GEOFIX

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MODELLING FIX RATE BIAS IN YUKON'S ARCTIC COAST

SIMON FRASER UNIVERSITY

GEOGRAPHY 455

Disclaimer

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Acknowledgements

GEOFIX would like to thank our GEOG 455 professor, Dr. Nadine Schuurman and our TA, Michael Martin for their guidance and assistance throughout this project. As well as, Dr. Ramona Maraj who has mentored us throughout this analysis and helped us improve the overall result.

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ABSTRACT

This study analyzes the effects of environmental variables on GPS performance in the Yukon's Arctic Coast. To test this, Telonics GPS collars were left during the summer of 2009 and 2010 throughout the study area for varying amounts of time. The fix records produced by these collars were then processed and cleaned, leaving 30 samples. Using these records along with a digital elevation model and a land cover classification, nine variables were extracted and analyzed in an attempt to find relationships, such that fix rate could be predicted throughout the landscape. The results indicated that very few strong relationships existed. Densiometer values proved to be the only relationship between an environmental variable and fix rate. Available sky and aspect produced results, which were contrary to those expected, and showed no effect on fix rate. Overall, Telonics Gen 3 collars had extremely high fix rates, high accuracy, and low positional dilution of precision. Moreover, there was little variation in these results. This means that future GPS studies in the region would likely require minimal correction for fix rate bias. Although, if corrections were to be made more data would have to be gathered to ensure results were statistically sound. The analysis suffered from a number of limitations, the most significant being a small sample size and low sample variance. Therefore, future studies should increase the number and diversity of sites tested.

INTRODUCTION

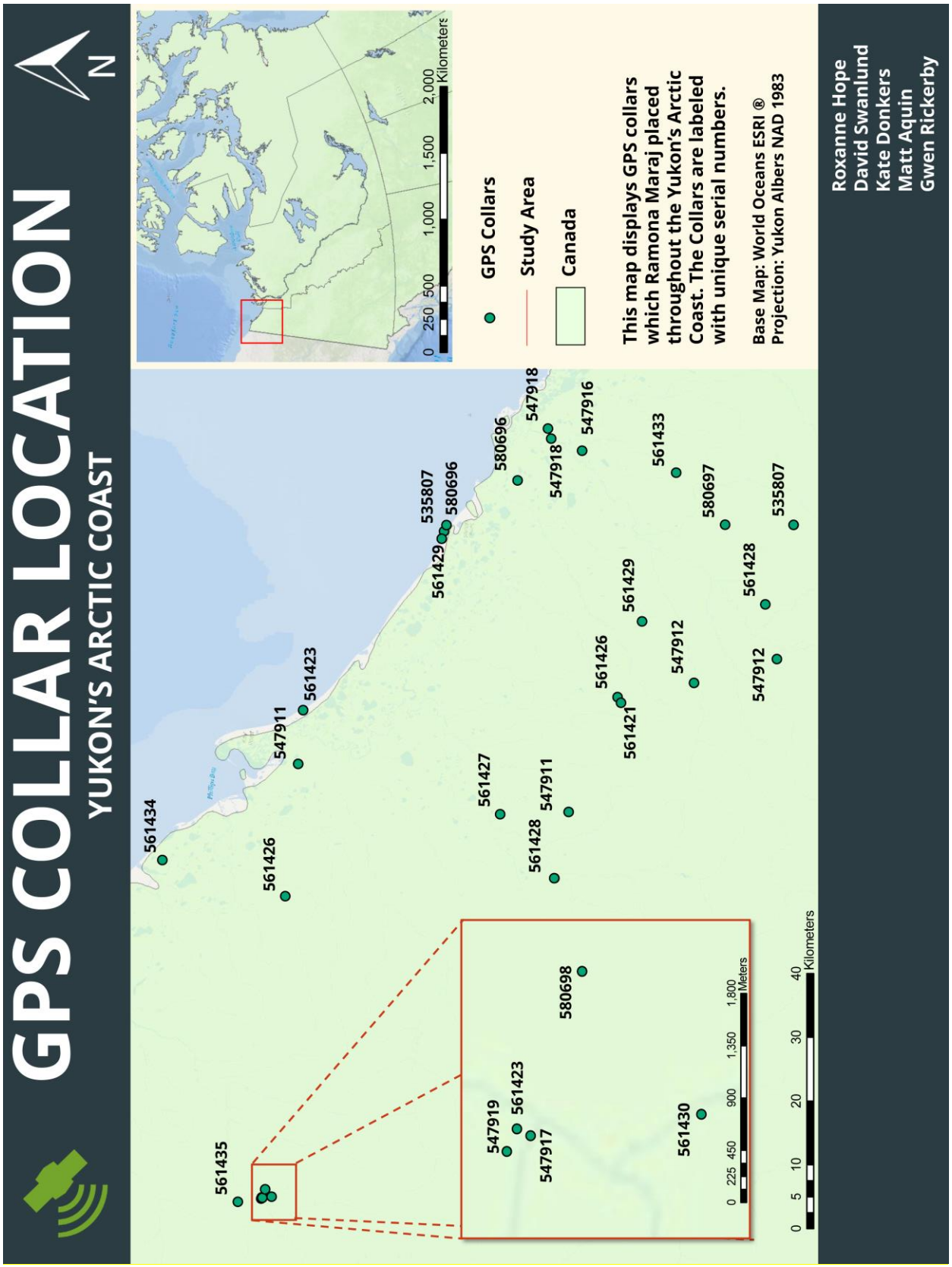
GPS collars are being increasingly use in animal studies to track their movement and analyze behavior and migration patterns (Friar et al., 2010). They are becoming more popular because of the advantages of automated tracking of animal movements (D'Eon et al., 2002). GPS collars are useful in animal studies because of their ability to provide a continuous record of animal locations that is not achievable with current traditional technologies, such as very high-frequency (VHF) devices (Friar et al., 2010). By communicating with satellites the GPS collars can collect locational data. However, obtaining good data is sometimes difficult as there are a number of variables that can influence the communication between receivers and satellites.

