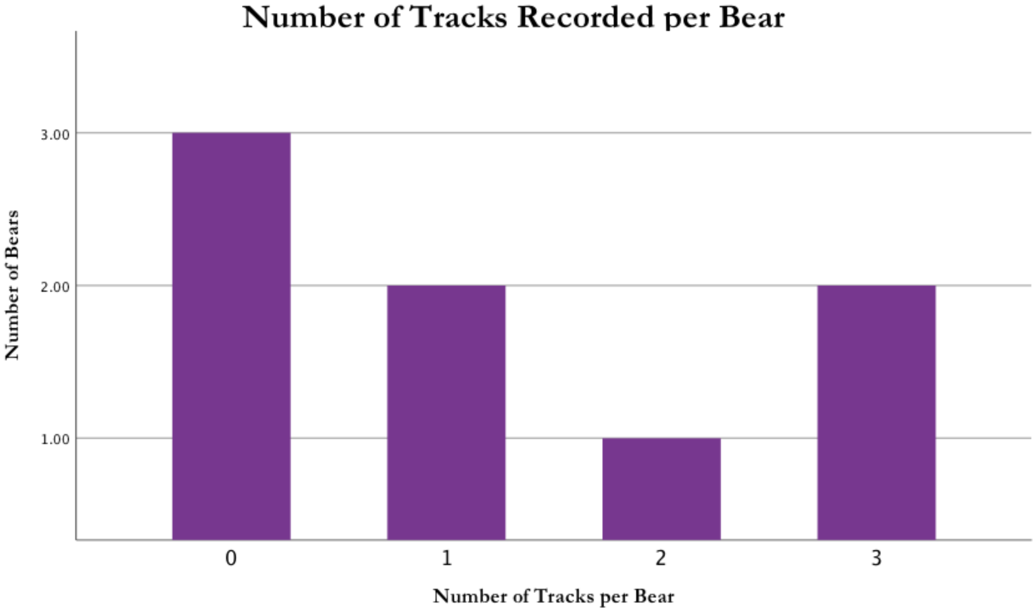


Figure 2.7. NUMBER OF TRACKS RECORDED PER BEAR DETECTED BY THE RADAR. Bar graph showing the number of tracks recorded per bear detected by the radar: 3 bears were not recorded, 2 bears had 1 track recorded, 1 bear had two tracks recorded, and 2 bears had three tracks recorded.

There were 5 bears for whom I could compare movements from direct observation versus those recorded by radar (Table 1.2) and so statistical comparisons were not possible. There were many discrepancies in start and end times between observer and radar. For 4 of 5 bears, the radar terminated the track while the bear was still being observed, leading to shorter total duration (5-10 min less) of observation.

Table 2.3. SUMMARY DATA ON BEARS WITH IDENTIFIED TRACK IDS. This table outlines the difference in data between the direct and radar observation for bears that were detected by both methods during the detection rate calculation period.

Observer Sighting Number	Observer Start Time	Radar Start Time	Difference (min)	Observer End Time	Radar End Time	Difference (min)	Observer Duration (min)	Radar Duration (min)	Difference (min)
1	13:00	13:01	-1 m	13:07	13:03	-4m	7	2.3	-4.7
3	13:56	13:53	3m	14:06	13:56	-10m	10	3.2	-6.8
4	14:46	14:38	7m	14:50	15:00	10m	4	17.9	13.9
5	14:58	14:58	0m	15:09	15:00	-9m	11	2.4	-8.6
12	13:54	13:54	0m	14:05	13:56	-9m	11	2.8	-8.2

2.3.2.D. Additional Bears Detected

During 7-12 Nov 2019, the radar detected an additional 26 bears that the human observer did not see. There were 3 bears seen solely by the human observer, and 8 bears detected by both for a total of detected 37 bears. Fisher's exact tests performed to test if environmental variables affected how the bear was detected. Time of day resulted in a Fisher's exact test value of 2.906, and a p-value of 0.585. The weather resulted in a Fisher's exact test value of 3.185, and a p-value of 0.427. Wind speed resulted in a Fisher's exact test value of 6.168, and a p-value of 0.150. As such, none of these factors significantly predicted the way a bear was detected.

2.3.3. Effect of Visibility Impediments on the Number of Bears Detected

2.3.3.A. Time

For direct sightings (i.e. by observers) across all dates, detection was highest from 06:00-20:00. No bears were detected between the hours of 01:30 and 07:00. The Kuiper test of uniformity had a result of 3.914 (α <0.01), meaning that detection was not uniformly distributed: there were clusters of bears at particular times of day showing that there was very likely an effect of the time of day on the number of bears seen.

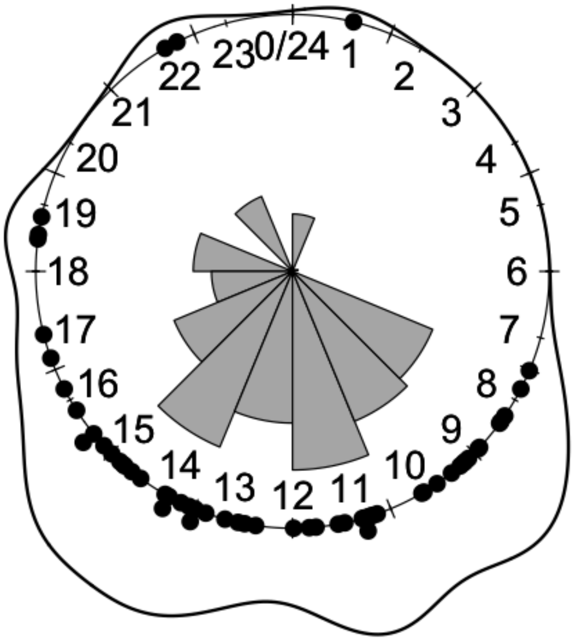


Figure 2.8. CIRCULAR ROSE PLOT SHOWING ALL DIRECTLY OBSERVED BEARS. This plot graphs the bears detected by the direct observers on a 24-hour circular plot. The wedges of the rose plot represent the number of bears seen at each hour interval, while the line outside the circle shows the general trend of the number of bears.

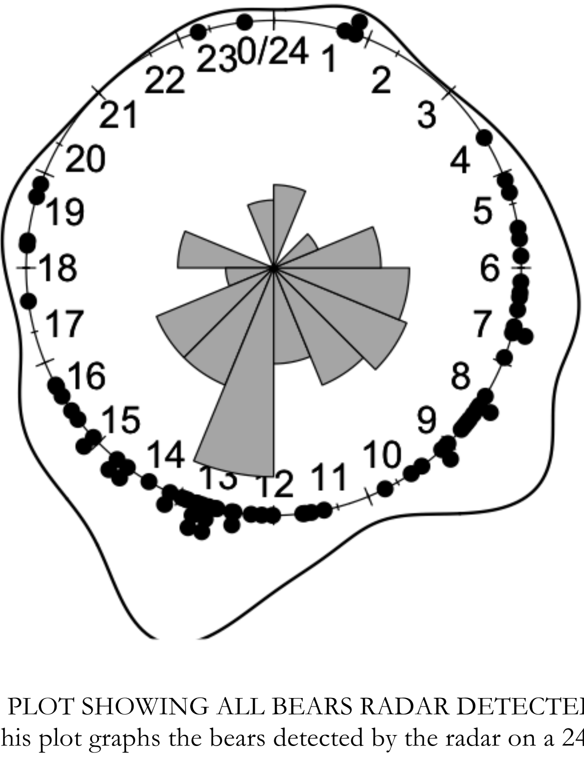


Figure 2.9. CIRCULAR ROSE PLOT SHOWING ALL BEARS RADAR DETECTED BEARS OVER THE OBSERVATION PERIODS. This plot graphs the bears detected by the radar on a 24-hour circular graph. The

wedges of the rose plot represent the number of bears seen at each hour interval, while the line outside the circle shows the general trend of the number of bears.

For radar sightings across all dates, irrespective of whether there were simultaneous observations occurring, the highest periods of detection are similar to those of the directly sighted bears, but there were more bears detected in the overnight hours. The Kuiper test of uniformity had a result of 3.4404 ($\alpha <0.01$) showing that the data was not uniformly distributed over time of day.

The results of the chi square test performed to compare the impact of time of day on direct and radar observations revealed a strong likelihood that the time of day did affect if a bear was detected or not by both methods (x-squared 7.2985, df 1, p-value 0.006). Bonferroni post-hoc tests corrected the alpha at 0.0125 and revealed that during daylight hours, the human observer was more likely to detect a bear than the radar (human: expected 43.82, actual 51, p-value 0.004; radar expected 58.18, actual 51, p-value 0.004). During hours without daylight, the radar was more likely to detect a bear than the human observer (human: expected 14.18, actual 7, p-value 0.004; radar: expected 18.82, actual 26, p-value 0.004). As such, we see that the radar was significantly less affected by the lack of daylight than the human observer. However, during the day light, the radar detected less than the expected value, calling into question if it is possibly negatively affected by daylight.

2.3.3.B. Weather

There was a significant relationship between the weather and the number of bears detected, as shown in the results of the chi square test (x-squared 37.833, df 2, p-value <0.001). The results of the Bonferroni post-hoc tests corrected the alpha at 0.005 and suggested that the radar's ability to detect polar bears was negatively affected by cloudy/rainy conditions, but functioned well in the snow. In cloudy and rainy conditions, the human observer was far better at observing polar bears (human: expected 21.48, actual 35; radar: expected 28.52, actual 15). These results were significant ($p < 0.001$). In snowy conditions the radar was far better at detecting bears than humans (human: expected 16.76, actual 2; radar: expected 22.24, actual 37). These results were significant ($p < 0.001$). In sunny conditions the human observer was slightly better at detecting bears (human: expected 19.86, actual 21; radar: expected 26.24, actual25), although this relationship was not significant ($p = 0.65$).

2.3.3.C. Wind Speed

The linear regression showed a slightly positive, significant relationship between the wind speed and the number of bears detected (r square 0.242, p-value 0.033). This is visualized in Figure 2.10. A Pearson's correlation resulted in a value of 0.492 with a p-value of 0.033, demonstrating a strong relationship linear relationship with the speed of wind and the number of bears detected – there are more bears detected as wind speeds increased.

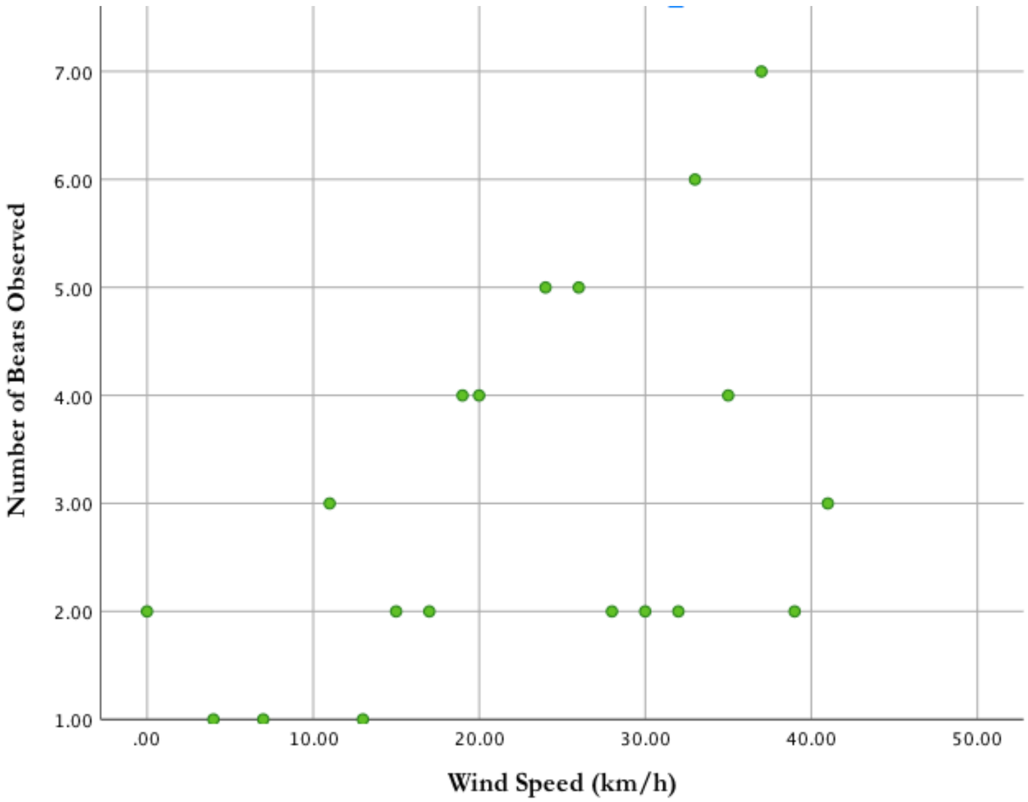


Figure 2.10. EFFECT OF WIND SPEED ON DETECTION OF BEARS BY THE HUMAN OBSERVER. Linear regression demonstrating the relationship between the wind speed and the number of bears detected by the human observer.

The radar was not affected wind speeds. The linear regression showed no significant relationship between the wind speed and the number of bears detected (r square 0.003, p-value 0.862). This is visualized in Figure 2.11. A Pearson's correlation resulted in a Pearson's correlation value of -0.051 and a p-value of 0.862.

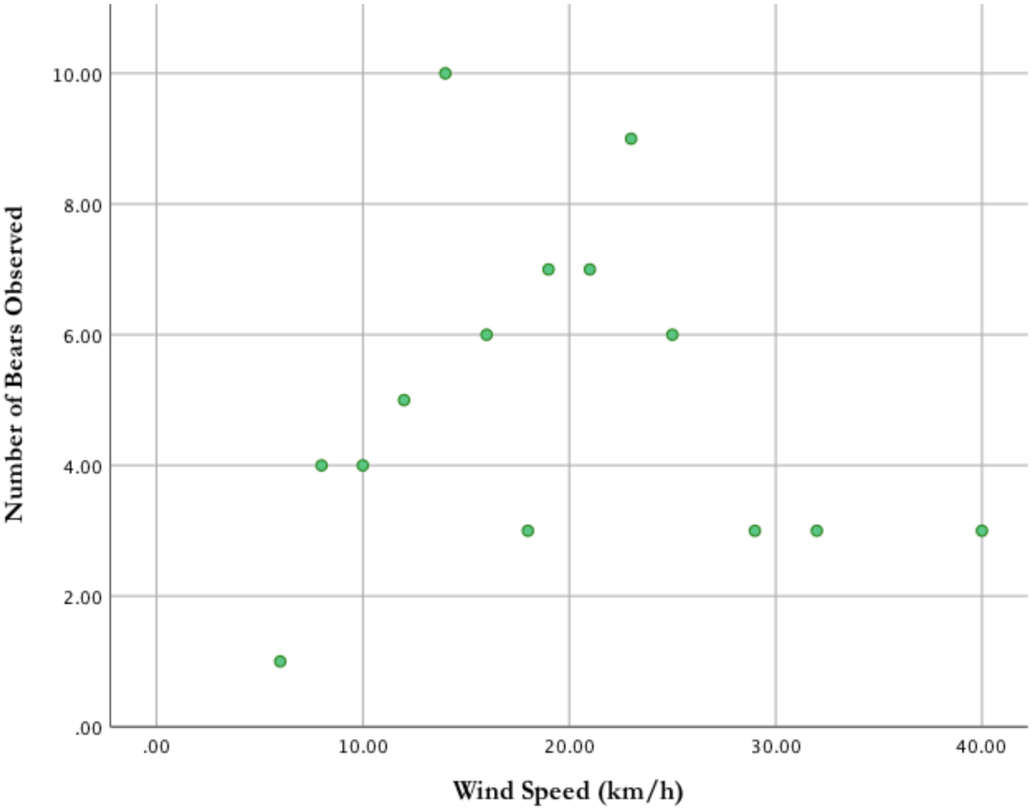


Figure 2.11. EFFECT OF WIND SPEED ON DETECTION OF BEARS BY THE RADAR. Linear regression showing the relationship between the wind speed (km/h) and the number of bears detected by the radar.

2.3.4. Radar Tracking Ability

Of the 77 tracks recorded by the radar over the entire observation period, 24 (31.2%) of these bears were recorded with more than one track (Figure 2.12).

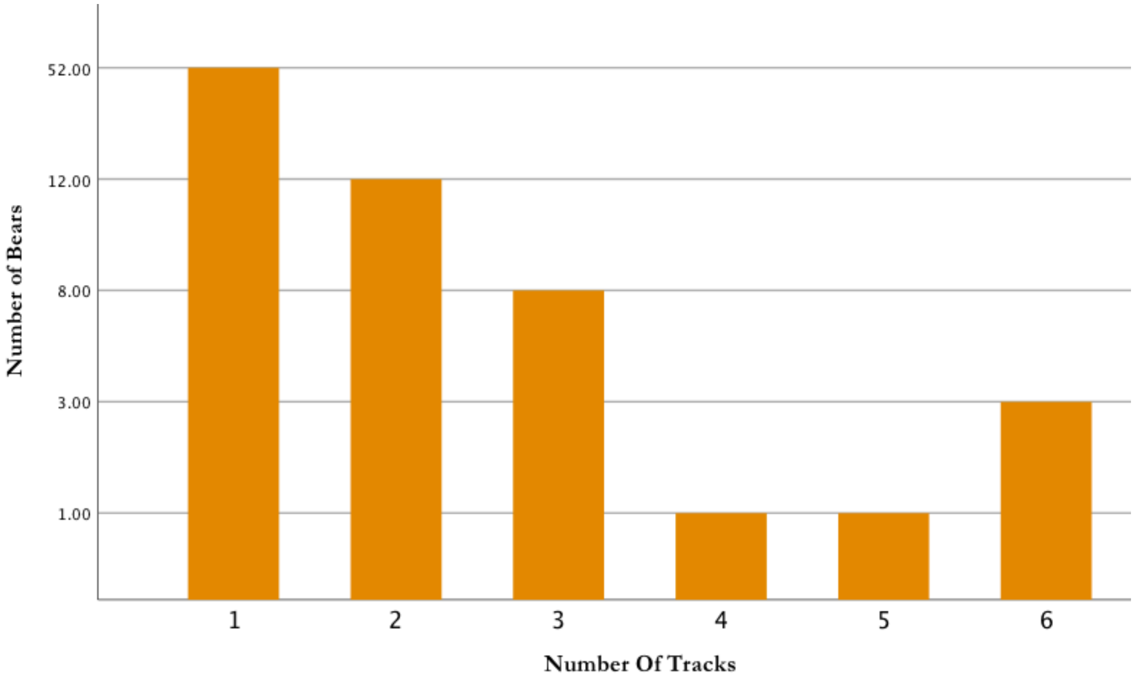


Figure 2.12. NUMBER OF TRACKS RECORDED PER BEAR DETECTED BY THE RADAR OVER THE ENTIRE OBSERVATION PERIOD. Bar graph showing the number of tracks recorded per bear detected by the radar.

The duration of sighting was significantly correlated with a higher number of tracks recorded per bear (R^2 0.568, p-value <0.001), where the longer a bear was recorded the more tracks a bear had. This is visualized in figure 2.13. No other variable had significant results.

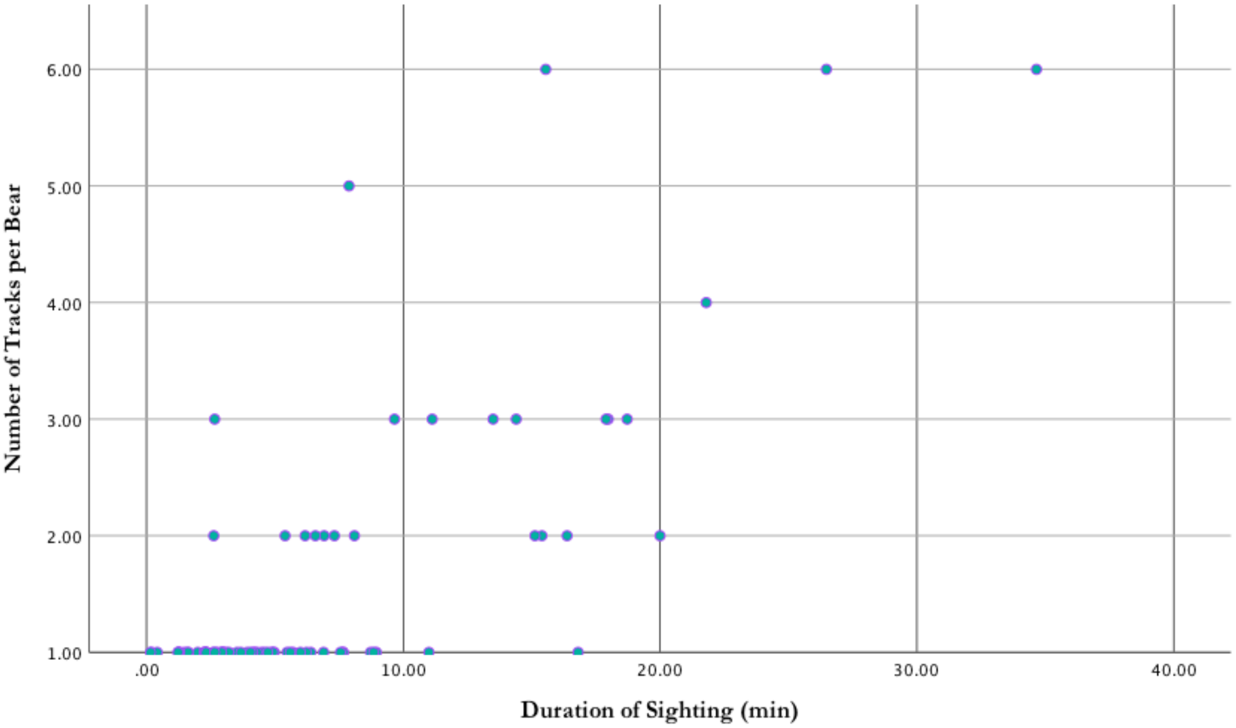


Figure 2.13. LINEAR RELATIONSHIP BETWEEN THE DURATION OF A SIGHTING AND THE NUMBER OF TRACKS RECORDED. This scatterplot visualizes the linear relationship between the duration of a sighting and the number of tracks recorded, with more tracks being recorded the longer the duration.

Multiple linear regressions showed that only those combinations of independent variables containing the duration of sighting predicted a higher number of recorded tracks per bear. As such we can assume that the predominant factor influencing the number of tracks recorded is the length of sighting, which increased the number of tracks recorded per bear as the sighting duration lengthened. The most significant relationships were: (1) speed of bear movement and duration of sighting (adjusted R^2 0.558, p-value <0.001), (2) wind speed, speed of movement, and duration of sighting (adjusted R^2 0.568, p-value <0.001), (3) weather, time of day, wind speed, and duration of sighting (adjusted R^2 0.552, p-value <0.001) and (4) weather, temperature, time of day, wind speed, and duration of sighting (adjusted R^2 0.548, p-value <0.001).

2.4. Discussion.

2.4.1. Radar Detection Ability

The detection rate was lower than anticipated at 66% (8/12) bears. The lack of explanatory variables for why the radar missed 34% of the bears suggests the need for further studies. It is possible that the reason the radar missed these bears was related to other factors such as their movement patterns, the presence of hills, bushes, or buggies that hid their movement, or the malfunctioning of the radar itself. However, without further studies there is currently no known cause for the missed bears. One of the major considerations for this is the very low sample size. Further studies that allow for a longer period of overlapping observation times between the direct observer and the radar may provide less equivocal results.

The radar detected an additional 26 bears. Analyzing the possible reasons why a bear was detected solely by the radar, the human observer, or by both showed no significant results. As such it is probable that the radar detected these bears when the observer was not collecting data. Additionally, it is important to note that as the radar rate was 66%, there is the possibility that there were bears present that were not detected by any method. Further studies with higher sample sizes and longer overlapping observation periods between the human observer and the radar could provide further insight into why or why not bears were detected as well as allow for the alteration of settings, such as sensitivity, that may increase its functionality.

2.4.2. Effect of Visibility Impediments on the Number of Bears Detected

The radar was able to detect bears during the day and night, while the human observer was negatively affected by the lack of daylight. The non-uniform pattern of sighting over the 24-hour period and Kuiper's uniformity tests showed that both methods detected more bears during the daylight hours. This is to be expected, as studies have shown that bear species are not only primarily diurnal, but appear to be more active when awake during the day than at night (Amstrup & Beecham 1976; Matthews et al. 2006).

The detection ability of the radar was negatively affected by certain weather conditions. It performed well during sunny and snowy conditions, but was negatively affected by cloudy and rainy conditions. The human observer performed better in cloudy/rainy conditions, seeing 13.52 more bears than the expected value, while the radar saw 13.52 fewer. When we consider that both methods had similar performance levels in sunny and snowy conditions, it is possible that cloudy and/or rain negatively affected the radars detection ability by impairing the ability of the radar pulses to reach bears and/or reflect back to the radar panel(s).

An important consideration is that the radar and direct observer only collected data simultaneously for 7 days, while all analyses were run using the entire data set. As such, it is possible that observation dates affected the results. Direct observation periods took place at the beginning (October 12-20, 2019) and end (November 7-13) of the polar bear season. The radar recorded data during the peak of the season (October 25-31, 2019) and the end (November 4-13). As such, it is not possible to rule out the fact that this is due to the number of bears in the area and not the effect of weather on the radar. Further studies with direct and radar observations simultaneously would allow for a deeper understanding of the functionality of the CSR system.

2.4.3. Radar Tracking Ability

The only explanatory variable for the number of tracks recorded for a bear was the duration of the track sighting, with more tracks recorded as sighting duration increased. While this makes somewhat intuitive sense, that the longer a sighting the larger the margin for error, it is possible this relates to the actual movement patterns of polar bears themselves. While in shorter sightings bears may be moving in a more directed manner through the radar zone, those in the area for longer may be less intent on their movement and exhibit less discrete movements. Polar bears in the area were often observed moving slowly, in a 'meandering' fashion. This behaviour included bears that were digging in foliage, pulling at and eating kelp, standing still and examining the area, and grooming. These smaller movements may not have been discernable by the radar, resulting in multiple tracks for one bear. If we assume these movements are more common in bears that are in the area for longer period of time, it is understandable that these bears would be recorded by multiple tracks.