Ramona Maraj is a carnivore biologist performing grizzly bear research for Environment Yukon. In the summers of 2009 and 2010, she placed 48 GPS collars in stationary locations throughout the Yukon North Coast. These collars were manufactured by Telonics. The purpose of the study was to understand the communication quality between the collars and GPS satellites. The primary concern of error was fix rate, with positional dilution of precision (PDOP) being secondary, and locational error being tertiary. Raw GPS data contains these errors, which were analyzed in an attempt to find the underlying causes for such error.

Fix rate bias is the likelihood of a radiocollar failing to obtain GPS fixes given a variety of terrain and habitat conditions (D'Eon et al., 2002). This is an issue since

physical obstructions between collars and satellites affect communication (D'Eon et al., 2002). Animals frequently move around many different types of vegetated areas. Forested areas can affect fix rate more by blocking satellite signals and preventing GPS collars from being able to calculate their locations (Moen et al., 1996). Another source of error for GPS receivers is the positional dilution of precision (D'Eon et al., 2002). PDOP is a unitless measure of satellite geometry and an overall estimate of location error precisions (Orio et al., 2003). Receivers determine their location by triangulating satellites, with better triangulation leading to lower PDOP values. Locational error is the horizontal distance between the location of a radiocollar and the associated true location, as well as the difference in elevation between the recorded and true location (D'Eon et al., 2002). Locational error is higher for 2D fixes than for 3D fixes (Lewis et al., 2007)

This report aims to analyze and discuss the data collected over the summers of 2009 and 2010. The purpose is to determine if a number of factors affect the communication between the GPS collars and the satellites. For example, fix rate bias and PDOP were examined along with the vegetation surrounding them to see if the vegetation had any effect as well as the topography. This report will describe the background research behind this study and examine previous research in a literature review. The project's methodology, results, and future recommendations will be discussed.