2.4.4. General Observations

Three areas of improvement for the radar system were identified: the ability of the radar to follow a bear without dropping the signal, the labeling of photographs on email alerts, and the size of the data set. Unfortunately, due to the low sample size I was not able to adequately identify factors that may have caused multiple tracks to be recorded. Possible reasons include bears pausing while walking or moving behind a sedentary object, causing the radar to end the sighting. Supporting this explanation is that the human observer did not end a sighting until the bear was sedentary or out of sight for 5+ minutes, or had left the radar zone. Additionally, the human observer recorded longer sighting durations for 4 of the 5 bears. Future studies may consider using a shorter sedentary time for the human observer and recording when bears moved behind sedentary objects to better understand how the radar functions and why multiple tracks were recorded.

Secondly, the photographs included in emails alerts did not always include an object's track ID, meaning that some bears were not able to be identified nor their data extracted. While track IDs were included in the body of the email, the only way to determine which photograph corresponding with a track ID was if that photograph was labeled. Conversations with the SpotterRF technical support confirmed there was no way to connect track IDs to their corresponding photographs unless a photograph had the ID stamped on it. Improvement on photograph labelling would allow more data on bears to further understand the functionality of the system.

One of the major issues with GPS technology is the extremely large data sets produced and the corresponding problems of data management (Cagnacci et al. 2010). This leads to issues including the preservation of data integrity and consistency, the avoidance of data redundancy, automation of data downloading, filtering and storage of data, management of specific data types, and definition standards for objects and formats (Urbano et al. 2010). These were issues that were all encountered in this study due to the extremely large data set produced by the radar.

For this study, no filters were added to understand how the system worked prior to customizing the settings. Because of this, the dataset produced was extremely large and included a lot of noise (e.g. tree movement, waves, birds). The issue of noise is a problem in many types of technology that use movement as a detection method, including camera traps and infrared (Viani et al. 2014). The data set produced by the CSR included the full csv files, summary csv files, and the email alerts. In total there were 59,519 tracks recorded, which translated into 8,058,865 lines of data in the full csv files. This presented issues of filtering out data on objects that were not polar bears. To do so required the use of email alerts, of which there were ~6000 (some emails were deleted at the beginning of the study, so the exact number is unavailable). Of these, 683 (about 10%) emails contained photographs of polar bears. Each email included between 0 and up to 70 photographs. This led to issues of consistency and standards to ensure that the same methods were used to identify bears and connect tracks for bears with multiple recordings. Additionally, due to the size of the data set, the process of identifying bears from photographs and connecting tracks that were the same bear took three months.

Storage of data was also an issue. Due to the large amount of email alerts, extra storage needed to be purchased to store all data. Issues of storage also arose in the NiO system itself. As the system had a limited storage capacity, data needed to be downloaded very frequently to avoid being overwritten. Unfortunately, a large portion of data was lost because downloads did not occur frequently enough. This led to a small dataset from which to calculate the detection rate, and thus limited the robustness of data and conclusions. While the CSR system has many benefits and high potential to be used in studying the movement and behaviour of bears, addressing these issues would significantly improve its applicability in polar bear management.

A program upgrade that could increase the detection rate and reduce the size of the dataset is artificial intelligence (AI), which SpotterRF is currently developing and refining. AI classifies the object the radar sees using its size. Users can create their own custom objects, such as a polar bear. Though in the early stages of development, this could significantly enhance the usability of the radar for polar bears. This would allow the sensitivity of the system to be high enough to detect the small-scale movement patterns of bears while simultaneously identifying bears automatically. The system can also be set to ignore certain object classifications. As such, it is possible that the system could be programmed to detect polar bears with one track and ignore other wildlife or vehicles.

Chapter 3.

The Use of Compact Surveillance Radar to Study Polar Bear Behaviour in an Area of Human Activity.

3.1. Introduction

Conflict with people is one of the major issues facing polar bears today. Unfortunately, information on the biophysical factors influencing human-polar bear conflicts is incomplete and insufficient to guide management (Clark, van Beest, & Brook 2012). This dearth of information is significant, as identifying and understanding factors that affect animal distributions can be important for predicting responses to changing environmental conditions (Mills and Gorman 1997; Musiega et al. 2006; Sutherland 2006). In polar bears, climate change causing the decrease in sea ice has led to shifts in habitat use, increasing the number of bears coming on shore as well as the time spent there (Rode et al. 2015; Atwood et al. 2016). This in turn has led to higher incidences of human-polar bear conflict (Dyck 2006; Towns et al 2009). By delaying winter sea ice formation and causing earlier break up, warming of the Arctic shortens bears' hunting season and lengthens the terrestrial fasting period (Cherry et al. 2013; Gleason & Rode 2009; Rode et al. 2015; Schliebe et al. 2008). Lengthened terrestrial periods of polar bears due to the loss of sea ice coupled with extended human activity into polar bears' ranges expand opportunities for overlap and thus conflicts (Derocher, Lunn, & Stirling 2004; Stirling & Derocher 1993; Stirling & Parkinson 2006). While it is difficult to directly attribute climate change to individual human-bear incidents (Hulme 2009), the causal chain of reduced Arctic ice, nutritionally stressed bears, and increased conflict with people is supported by considerable empirical evidence (Clark 2003). Supporting this is the fact most human-polar bear conflicts occur during this terrestrial period (Dyck 2006; Fleck and Herrero 1988; Gjertz & Persen 1987; Gjertz & Schie 1998; Gjertz, Aarvik, & Hindrum 1993; Stenhous, Lee, & Poole 1988).

Due to the dearth of information on the biophysical factors influencing human-polar bear conflict, mitigation efforts cannot be designed around the underlying factors that drive human-polar bear conflict. An inability to design management programs around the underlying factors is known to be detrimental to wildlife management programs (Knight, J. 2001). Understanding how and why polar bears behave in areas of human activity may allow managers to create specific management plans. Animal movements are involved in many fundamental behaviours and ecological processes, including navigation, migration, dispersal, and food searching (Benhamou 2004). Such knowledge allows for the development of comprehensive management programs (Evans, Lea, & Patterson 2013). Mitigation and management efforts need to be based not only on the small-scale behaviours of polar bears, but be specific to each community. As such, more studies are needed to understand the underlying ecological and behavioural drivers of human-polar bear conflict in order to inform management. Technology that could provide adequate information on specific populations of bears could provide the information necessary to design sustainable management efforts.

The majority of movement data for polar bears are data collected by GPS telemetry, primarily collars or ear tags. GPS telemetry allows researchers to collect large quantities of continuous location data, monitor and map animal movements, model habitat and movement patterns, and evaluate wildlife movements and space use all with a high degree of precision and accuracy, 24 hours a day (Gavrilov et al. 2015; Cagnacci et al. 2010; Lewis et al. 2007). This is especially useful for animals that are not easily observed in person, such as those with large home ranges or marine animals (Hebblewhite & Haydon 2010). Indeed, even for species that are more easily observed, direct human observation is unable to provide adequate, thorough, and standard data to analyze ecosystem use without risk of falsification (Cagnacci et al. 2010; Hebblewhite & Haydon 2010). If properly applied, GPS can be used to improve habitat modeling and conservation, study mechanisms of migration, understand basic ecology of wide-ranging species, positively impact conservation, and even project the impacts of climate change (Hebblewhite & Haydon 2010).

However, GPS has setbacks. Two types of error are inherent in GPS telemetry and can bias data sets: missed locations and location error (Lewis et al. 2007). Missed locations can occur from failed location attempts if an animal enters an area that lacks GPS coverage (Friar et al. 2010; Lewis et al. 2007). Alternatively, systems may send out inaccurate spatial data, giving a false location (Friar et al. 2010; Lewis et al. 2007). Combined, these factors can lead to mistaken inferences of animal behaviour, particularly those involving movement paths and habitat selection (Friar et al. 2010). Environmental conditions, such as climate, habitat types, and terrain roughness can also cause the collars to give false data. GPS collar functionality is constrained by animal behaviour, such as their movement type and the orientation of the collar. For example, a study in 2011 on the swimming habits of a female polar bear saw only 25% of the total daily GPS locations transmitted automatically as transmissions were impeded when the bear was swimming, submerging the device's antenna (Durner et al. 2011). Fully understanding and modeling these errors is difficult due to the difficulties of setting up field tests (Heard, Ciarniello, & Seip 2008). Best practice for reducing these errors would be to observe the study species at the same time the GPS is collecting data in order to validate the statistical models and accuracies of the technology. However, in reality this is not often possible, particularly with large and/or dangerous animals or those with large home ranges (Hebblewhite & Haydon 2010).

GPS collars are costly, which can limit the number of individuals that can be fitted (Cagnacci et al. 2010). A single GPS collar can range from between USD 2000-8000 (Hebblewhite & Haydon 2010). A review by Lindberg and Walker (2007) concluded that a minimum of 20 animals are necessary to make reliable statistical inferences. This trade-off between cost and sample size (number of collared animals) has led to the inappropriate use of technology in the acceptance of smaller sample sizes (Hebblewhite & Haydon 2010). Collars also require that the animal be capable of carrying the collar. For example, in polar bears, only adult females are able to be collared as cubs and sub-adults will outgrow the collars, while in males the conical shape of the head prevents the collar from staying on (Laidre et al. 2013). As such, in this species the number of animals able to be tagged is limited and comes with a sex-bias.

A possible alternative to GPS systems is radar telemetry. Radar allows a more complete assessment of wildlife movement patterns than visual observations due to its capability to work after sunset (Russell & Gauthreaux 1998; Harmata et al. 1999). Different types of radar operate at different spatial scales, mainly in their resolution and extent. As such, they can be used to gather different types of data (Gauthreaux & Schmidt 2013). Radar can provide information on origin, timing, extent, and volume of movements of animals (Russell & Gauthreaux 1998). Radar has been adapted and used to study many species of wildlife. Weather surveillance radar (WSR) has been used to study bird movements and bat roosts since the late 1950s (Gauthreaux & Schmidt 2013; Russell & Gauthreaux 1998). Other studies have used ground-penetrating radar (GPR) to study the subterranean tunnels of European rabbits in South Australia (Stott 1996), provide visualization on pocket gopher burrows (Cortez et al. 2013), and study European badger dens (Nichol et al. 2003).

This study sought to examine the use of compact surveillance radar (CSR). CSR is most commonly used in security and surveillance applications. These systems are a series of radar panels that are connected to an online NiO system. The panels detect objects and collect data, while the NiO is an online system that stores that data. The system can also be linked to surveillance cameras. Utilizing radio waves as opposed to heat- or visual-based technology allows CSR systems to detect and track multiple moving objects regardless of light and weather conditions. Further advantages include the elimination of the need for contact with the study species, the elimination of sex- and age biases, the ability to identify and correct for device errors, and the ability to integrate detailed information on resource availability and habitat use. As CSR equipment is mounted to a stationary object (such as a building) and collects small-scale movement data, it offers a unique method of studying the movement of polar bears in areas of human activity. As such, this study sought to test its efficacy in gathering high quality data on the movement and behaviours of polar bears outside Churchill, Manitoba. To do so, five major data groups were examined: (1) bear movement and patterns, (2) the influence of environmental variables on the number of active bears, (3) curiosity behaviours, (4) tortuosity of movement, and (5) movement modes.

Movement was examined by looking at density of habitat use, the direction of movement, speed of movement, the distance of movement, and the duration of a sighting. These variables allow the basic understanding of how bears behave and move in the area, identify any patterns in movement, and hotspot areas of use. To examine the impact of the environment on bear activity, the variables of temperature, time of day, weather, and wind speed were examined both individually and in groups to determine if any environmental variables impacted the number of bears active in the area. Curiosity behaviour was determined by how close bears came to the tourist lodge the radar was mounted on. Analyses were also run to determine if any environmental factors or specifics of bear movement impacted this behaviour. To determine tortuosity, the displacement of each bear's track was divided by the total distance to determine how tortuous the path was. This measurement was then used to classify bears into three movement modes to understand the possible behaviours being exhibited. Environmental variables were then tested to determine if they influenced the tortuosity of a path and the movement mode a bear exhibited. In doing so, this study was able to examine the functionality of the radar in studying bear movement and habitat use.

3.2. Methods

3.2.1. Study Site, Radar Installation, Data Collection, & Data Cleaning

The study site and basic methods for radar installation, data collection, and data extraction were the same as those for Chapter 2. Unlike Chapter 2, all bears with multiple tracks (24 of 77) were eliminated from the dataset to account for the fact that if the data were combined this would increase the likelihood of inaccurate data. For example, if two tracks for the same bear overlapped in start and end time, the total duration for the sighting would be over estimated. This is also true of the total distance traveled.

3.2.2. Movement Patterns

3.2.2.A. Density Patterns

ArcMap was used to create one kernel density map of bear movement in order to identify areas of high activity. Bear path and location coordinate data generated by the radar were imported into ArcGIS as csv files. All bear path and location coordinate data were converted from point to line data. The line features were used as the input into the kernel density map to create a single line density map for the entire observation period (October 25-31 and November 4-12 inclusively). The geographic coordinate system used was WGS 1984, the cell size was set to 2.5, and the area units were set to square metres, and the search radius set to 25 metres, based on the total study area.

3.2.2.B. Direction of Movement

ArcMap was used to calculate the direction of movement for each bear. The CSV files generated by the radar were imported into ArcMap and converted from point to line data. The geographic coordinate system and map settings used were the same as 3.2.2.A. These data were then used to create sixteen daily maps showing the movement of individual bears for the observation period of October 25-31 and November 4-12 inclusively. Each bear's movement path was represented by a single line and colour-coded with the track ID generated by the radar. The linear directional mean for each bear was then calculated by the program and the direction of each bear was shown as a straight line with an arrow showing the mean direction, transposed over the total movement line. This data was manually extracted for each bear. The direction was classified as the closest direction (<45º) of: North, North East, East, South East, South, South West, West, or North West.

3.2.2.C. Speed of Movement, Distance Traveled, & Duration of Sighting

The CSR system calculated the speed of movement, the distance traveled, and the duration of a sighting for all objects tracked. This information was extracted from the csv files. Separate linear regressions were run to determine if the temperature, wind speed, weather, or time of day affected each of these variables.

3.2.3. Influence of Environmental Conditions on Bear Activity

The focus of this study was to to determine if any environmental variables affected how many bears were within the 400m radar zone. As the radar did not detect bears that are sedentary, these data provide information only on bears that are moving in the area. As such, I could examine if environmental factors affect how many bears we see active, but not how many bears were possibly within the zone but are sedentary. Sedentary bears were relatively common within the zone, primarily found resting in the cover of the willows south of the lodge.

Separate linear regressions were run to determine if the wind speed (km/h), the temperature (ºC), the weather, or the time of day affected the number of bears that were active in the radar zone. Wind speed and temperature were kept as continuous variables. Weather was binned into three categories: (1) sunny and partial sun, (2) cloud and rain, and (3) snow. Time of day was binned into three categories: (1) 06:00-13:59, (2) 14:00-21:59, (3) 22:00-5:59. Following the linear regressions, Pearson's correlations were run on each variable to further examine their effect on the number of bears present.

3.2.4. Multiple Variables Affecting Bear Activity

To determine if the combination of multiple environmental variables affected the number of bears active within the radar zone, a series of Fisher's exact tests were run. Fisher's exact test was chosen due to the low expected values resultant from combined variables and a low sample size. For these analyses, weather and time of day were binned according to 3.2.4. Temperature and wind speed were binned into three categories each. Temperature was binned into the categories of: (1) -23ºC to -14ºC, (2) -13ºC to -5ºC, and (3) -4ºC to +3ºC. Wind speed was binned into three categories determined by the Beaufort scale of wind speed. Each category had a span of 14km/h, resembling the classification of calm winds, gentle winds, and strong winds. These resulted in the categories of: (1) 0-14km/, (2) 15-29km/h, and (3) 30-44km/h. Combined variables were: (1) weather and temperature, (2) weather and time of day, (3) weather and wind speed, (4) time of day and temperature, (5) time of day and wind speed, and (6) wind speed and temperature. Bonferroni post-hoc tests were run on all variable combinations to determine any specific deviations from the expected values and thus those that had a stronger effect on bear activity.

3.2.5. Zone Use & Curiosity Behaviour

The maps created to show the movement of each bear per day – see 3.2.3.B. – were used to extract the data for zone use and curiosity behaviour. As each line was labelled with the corresponding track ID, it was possible to determine which zones each bear entered and thus how close they came to the lodge. This information was used to determine how curious a bear was about the lodge. This analysis assumed that any bear in the radar zone (<400m) was aware of the lodge, and thus any movement further toward it was not accidental but rather indicative of some form of curiosity.

To classify this behaviour, the four radar zones were used. Each bear's track was examined to determine the closest zone to the radar it entered and assign a corresponding curiosity index number. The furthest (301-400m zone) was considered the least curious and assigned number 1. Bears in the 201-300m range were considered slightly more curious and assigned number 2. Bears in the 101-200m zone were assigned number 3. Those bears entering the 0-100m zone were considered the most curious and assigned number 4. This increasing scale made the curiosity level categorical, with curiosity increasing as the assigned number increased. It also allowed the application of linear regression analyses to understand if any environmental variables affected bear curiosity. Linear regression analyses were run to determine if time of day, temperature, wind speed, or weather affected the level of curiosity. For these analyses, weather was binned as per 3.2.4.C and time of day was binned as per 3.2.4.D. Temperature and wind speed were left as continuous variables. Further multiple regression analyses were run to determine if the combination of any of these variables affected the number of bears within this zone.

3.2.6. Tortuosity

Tortuosity is an important measurement in orientation and searching behaviours. Tortuosity of a random search path demonstrates the searching intensity, which animals adjust to the local profitability of the environment (Benhamou 2004). To determine the tortuosity of movement, the straight line distance of a path is divided by the length of the actual path taken to get from the same point A to point B. The closer this value is to 1, the less tortuous and more efficient the path taken (Benhamou 2004). For this study, the total displacement of a bear's track was used as the straight line distance, and the total distance of the track was used as the actual path taken. Regression analyses were run to determine if the time of day, temperature, wind speed, weather, speed of bear movement, or duration of sighting had an affect on the tortuosity of a bear's path. Further multiple regression analyses were run on combinations of two, three, four, and five variables to determine the affect on tortuosity.

3.2.7. Movement Modes

To further understand bear movement in the radar zone, tortuosity was used to qualify behaviour and analyze any environmental impacts on such behaviour. This was done using the process of identifying and classifying movement patterns set out by Morelle et al (2017). Their study firstly segmented GPS tracks of animals into meaningful segments of movement based on similar “states" (mainly net squared displacement). For this study, this was replaced with the calculation of tortuosity for each polar bear, given its usefulness in identifying behaviour (Benhamou 2004) as well as the available data collected by the radar.

Secondly, Morelle et al. defined the potential movement modes – meaning defining what behaviour is likely to be happening within each defined segment of movement (2017). Their requirements for this step are that there be ecological significance to each mode and that each mode be as comprehensive as possible to ensure that mode segments are correctly classified. Three mode segments were identified for this study, based on a paper by Benhamou (2004). His paper examined best methods to calculate tortuosity of an animal’s path. It outlines two major forms of animal movement: (1) oriented paths with tortuosity measures equal to or close to 1, and (2) random search paths with tortuosity measures below 1. Using this as a baseline, my study classified three mode segments for tortuosity-indicated bear behaviour: (1) Oriented behaviour: identified as a tortuosity measure between 0.90-1.00 and indicating a bear is following an oriented path with some “goal” in mind. (2) Opportunistic searching behaviour: identified as a tortuosity 0.45-0.89 and indicating a bear was likely relatively oriented in its path but showing some willingness to stray from that path to exhibit searching behaviours. (3) Active searching behaviour: identified as a tortuosity measure between 0.00-0.44 and indicating that a bear was moving slow enough they were actively searching.

Finally, Morelle et al. classified each segment as a movement mode (2017). For this study, this meant assigning a movement mode to each bear based on its tortuosity.

After classifying the movement mode of each bear using the measure of tortuosity calculated in 3.2.6., Fisher’s exact tests were run to determine if any environmental variables affected the movement mode of a bear. To do so, time of day was binned as per 3.2.4.D, weather was binned as per 3.2.4.C, and temperature and wind speed were binned as per 3.2.5. Bonferroni post hoc tests were run to identify any specific variables impacted tortuosity.

3.3 Results

3.3.1. Movement Patterns

3.3.1.A. Density Patterns

Three of the 53 bears recorded by the radar were unable to be mapped due to the radar's csv data not being sufficient to create a path in the ArcGIS software. Figure 3.6. shows the 50 useable tracks recorded over the entire observation period. Figure 3.7. shows the heat map generated from these tracks. Two major areas of activity were highlighted, one in the North and one in the West. The hotspot to the North of the radar was located between 100-200m away and the hotspot to the West was within 100m of the radar. Four, less frequented hot spots were located to the East of the lodge within the 0-200m zones, and a fifth to the West in the 100-200m zone.

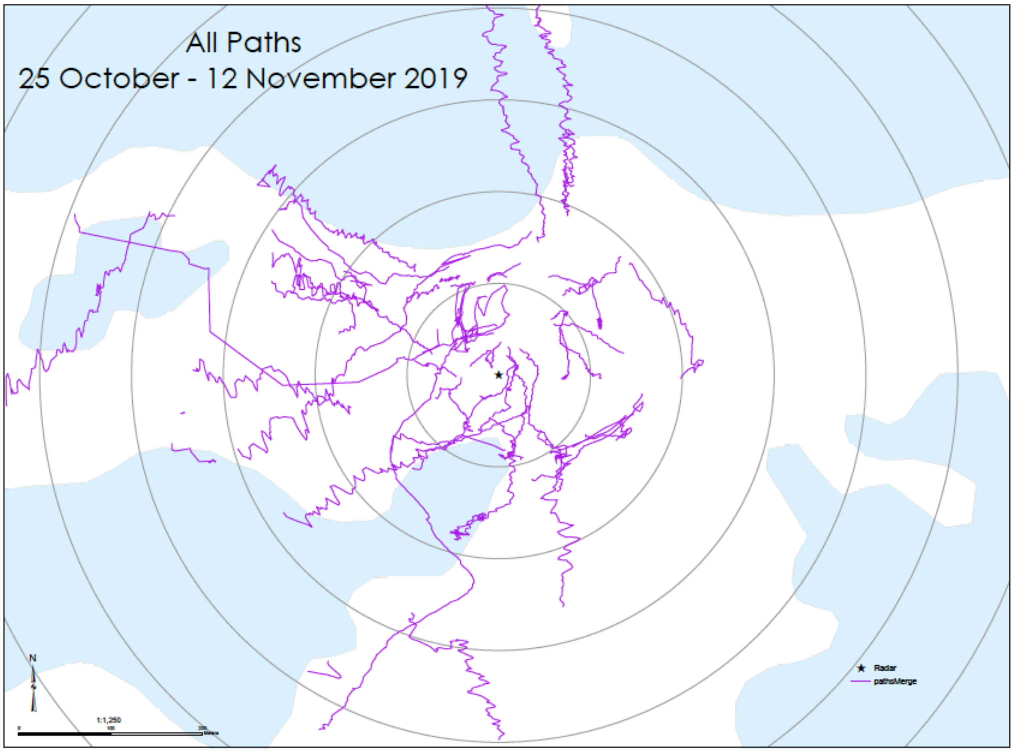


Figure 3.1. PATHS OF ALL BEARS DETECTED BY THE RADAR DURING THE ENTIRE OBSERVATION PERIOD. Translation of all data gathered by the CSR system and translated into line plots for each individual bear.

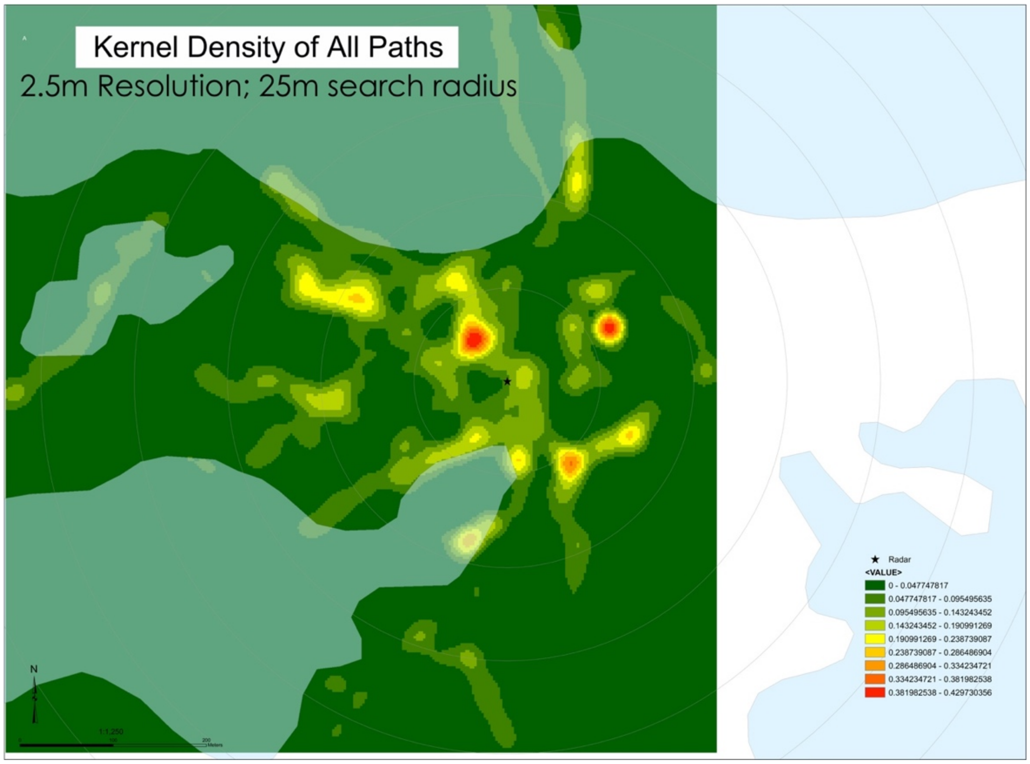


Figure 3.2. KERNEL DENSITY MAP SHOWING HOT SPOTS OF ACTIVITY FOR BEARS DETECTED BY THE RADAR OVER THE ENTIRE OBSERVATION PERIOD. Data collected by the radar and translated into a kernel density map showing all areas of activity and their relative frequency of use.