GPS COLLAR LOCATION
YUKON'S ARCTIC COAST
N
0 250 500 1,000 1,500 2,000 Kilometers
GPS Collars
Study Area
Canada
This map displays GPS collars which Ramona Maraj placed throughout the Yukon's Arctic Coast. The Collars are labeled with unique serial numbers.
Base Map: World Oceans ESRI ®
Projection: Yukon Albers NAD 1983
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Matt Aquin
Gwen Rickerby
561435
561434
561426
547911
561423
561427
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547911
561429
535807
580696
580696
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547918
547916
561421
561426
561429
547912
561433
580697
561428
547912
535807
547919
561423
547917
580698
561430
0 225 450 900 1,350 1,800 Meters
0 5 10 20 30 40 Kilometers

BACKGROUND

A constellation of 24 GPS satellites orbiting around the Earth provides their positions to any listening receivers on the Earth's surface (Moen et al., 1996). A minimum of three satellites is needed to get a 2D fix location and four satellites are required for a 3D fix location including altitude (D'Eon et al., 2002; Moen at al., 1996). These orbits are organized so that at any given location on the planet a receiver will be able to communicate with a number of satellites, giving locational data. Receivers at lower latitudes are able to communicate with more satellites, while higher latitudes have difficulty because the orbits do not cover the high latitudes well.

Before May 2000, GPS receivers experienced error from "selective availability" (D'Eon et al., 2002). Selective availability is the purposeful inclusion of error because the United States Department of Defense had concerns over providing accurate location data for reasons of national security (Friar et al., 2010). Researchers attempted a variety of ways to remove this error in an effort to increase the accuracy of their collected data. Removing selective availability has made it more practical to perform studies tracking animal behavior as more precise locations can be recorded (Orio et al., 2003). Without introducing the error directly into the data, more accurate conclusions can be accepted from any data collected in the field. This allows researchers to track animals for various purposes.

Animals may be tracked to study migration patterns and behaviors. By tracking where the animals move, researchers can determine variables such as habitat range, time of movement, how their eating habits may be influenced by the available vegetation, and prey, amongst other factors. This study focused on the movements of grizzly bears in the Yukon North Coast during the summer months of August 2009 and 2010.

Grizzly bears have a large range in western North America, with a large populations living in Alaska and northern Canada (National Wildlife Federation, n.d.; Schwartz et al., 2003). They hibernate during the winter months in order to reduce their energy consumption and are active during the rest of the year. From spring to fall, grizzly bears build up their fat reserves by foraging for food while wandering through their territories (National Wildlife Federation, n.d.). Before hibernating, they will dig a hole into the hillside where they can sleep through the winter months. This reduces their body temperatures and lowers their metabolic rate so that they may live off of their fat reserves. Pregnant females will have their cubs during this time, nursing them until spring arrives. Grizzly bears are mainly solitary and territorial, except for when a mother is caring for her cubs or when there is a plentiful food source, such as a river with many fish (National Wildlife Federation, n.d.).

The Yukon Territory is located in the northwestern corner of Canada. This region is a subarctic plateau interspersed by mountains (Wonders, 2011). The

exception is the Arctic Coastal Plain, which slopes down to the Beaufort Sea from the British, Barn and Richardson Mountains (Yukon Government, n.d.). In this region, there are several small streams flowing into larger rivers throughout the Coastal Plain, which broaden into large alluvial fans when they meet the Beaufort Sea (Yukon Government, n.d.). Due to its high latitude location, there are brief summers and long winters lasting from October to June (Yukon Government, n.d.). Coastal areas are sparsely vegetated and support early-succession vegetation tundra species, such as herbaceous annuals and perennial plants (Yukon Government, n.d.).