3.3.1.B. Direction of Bear Movement

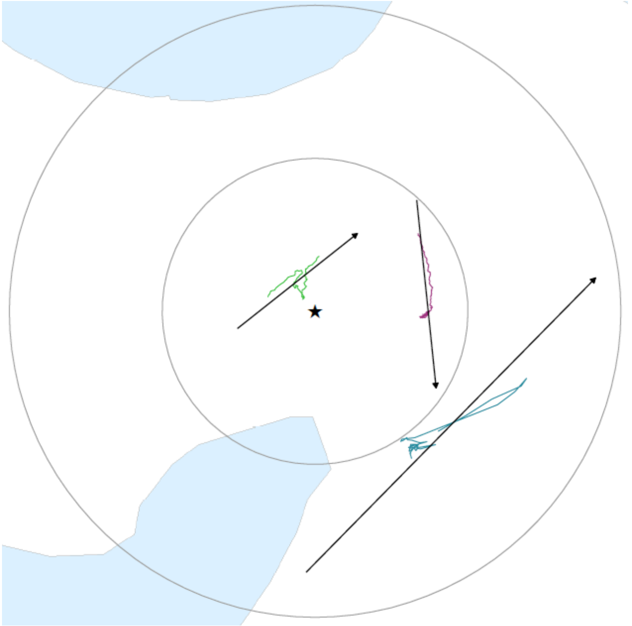
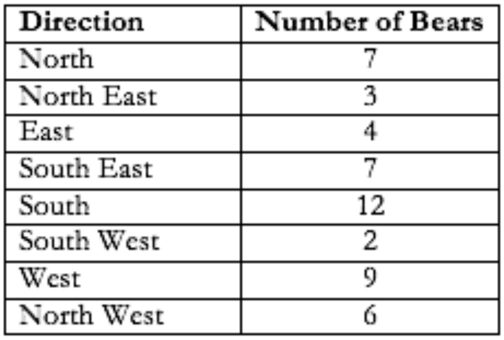


Figure 3.3. EXAMPLE OF A MAP SHOWING THE LINEAR DIRECTIONAL MEAN OF BEAR MOVEMENT. This map from November 8th, 2019 shows the linear directional movement of the three bears detected on that day. The coloured line shows the exact movement of the bear while the black arrow indicates the linear directional mean.

Table 3.1. summarizes the number of bears moving in each direction. Figure 3.3. shows an example of the results from calculating the linear directional mean and transposing this onto the entire track for a bear (see figure 3.8). From this we can see that the most common direction was South, with 12 of 50 bears (24%) found to have this as their linear directional mean. The fewest bears (2, 4%) moved South West.

Table 3.1. NUMBER OF BEARS WITH THE CORRESPONDING LINEAR DIRECTIONAL MEAN DIRECTION. This table outlines the number of bears that had the corresponding direction as their linear directional mean. Direction was classified as the closest direction of each of these 8 categories.



Direction	Number of Bears
North	7
North East	3
East	4
South East	7
South	12
South West	2
West	9
North West	6

3.3.1.C. Speed of Bear Movement, Distance Traveled, & Duration of Sighting

The mean speed of movement for bears was 7.33km/h ±4.84 (SD), ranging from 1.0 to 19.0km/h. Linear regressions did not show any relationship between environmental variables and the speed at which a polar bear moved: temperature: R^2 0.00004, p-value 0.962; wind speed: R^2 0.005, p-value 0.625; weather: R^2 0.001, p-value 0.873; time of day: R^2 0.012, p-value 0.443.

The mean distance traveled by bears was 0.23 km ±0.18 (SD), ranging between 0.0 and 0.68km. Linear regression analyses did not show any relationship between environmental variables and the distance a polar bear moved within the radar zone: temperature: R^2 0.039, p-value 0.156; wind speed: R^2 0.005, p-value 0.623; weather: R^2 0.015, p-value 0.375; time of day: R^2 0.012, p-value 0.438.

The mean duration for a sighting was 4.27 minutes ±3.02 (SD), ranging between 10 second and 16.2 minutes. Linear regression analyses did not show any relationship between environmental variables and duration of bear movement within the radar zone: temperature: R^2 0.031, p-value 0.210; wind speed: R^2 0.029, p-value 0.220; weather: R^2 0.013, p-value 0.417; time of day: R^2 0.004, p-value 0.656.

3.3.2. Influence of Environmental Conditions on Bear Activity

3.3.2.A. Wind Speed

A linear regression showed no relationship between the wind speed at which active bears moved (R^2 0.001, p-value 0.915). Figure 3.4. shows a graphical representation of this result. A Pearson's correlation resulted in a value of -0.031 (p-value 0.915), further confirming that there was no relationship between wind speed and bear activity in the radar zone.

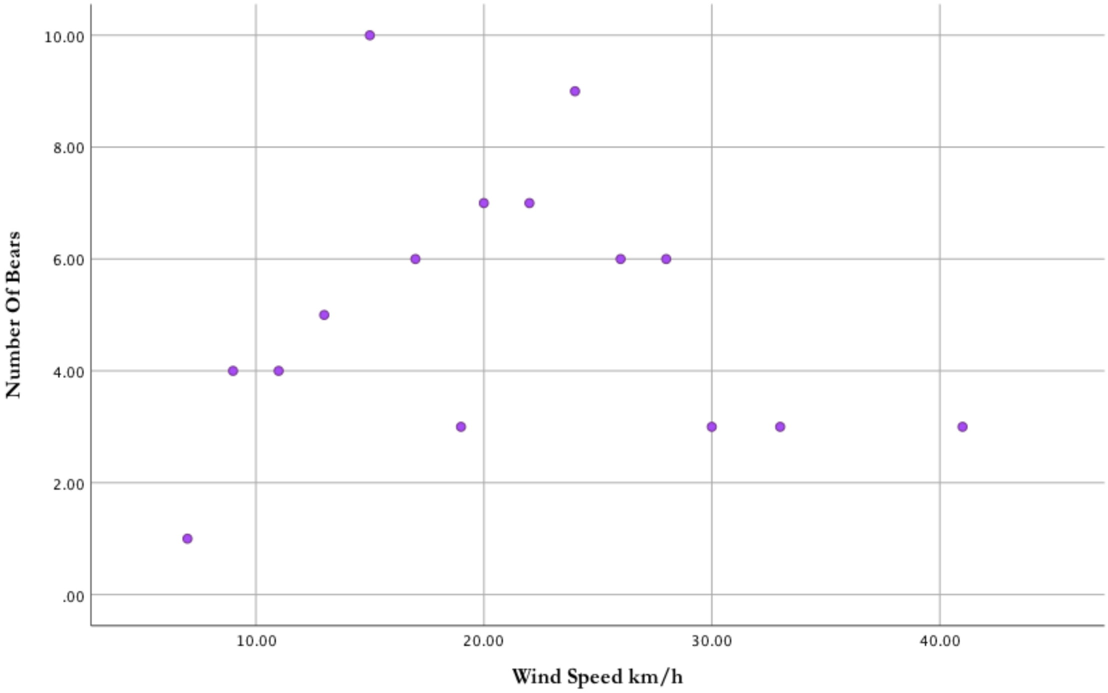


Figure 3.4. SCATTERPLOT SHOWING THE RELATIONSHIP BETWEEN WIND SPEED AND NUMBER OF ACTIVE BEARS. This graph shows that wind speed is not a predictor of the number of active bears.

3.3.2.B. Temperature

A linear regression resulted in no relationship between the temperature and the number of bears active in the radar zone (R^2 0.004, p-value 0.798). Figure 3.5. shows a graphical representation of this result. A Pearson's correlation resulted in a value of 0.065 (p-value 0.798), further confirming the lack of a relationship between the temperature and bear activity in the radar zone.

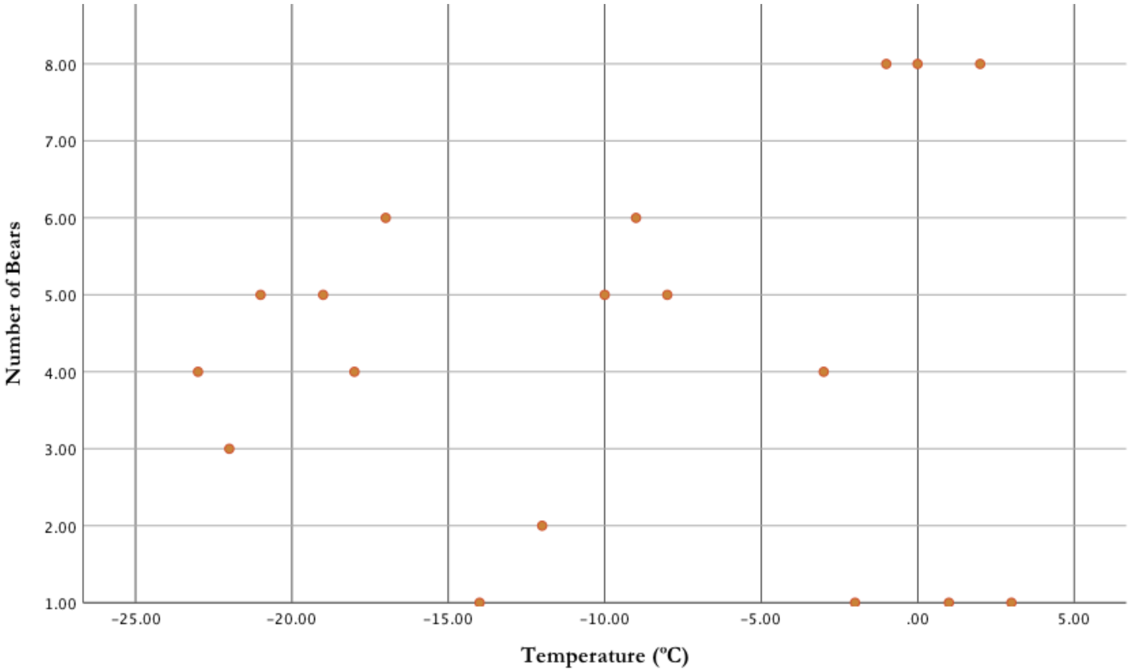


Figure 3.5. SCATTERPLOT SHOWING THE RELATIONSHIP BETWEEN TEMPERATURE AND NUMBER OF ACTIVE BEARS. This graph shows that temperature is not a predictor of the number of active bears.

3.3.2.C. Weather

A linear regression showed that the weather explained a small amount of the bear activity within the radar zone, however the large p-value shows that this was not a significant result (R^2 0.318, p-value 0.619).

3.3.2.D. Time of Day

A linear regression showed that the time of day explained much of the bear activity within the radar zone, however the p-value was not low enough to consider these results statistically significant (R^2 0.852, p-value 0.251). Kuiper's test of uniformity was 2.9549 (p-value <0.01). As such, these results showed that bear activity was not uniformly distributed across the 24-hour day. When considered with the results of the linear regression analysis we can assume that there was some relationship between the time of day and how many bears are active. The circular rose plot shows that between 05:00 and 15:00 had the most activity. Within this time frame, activity was primarily clustered during the hours of 05:30-07:00, 08:00-10:00, and 11:30-14:30. Between the hours of 15:00 and 05:00 activity drops off, but does not cease.

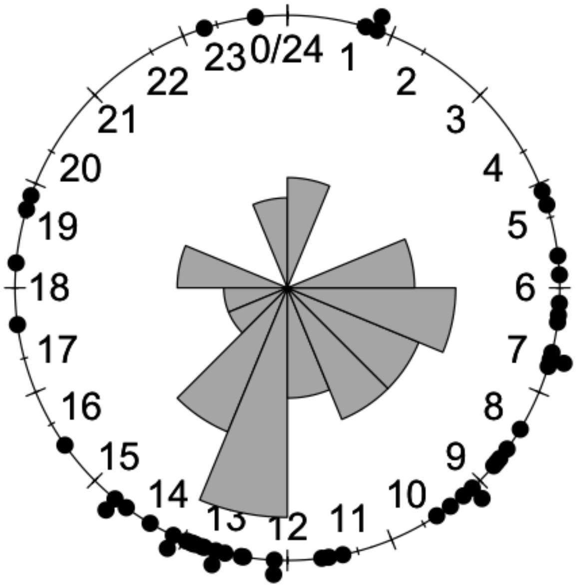


Figure 3.6. CIRCULAR ROSE PLOT OF ALL BEARS DETECTED BY THE RADAR OVER THE ENTIRE OBSERVATION PERIOD. This graph shows all the bears detected by the radar plotted on a circular graph according to the 24-clock. The wedges of the rose plot represent the number of bears seen at each hour interval.

3.3.3. Multiple Variables Affecting Bear Activity

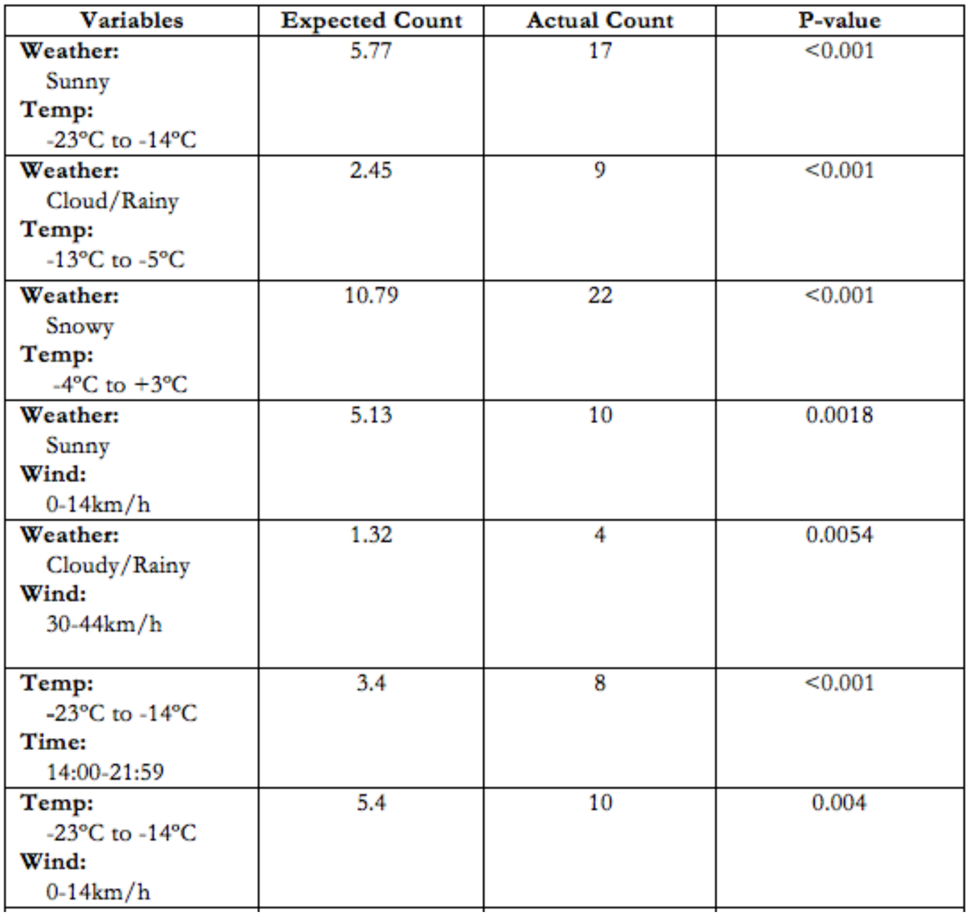
Fisher's exact tests run on combined variables showed four combinations of environmental factors that may have explained the number of bears active within the radar zone.

The combinations of weather and time of day and wind speed and time of day did not result in significant Fisher's p-values (weather and time of day p-value: 0.61; wind speed and time p-value: 0.542). As such, combinations of these environmental variables likely did not affect the activity of polar bears within the radar zone.

The following combinations of environmental conditions resulted in significant p-values from the Fisher's exact test: (1) weather and temperature, p-value: <0.001; (2) weather and wind speed, p-value: 0.001; (3) time of day and temperature, p-value 0.02; (4) wind speed and temperature, p-value 0.002.

Further Bonferroni corrections revealed significant outliers within these, and corrected the p-value to 0.005 for significance. Possible favourable conditions for polar bear activity were seen during the following combinations of environmental conditions, with more bears observed than the expected count: (1) Sunny with temperatures between -23ºC to -14ºC, p-value <0.001. These conditions saw far more 17 bears observed while the expected count was 5.77. (2) Cloudy/rainy with temperatures between -13ºC to -5ºC, p-value <0.001. 9 bears were seen during these conditions while the expected count was 2.45. (3) Snowy with temperatures between -4ºC to +3ºC, p-value <0.001. 22 bears were observed while the expected count was 10.79. (4) Sunny with winds between 0-14km/h, p-value 0.0018. 10 bears were observed despite a 5.13 expected value. (5) Cloudy/rainy with winds between 30-44km/h, p-value 0.0054. 4 bears were observed while the expected count was 1.32. (6) Temperatures between -23ºC to -14ºC between the hours of 14:00-21:59, p-value <0.001. 8 bears were observed while the expected count was 3.40. (7) Temperatures between -23ºC to -14ºC with wind speeds between 0-14km/h, p-value 0.004. 10 bears were observed while the expected count was 5.4. This is summarized in table 3.2.

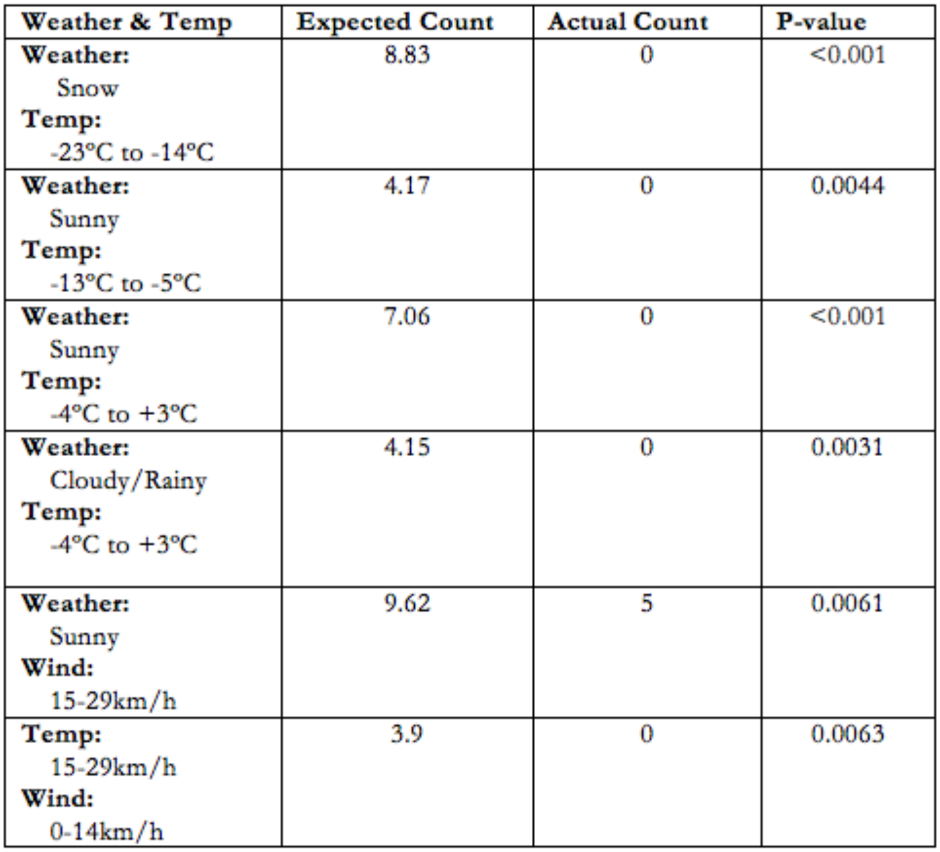
Table 3.2. SIGNIFICANT COMBINATION OF VARIABLES POSITIVELY AFFECTING NUMBER OF BEARS DETECTED. This table outlines combinations of variables that showed a significant, postive affect on number of bears observed.



Variables	Expected Count	Actual Count	P-value
Weather: Sunny **Temp:** -23ºC to -14ºC	5.77	17	<0.001
Weather: Cloud/Rainy **Temp:** -13ºC to -5ºC	2.45	9	<0.001
Weather: Snowy **Temp:** -4ºC to +3ºC	10.79	22	<0.001
Weather: Sunny **Wind:** 0-14km/h	5.13	10	0.0018
Weather: Cloudy/Rainy **Wind:** 30-44km/h	1.32	4	0.0054
Temp: -23ºC to -14ºC **Time:** 14:00-21:59	3.4	8	<0.001
Temp: -23ºC to -14ºC **Wind:** 0-14km/h	5.4	10	0.004

Possible unfavourable conditions for polar bear activity were seen during the following combinations of environmental conditions, with fewer bears observed than the expected: (1) Snow with temperatures between -23ºC to -14ºC, p-value <0.001. No bears were observed here, counter to the expected count of 8.83. (2) Sunny with temperatures between -13ºC to -5ºC, p-value 0.0044. No bear were observed during these conditions while the expected count was 4.17. (3) Sunny with temperatures between -4ºC to +3ºC, p-value <0.001. No bears were seen during these conditions despite an expected count of 7.06. (4) Cloudy/rainy with temperatures between -4ºC to +3ºC, p-value 0.0031. No bears were seen while the expected count was 4.15. (5) Sunny with winds between 15-29km/h, p-value 0.0061. 5 bears were observed while the expected value was 9.62. (6) Temperatures between 15-29km/h with wind speeds between 0-14km/h, p-value <0.001. No bears were seen despite an expected count of 3.9.

Table 3.3. SIGNIFICANT COMBINATION OF VARIABLES NEGATIVELY AFFECTING NUMBER OF BEARS DETECED. This table outlines combinations of variables that showed a significant, negative affect on number of bears observed.



Weather & Temp	Expected Count	Actual Count	P-value
Weather: Snow **Temp:** -23ºC to -14ºC	8.83	0	<0.001
Weather: Sunny **Temp:** -13ºC to -5ºC	4.17	0	0.0044
Weather: Sunny **Temp:** -4ºC to +3ºC	7.06	0	<0.001
Weather: Cloudy/Rainy **Temp:** -4ºC to +3ºC	4.15	0	0.0031
Weather: Sunny **Wind:** 15-29km/h	9.62	5	0.0061
Temp: 15-29km/h **Wind:** 0-14km/h	3.9	0	0.0063

3.3.4. Zone Use & Curiosity Behaviours

Curiosity zone analyses showed 25 (50%) bears came into the 0-100m zone, 22 (44%) into the 101-200m zone, 2 (4%) into the 201-300m zone, and only 1 (2%) stayed in the 300-400m zone.

As such, the majority of bears (94%) that came into the entire radar zone came within 200m of the radar and thus human habitation. This is shown in Figure 3.7.

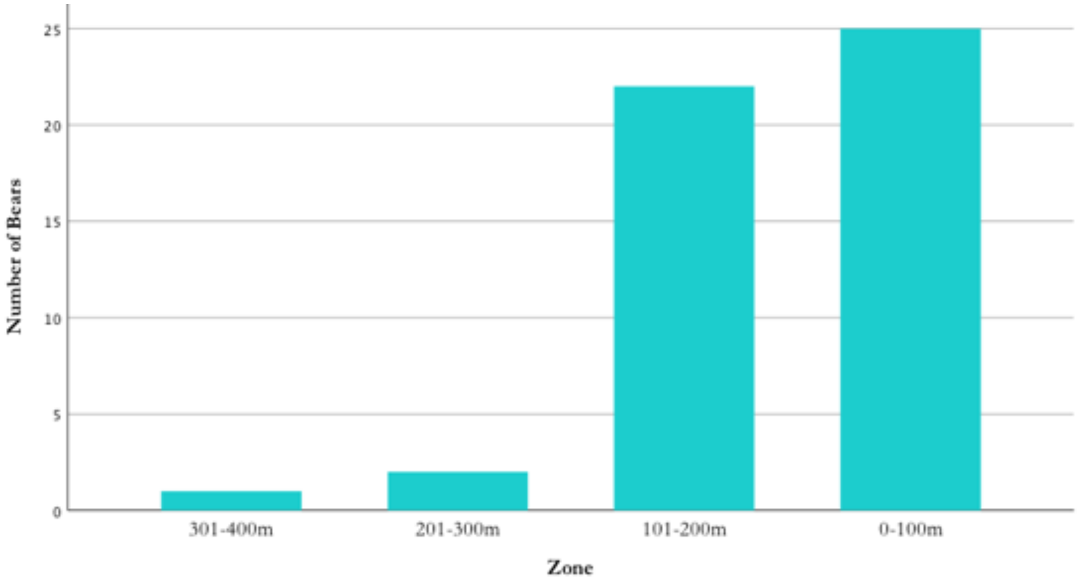


Figure 3.7. BAR GRAPH SHOWING THE CLOSEST ZONE OF ENTRY FOR BEARS. Graph showing the number of bears that had which zone of entry as their closest point to the radar.

Regression analyses performed on the effect individual variables had on how close a bear came to the lodge showed that no significant effects: time of day: r square 0.032, p-value 0.213; temperature: r square -0.003, p-value 0.364; wind speed: r square 0.046, p-value 0.074; weather: r square 0.007, p-value 0.252; duration of track: r squared -0.016, p-value 0.641. Multiple regression analyses performed on combinations environmental variables in groups of 2 and 3 also did not yield any significant results.

3.3.5. Tortuosity

The average tortuosity of a bear was 0.5 ± 0.24 (SD), ranging between 0 and 1. Regression analyses of individual variables' affect on tortuosity showed that the weather, temperature, and the duration of the track all significantly impacted the tortuosity of a bear's movement. The weather was positively correlated with the tortuosity measure, showing that as the weather became snowier bears had tortuosity levels closer to one – i.e. less tortuous, more directed paths (r square 0.142, p-value 0.005). The temperature was also positively correlated with tortuosity level, showing that bears had less tortuous paths as the temperature increased (r square 0.108, p-value 0.009). Duration of the track was positively correlated with tortuosity, showing the longer a bear was recorded the less tortuous the path (r square 0.112, p-value 0.014). Time of day, wind speed, and the speed of bear movement were not significantly related to the tortuosity of a bear's movement.

Multiple linear regressions showed that all but 8 combinations of variables had significant impacts on the tortuosity of a bear's movement, with p-values <0.05. The most significant results from combinations of 2, 3, 4, and 5 variables are summarized in table 3.4 outlined below.

Table 3.4. SIGNIFICANT COMBINATION OF VARIABLES ON TORTUOSITY OF MOVEMENT. This table outlines combinations of variables that showed significant affect on the tortuosity of bear movement.

Variables	Adjusted R Squared	P-value
Weather and duration	0.201	0.001
Weather, wind, and duration	0.202	0.003
Weather, speed of movement, and duration	0.198	0.003
Weather, wind speed, speed of movement, and duration	0.201	0.005
Weather, temperature, wind speed, duration	0.198	0.005
Weather, wind speed, temperature, speed of movement, duration	0.199	0.008

The most significant results of regressions performed on two variables combinations were weather and duration of the track, which suggests that as the weather became snowier and the duration of a track lengthened, the less tortuous the bear's movements were (adjusted r square: 0.201, p-value 0.001).

There were two highly significant results of regressions performed on three variables. (1) The weather, wind speed, and the duration of the track (adjusted r square 0.202, p-value 0.003). This result suggests that as the weather became snowier, the wind speed increased, and the duration of the track lengthened, bear movement became less tortuous. (2) Weather, the speed of bear movement, and the duration of the track (adjusted r-square 0.198, p-value 0.003). These results suggest that as the weather became snowier, the bear's speed of movement increased, and the duration of the track increased, bear's movements became less tortuous.

There were two highly significant results of regressions performed on four variables combinations. (1) Weather, wind speed, speed of bear movement, and track duration (adjusted r square 0.201, p-value 0.005). These results suggest that as the weather became more snowy, the wind speed increased, the speed of bear movement increased, and the track duration increased, bear movement became less tortuous. (2) Weather, temperature, wind speed, and track duration (adjusted r square 0.198, p-value 0.005). These results suggest that as the weather became snowier, the temperature increased, the wind speed increased, and the track duration increased, bear movement became less tortuous.

The most significant result of regressions performed on five variables combinations was the weather, wind speed, temperature, speed of bear movement, and duration of the track (adjusted r square 0.199, p-value 0.008). This suggests that as the weather became snowier, the wind speed increased, the temperature increased, bear speed increased, and the duration of the track increased, bear movement became less tortuous.

3.3.6. Movement Modes

Of the 53 bears, 2 bears (3.8%) were classified as mode 1 (oriented path), 23 bears (43.4%) were classified as mode 2 (opportunistically searching), and 28 bears (52.8%) were classified as mode 3 (actively searching). Fisher's exact tests showed that neither time of day nor the wind speed had a significant relationship with the movement mode of a bear (time of day, p-value 0.078; wind speed, p-value 0.963). However, weather and the temperature both had a significant relationship with the movement mode of a bear (weather, p-value 0.003; temperature, p-value 0.001).

Bonferroni post hoc tests corrected the alpha at 0.005. The tests performed on the weather and the movement mode showed two specific significant variables. Firstly, for cloudy/rainy weather and movement mode 2 (opportunistic searching) the expected value was 7.38, while the actual count was 2 (p-value 0.0014). These results show that bears were less likely than expected to be opportunistically searching during cloudy/rainy weather. Secondly, during rainy weather and movement mode 3 (active searching), the expected value was 8.98, while the actual count was 15 (p-value <0.001). These results showed that during rainy weather, bears were actively searching more than expected.

Bonferroni post hoc tests run on temperature and movement mode showed two specific significant variables. Firstly, at temperature one (-23°C and -14°C) and mode two (opportunistically searching), I saw fewer bears than expected – 2 bears detected while expected was 7.87. (p-value <0.001). Secondly, at temperature one (-23°C and -14°C) and mode three (actively searching), I saw more bears than expected – 16 detected with an expected count of 9.51 (p-value <0.001).

3.4. Discussion.

3.4.1. Movement Patterns

The radar worked effectively to provide data that could be used to study both the movement patterns and behaviour of polar bears, providing detailed data on the small-scale movement of bears that was suitable for studying patterns of movement.

3.4.1.A. Density Patterns

The data recorded by the radar were able to be transformed into GIS software and used to create a kernel density map. As such, the radar data was compatible with GIS software and allowed the analyses of the data in this format. The kernel density plot showed three major areas of density, all of which were within >200m from the Tundra Buggy Lodge. This suggests that bears were not apprehensive to come close to the lodge. These high density areas were to the North, West, and East of the lodge. Though no topographic map was available to overlay with the kernel density map, from performing the direct surveys I identified the area of use to the West and North of the lodge as rocky areas fairly close to the water. These areas had high kelp coverage, which bears were often seen eating and laying down in. The area of density to the East of the lodge is primarily covered in willows, where bears were often seen to lay in for extended periods of time. It is interesting that these areas of high use had very different topography – one providing coverage in bushes and the other providing no coverage but some sustenance. As the radar data were compatible with GIS software, future studies are possible that overlay topographic maps with the kernel density maps to map habitat and resource use in the area.

3.4.1.B. Direction of Bear Movement

The results of the linear directional mean analyses were different than expected. During direct observations, most bears came in from the East and left toward the West. This corresponded with the topography of the area – the East leads inland while the West follows the bay. This is consistent with the fact that bears congregate in the area to access the forming sea ice. However, the linear directional mean showed that the most common direction was South. There were only 4 bears (8%) that moved East. However, it is likely that this does not represent that general direction of movement through the radar zone nor of bear's overall movement in the area. The linear directional mean applies a mathematical model to categorize the overall movement, and not the final direction when exiting the radar zone. As such, this information is not entirely descriptive of actual movement. If a bear had moved in a circular pattern the entire time it was observed, the program would still assign a general direction. As such, for this study the linear directional mean was not an appropriate measurement to use identifying the direction of movement.

3.4.1.C. Speed of Bear Movement

Data on the speed of movement was easily accessed and extracted as it is automatically recorded by the radar. No environmental factors influenced the speed at which bears moved. As such, I was unable to determine why bears moved at the speeds they did. It is likely that the bear recorded at 19km/h was likely an anomaly, possibly spooked by a tundra buggy (a behaviour which was observed multiple times during the direct observations, but unable to be determine using solely the radar data). While there were no significant results explaining the speed of movement in this study, the radar was able to provide the data necessary to perform this analysis. As such, the radar is capable of providing the data necessary to study the influences of speed of movement in future studies with larger data sets. These studies could analyze the effect of environmental conditions, the presence/absence of vehicles, and even the speed of movement in relation to a topographical map and the possible influence of resource use.

3.4.1.D. Distance Traveled

The distance traveled by a bear showed the total distance traveled, not the straight line path. No environmental variable significantly explained the distance a bear traveled. As such, it is likely that the distance a bear walked within the radar zone is more reflective of the resources available within the zone than the influence of the environment. Though no significant results were found in this study, the radar provided the data necessary to examine environmental influences on distance traveled and as such has the potential to understand the distance bears traveled in future studies with larger data and the inclusion of topographic data.

3.4.1.E. Duration of Sighting

As with the distance traveled and the speed of movement, the duration of a sighting was automatically recorded by the radar, thus providing a very accessible data set on bear movement. For this study, the mean duration of a bear sighting was 4.27 minutes, a relatively long period of time given the small radar zone. However, environmental variables had no significance to the duration of a sighting. As with the distance traveled and speed of movement, it is thus likely that incorporating topography and resource data would provide better explanation for the duration a bear was active within the radar zone. Future studies could also potentially examine the influence of tundra buddies in the area to determine if their presence negatively or positively influences the duration of the sighting.

3.4.2. Influence of Environmental Conditions on Bear Activity & Multiple Variables Affecting Bear Activity

Results showed it was highly unlikely that the temperature, the weather, or the wind speed affected how active the bears were. Time of day was the only variable that did have significant results. Though the linear regression did not have a significant p-value, the test of uniformity confirmed that activity was not uniformly distributed – there were times that there was more activity than others. The circular rose plot showed that the evening and overnight hours had far less activity than the daytime. These results are to be expected, as studies have shown that bear species are primarily diurnal (Amstrup & Beecham 1976; Matthews et al. 2006). Within the daytime, this plot also revealed the three main clusters of activity (05:30-07:00, 08:00-10:00, and 11:30-14:30). This was similar to the results from radio collared black bears where activity increased shortly after sunrise, peaked at 08:00 and 21:00, and declined significantly after sunset, reaching a low between 01:00 and 04:00 (Amstrup & Beecham 1976). These results allowed me to conclude that bears were more active during the day than overnight, and that there were periods of time with higher activity levels.

When environmental variables were combined, the results showed that there were specific combinations that saw higher than expected levels of bear activity. However, these combinations showed no specific patterns of variables. For example, while the weather was a variable in two of the significant combinations, there was no specific weather condition that was significant – all weather conditions were involved in some capacity. The lack of discernible patterns was also seen with the temperature and wind speed. This was true also for combinations of variables that appeared to deter bear activity. While there were some combinations that saw lower than expected bears, there were no specific patterns discernible. When considered in reference to the lack of significant results for individual variables, it is unlikely that any combinations of environmental variables affected the number of bears seen. However, it is possible that these results were achieved due the small dataset. Similar studies with a larger data set may produce more significant results showing specific variables that negatively or positively affect bear activity.

Though the results of this study showed time of day as the only variable that affected the number of active bears, the radar was able to provide the data necessary to perform these analyses. As such, the radar offers potential to study the influence of environmental variables on bear activity by providing detailed and specific information on bear sightings that can be directly compared to the environmental variables seen at their exact time and location.

3.4.3. Zone Use & Curiosity Behaviours

The data collected by the radar on the movement of bears were sufficient to translate into GIS software and create line paths for 50 of 53 bears (the data for three bears was insufficient to allow mapping). This allowed the analysis of curiosity behaviours. The results showed that only 3 bears of the 50 bears stayed over 200 metres away from the lodge. Therefore, 47 of 50 (94%) of the bears came within 200m of the lodge, while 25 (50%) came into the 100m zone. These results demonstrate that the large majority of bears appeared to be willing to being close to a human settlement. Supporting this is that no environmental variable provided any significant explanation for why bears came close to the lodge. The duration of the track also did not correlate to the proximity to the lodge. As such, it is possible that bears came close to the lodge out of curiosity.

These results are consistent with other studies performed on bears' reactions to human activity and settlements. A study performed on data from 1991 on the behaviour of polar bears around icebreakers in the Chukchi Sea showed that while 79% of observed bears reacted to the vessel, only 11% approached it (Smultea et al. 2016). Their results showed that reactions overall to the icebreakers tended to be brief, with bears returning to their previous activities within 5 minutes. They concluded that the bears appeared to quickly habituate to the icebreakers, and noted that this was consistent with other findings that bears are not particularly disturbed by human activity (Smultea et al. 2016; USFWS 2008). Another study by Stirling (1988) on the attraction to human activities showed that bears were attracted to drilling sites, but the amount of time they spent in proximity to them depended on the availability of other resources (such as access to seals due to the broken ice). These, and other studies, suggest that polar bear reactions to human activity vary with the level and extent of human activity, as well as the sex of the bear, the bear's activity, and the availability of food (Smultea et al. 2016; Stirling 1988; Dyck & Baydack 2004; Anderson & Aars 2008). Given the results of these studies it is possible that due to the constant presence of the lodge during the fall, bears became habituated to it, allowing the transition to curiosity behaviours. Given that the lodge has relatively low human activity and noise levels (as tourists are not at the lodge during the day), this could have influenced the curiosity behaviours of bears. Additionally, the early freeze-up of the Bay in this area could be classified as a resource for the bears, contributing to the overall time spent in the area and thus habituation. Overall, considering my results in relation to previous studies, it is possible that polar bears not only became habituated to areas of human activity, but this potentially facilitated curiosity behaviours.

3.4.4. Tortuosity

Weather, temperature, and duration of the bear's track all significantly impacted the tortuosity of movement. When the weather became snowier and the temperature became warmer, bears had less tortuous paths – their movements were closer to a straight path. These results suggested that it was possible these conditions influence bear behaviour. Specifically, that bears were more likely to have oriented paths and less likely to show searching behaviours in these environmental conditions. This may suggest that bears had a preferential aversion to snowy weather conditions and warmer weather that negatively affected their likelihood of searching an area.

Further results showed that as the duration of the sighting increased the less tortuous the bears path was. This meant that the longer a bear was observed the more likely it was to be walking in a straight line. It is possible that this is a reflection of the radar's ability to detect small, indiscrete movement and not the behaviour of bears. If a bear was exhibiting high searching behaviour in a small area, these movements may not have been discrete enough to record as a single track. This may have influenced the results to show that bears in the area for longer periods of time were exhibiting oriented behaviour when in reality bears in the area for longer periods of time were simply exhibiting such high searching behaviours they were recorded multiple times.

When I combined variables, all significant combinations contained weather, suggesting that this was the most influential environmental variable affecting the tortuosity of bear movement. These results may suggest that bear searching behaviour is influenced by preference of weather conditions. Analyzing the effect of the weather on tortuosity showed that tortuosity declined as the weather became snowier, suggesting that bears exhibited less searching behaviour in the snow and walked in straighter paths.

3.4.5. Movement Modes

The calculation of tortuosity allowed me to examine possible movement modes to classify bear behaviour. Results showed that the majority of bears (96.2%) had paths that exhibited some form of searching behaviour, either active or opportunistic. Analyzing the impact of environmental variables on these modes showed that the weather condition and the temperature had significant effects on the behaviour of bears. Bonferroni tests run on movement modes showed that when the weather was cloudy or rainy bears were more likely to exhibit active searching behaviour (mode 3) and less likely to exhibit opportunistic searching behaviour (mode 2). As such cloudy/rainy conditions may have encouraged active searching behaviour, as demonstrated by highly tortuous paths. Bonferroni tests on temperature showed that when the weather was cold (between -23ºC and -14ºC), bears were less likely to be opportunistically searching (mode 2) and more likely to be actively searching (mode 3). These results demonstrate that bears may have been more inclined to actively search in colder temperatures. This may suggest bears had a preference for colder temperatures and thus were more likely to actively search during these times.

While not performed in this study, the integration of specific environmental data is possible. As the radar has a small range of sight, using tortuosity and movement modes to determine behaviour offers a method for researchers to study small-scale habitat and resource use. By quantifying movement, we can qualify behaviour, which can be used to understand resource availability. For example, Amstrup and Beecham (1976) showed that in black bears, the availability and distribution of food significantly affected the movement of bears. Specifically, movement was greater when food was sparse. They found that the inverse relationship between daily movements of black bears and the availability of food confirmed the correlation between locations of bears and the availability of food (Amstrup & Beecham 1976). They were also able to quantify movement over varying elevations based on the availability of food sources (Amstrup & Beecham 1976). As such, the results of this study show that as compact surveillance radar is able to quantify movements modes, it has great potential to be used as a tool to study the behaviour of bears and their response to resources in areas of human activity.

Chapter 4.

Conclusion.

4.1. Summary.

The overall goal of this thesis was to examine how well CSR technology worked to detect and follow bears in order to examine its potential efficacy as a tool in the management and ecological study of polar bears. I was able to determine the detection rate of the radar, how well it tracked bears, and examine any variables that may have affected its performance. Further, I was able to use the data collected by the radar to study the movement patterns, the influence of environmental variables on bear activity, curiosity behaviours, tortuosity, and movement modes.

The results of these studies showed that CSR technology has very high potential for use in both polar bear management and research. The ability to alert users of polar bears in combination with the advantages over GPS technology allow CSR to be a promising new technology in this field. The radar performed fairly well in detecting and tracking polar bears. Though the detection rate was low, it was not significantly affected by any environmental variables. It was also able to detect 26 additional bears that the human observer did not see. While some bears did have multiple tracks that needed to be connected, the majority of bears were recorded with a single track. When we consider that there is no other technology that allows the autonomous detection of bears, the automatic alert of managers, and the ability to see the bears remotely, this system offers the potential to aid managers and improve on traditional techniques of detecting bears using human observers. As such, with improvements there is high potential for the system to be integrated into management programs as an alert program to help managers keep communities bear free.

The radar performed very well in gathering data needed to study bear movement and behaviour in areas of human activity. As the radar has a small detection zone, it offers the potential to study small-scale, short movements that GPS does not. It also allows for the correction of errors, meaning higher quality data when compared to GPS technology. Furthermore, it removes the issue of sex and age biases for studying polar bears, meaning that researchers could use this data to understand how males and juveniles move and behave. Overall, the types and quality of data recorded by the radar offer great potential for its use in studying fine-scale polar bear movements, the impact of the environment and resources on movement and behaviour, and possible underlying drivers of human-polar bear conflict. As such, the radar has great potential to improve our understanding of the biophysical factors contributing to conflict and create management plans that address them.

Despite these results, there are still improvement to be made to the system before it can be reliably used to detect bears and alert managers and its use as a tool to study bears. These include improving the detection rate, reducing the number of tracks per bear to 1, and the use of AI and other settings to reduce the size of the datasets produced. Firstly, the detection rate could be improved before any integration into management. As no definitive variables allowed me to determine why bears were missed, further studies are needed to correct for this and significantly improve the detection rate. Secondly, the tracking ability could also be improved. To be used effectively both as a detection method and to study bears, the system would benefit from tracking bears with a single track. This would allow the CSR system to be a more reliable method of detecting polar bears as well as improve the consistency of data for behavioural and movement studies. Finally, the size of the dataset and detection/alert for objects that are not bears also needs to be improved. To be used as an alert system, the system must be able to determine what objects are not bears so as to ensure the user is not overwhelmed with alerts. If the user is alerted to every object detected, this defeats the purpose of an autonomous detection system. Additionally, the large data set produced affects the ability of researchers to use the data collected, as the time it takes to filter bears out of the data and remain consistent significantly hinders the use of this system. By re-producing the studies performed here, future users can gain a better understanding of how to adjust the settings and improve the AI technology in order to ensure the CSR system can be used as both an alert system and a means to study polar bear movements and behaviour.

4.2. Implications for Conservation.

4.2.1. Alert System

This system offers a tool that could significantly improve polar bear management strategies. By allowing communities to detect bears before they enter areas of human settlement, conflict with humans can be avoided. This allows the opportunity to keeping both people and bears safe. With climate change threatening the survival of bears and its potential to increase conflict, it is extremely important to mitigate any and all conflicts with people.

CSR technology also offers the potential to lessen the indirect impacts of human-polar bear conflict by keeping communities bear free. By mitigating conflict with bears public perception can be improved. As many communities have to practice extreme diligence to avoid bears as well as alter their traditional practices (such as hunting), ensuring that community perimeters are secure could help improve the overall sense of security. By allowing northern communities to feel more safe, overall perception of polar bears could be improved. This in turn could potentially improve efforts to conserve them – an important precondition for conserving species.

There also exists potential to implement these systems in areas often frequented by people, but not in towns. For example, the CSR systems could be set up around dumps outside of town to alert people of the presence of bears in the area. This could work by means of a traffic light system. When a bear is detected in the area, red lights would be turned on. When no bears are in the area, green lights would be on. Yellow lights could fill times between activity and no activity to alert people of the potential for bears and to ensure they are on alert.

With improvements, CSR technology offers a great method of detecting polar bears and mitigating conflict with people.

4.2.2. Movement and Behaviour Studies

One of the major challenges in ecological studies is the attempt to understand how resource selection drives movement, and vice versa (Hebblewhite & Haydon 2010). Despite having many advantages for wide-ranging species, GPS technology has a disconnect between mapping where an animal moves and the specifics of that landscape (Hebblewhite & Haydon 2010; Turchin 1998). GPS locations sent by collars are also unable to provide information on the actual resources animals use, and thus information on the resource drivers of movement (Hebblewhite & Haydon 2010; Cagnacci et al. 2010). To date, this knowledge is lacking for polar bears, as is our biophysical understanding of the drivers of human-polar bear conflict. However, as the radar collects high quality data on the movement of bears, there is great potential for its use in studying how bears move on the landscape based on resource availability. CSR technology also offers the opportunity to study the finer spatial and temporal information about small-scale movement patterns and behaviours of polar bears in area of human activity, something lacking in GPS data (Hebblewhite & Haydon 2010). It may also allow researchers to determine resources and conditions that either deter or attract polar bears. This includes times of day bears are more active, weather conditions that may affect activity, and times of year that see higher or lower concentrations of bears. This in turn could inform management strategies based on finer scale resource-based movement patterns.

4.3. Future Directions.

Due to the many types of data collected by the radar and the ability for customization, there is great potential for futures studies with this technology. Specifically, repeat studies with larger data sets to improve on the analyses performed in this thesis, the integration of topographic information to understand the influence of the landscape and resources on bear movement and behaviour, the quantification of bear body condition, the creation of baseline datasets to compare to future studies, and even the potential to study other species of wildlife or elements of climate change.

Further studies are needed to re-test the analyses performed in this thesis, primarily due to the small dataset. Of particular importance is determining the detection rate, as this study had a very small sample size and a relatively low detection rate (66%). By repeating this study with a longer period of overlap between the human observer and the radar, the detection rate can be re-calculated. This is important as it is the basis for understanding how well the radar works to detect polar bears. This will also allow for further studies to be conducted on factors affecting the detection rate, the ability of the radar to follow bears, and how many bears were recorded multiple times and factors that affected this. This also would allow for a study on landscape factors that affect when the radar drops a track, such as tundra buggies and foliage. These studies would allow for a better understanding of how well the radar works, and improvements that need to be made, and a more robust study of its efficacy in managing human-polar bear conflict.

Future studies that integrate topographic maps of the landscape would be very beneficial for understanding areas of interest, drivers of movement, how well the radar functions when bears are in different areas (such as vegetated vs non-vegetated), and the impact of resources on behaviour and movement. Detailed spatial maps of wildlife habitat relationships have proven to be important tools in conservation and management, including for species that may be impacted by large-scale climate change (Vogeler & Cohen 2016; Maclean et al. 2008). Increasing pressures on wildlife populations through the loss and degradation of habitat had led to the need for detailed representations of habitat relationships (Scott et al. 1993). Indeed, understanding what resources drive behaviour is essential for creating effective management programs (Wilson et al. 2017). For example, Amstrup and Beecham (1976), conducting a study using GPS collars on black bears, found that there was a significant correlation between plant phenological stage and the amount of time a bear associated with each plant. Understanding the drivers of behaviour allows managers to alter that behaviour. This information is critical for developing both management plans for human-polar bear conflict and understanding how the landscape and resources affect behaviour – for both of which there is a dearth of information.

As the CSR system provides photographs of the bears detected, future studies have the potential to study body condition of the bears. This is of particular importance given the threats that climate change present to the ability of bears to hunt and create fat stores to use over the summer months. As outlined by Sutherland (1998), it is important to have measures of deteriorating conditions in order to evaluate the impacts of environmental conditions. Bears in the Western Hudson Bay population have been observed to have significantly poorer body conditions when returning to shore in the spring (Stirling, Lunn, & Iacozza 1999; Stirling & Parkinson 2006). As such, a future study could involve body condition quantification both when bears return to the land in the spring as well as their condition when they return to the ice in the fall. While the condition of polar bears varies throughout the year depending on available food sources (Dowsley & Wenzel 2008), quantification of this variance would allow a deeper understanding of the health of bears in the Churchill area. This would not only allow the study of overall health of bears but also a comparison of body condition from the beginning to the end of the terrestrial period. These studies could also be used to inform human-polar bear conflict management. As Stirling, Lunn, and Iacozza (1999) found that early spring breakup of sea ice was associated with increased human-polar bear encounters in the Churchill area, understanding the condition of bears coming ashore may help predict the likelihood of encounters with humans. This is particularly important given that nutritionally stressed bears are more likely to take chances to obtain food, including interacting with people (Derocher, Lunn, & Stirling 2004; Mattson 1990; Peacock et al. 2010; Regehr et al. 2007; Stirling and Derocher 1993; Stirling and Parkinson 2006 Stirling, Lunn, & Iacozza 1999; Towns et al. 2009. Furthermore, these types of studies could be used to create a baseline of bear body condition currently to compare with conditions in the future in efforts to understand the impacts of climate change on bears in the Churchill area.

A final possible study is that of other species and the landscape. A major advantage of CSR technology is the ability to collect a wide range of data simultaneously. The same data collected on movement of bears could be used to understand the timing of congregation and dispersal onto the ice, the demographics of bears in the area, and even the physical condition of bears using the camera footage. These in turn used to develop databases of archival data to understand the effects of climate change in the future. Information can also be collected on species other than polar bears using the same data set. As the radar collects information on all moving objects, potential exists to examine the presence and movement habits of other wildlife in the area. We can also use the footage to understand how the landscape changes over the period of observation, including snow coverage and sea ice formation and break up.

In summary, though CSR technology needs to be studied further, it has potential. If the detection and tracking rate can be improved and the system taught to filter out objects that are not polar bears, this system could be a great tool for northern communities. This would allow for the autonomous surveillance of communities and areas of human activity in order to significantly reduce conflict between people and polar bears. It also holds potential for improving our understanding how polar bears behave in areas of human activity and any resources or environmental factors that may affect this. This data can then significantly improve management, allowing us to understand the drivers of polar bear movement and behaviour and adjust our management strategies accordingly. As such, CSR offers an opportunity to significantly improve polar bear management in Canada's north and ensure the future peaceful coexistence of polar bears and people.

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