In the Arctic, the landscape undergoes changes through the seasons as the amount of Sun varies considerably, which affects the variety and amount of vegetation (Yukon Government, n.d.). Plants that are dormant during the winter grow and bloom in the spring and summer, taking advantage of the warmer temperatures and the long daylight hours. Salt marsh development is inhibited by sea ice moving along the coast and low inland terrain is covered by wetlands and cottongrass tussock tundra (Yukon Government, n.d.). Cottongrass in association with shrubs, lichens and forbs grow in well-drained sites. Major active channels flowing in a north-south direction from the mountains are scoured and unvegetated, while stabilized river features are gradually vegetated by bear root, lupine, dryas and willow (Yukon Government, n.d.). Floodplains of major, but less active drainage systems, support well-established vegetation such as sedges, willows and trees. While in the foothills,

gentle slopes are vegetated with shrubs, birch and willow, dryas, lichen (Yukon Government, n.d.).

Vegetation has been known to affect the quality of GPS communications, which can be an issue when tracking animals (Moen et al., 1996). It can prevent successful communications, creating errors in locational records. While open areas have little to no effect on GPS collar communications, forested areas have been proven to make fixes more challenging with lower fix rates than in open areas (Moen et al., 1996; D'Eon et al., 2002; Wells et al., 2011). Interference from vegetation has been recorded in many previous studies of GPS communications and animal tracking, which has been well documented.

LITERATURE REVIEW

The study of animal movement can be researched using various telemetry techniques. Many of the field and analytical techniques developed in studies of movement have focused on small vertebrate populations at local scales (DeCesare, Squires, & Kolbe, 2005). However, the advancement of Global Positioning System (GPS) technology in ecology has made it possible for larger and more mobile species to be studied (DeCesare, Squires, & Kolbe, 2005). This includes direct deployment of GPS units on study animals that allow for tracking location and movement. For a GPS unit such as a telemetry collar, functioning can be prone to error due to a number of factors including: topography, vegetation, location, and satellite reception. These factors influence the accuracy of GPS collars, and affect the rate at which a fix can be obtained, known as the fix rate (D'Eon, 2003).

This review will focus on past research from radiotelemetry and GPS collar studies. These studies were predominately located in North America, where researchers tracked large mammals such as deer, moose, and bears. GPS radiotelemetry is arguably still in its infancy due to unknown and unquantified sources of error and bias in collected data, including collar malfunctions, location errors, and fix rate biases (D'Eon, 2003). Therefore, multiple studies have placed GPS collars in known locations in order to act as control points for locational error and fix-rate bias modeling. The objective of this review is to study past research of GPS

collars on animals and at stationary locations. Multiple factors, such as vegetation, will be analyzed to identify how they affect GPS fix-rate. Lastly, the results from past studies will be interpreted and limitations will be discussed.

Methods from Previous Studies

Researchers have often worked both in-situ and in laboratory environments for radiotelemetry studies. Techniques to determine animal locations have included triangulation, location from aircraft, and transmittal of radio signals to satellites (Moen et al., 1996). However, ground and air-based methods are likely inaccurate because locations are determined by visual interpretation on a map, rather than from a GPS unit (Moen et al., 1996). By incorporating a GPS unit in a collar, the accuracy of animal locations is greatly increased compared to conventional telemetry methods (Moen et al., 1996). GPS collars have the ability to collect high quantities of accurate location data, 24 hours/day, over large geographic areas and under all weather conditions (Cain et al., 2005). Therefore, the use of GPS collars in wildlife research has increased.

Studies are divided into fieldwork and laboratory analysis. In the field, radiocollars were either deployed on animals or attached to stakes. (D'Eon et al., 2002) attached radiocollars to stakes at approximately 1 m from the ground ensuring that the GPS receiving unit was horizontal. This allowed the evaluation of GPS radio collar performance prior to deployment on mobile animals (D'Eon et al., 2002). When

employing the stationary collar sampling design, the time interval should match those of collars deployed on wildlife and the influence of animal behavior needs to be addressed for specific species of interest (Wells et al., 2011). Whereas, radiocollars deployed on animals, such as in Moen et al. (1996), directly report animal activity, collar orientation, and the cover type for the duration of each location attempt. However, often researchers cannot collect control locations because the GPS collars are continuously mobile (Moen et al., 1996).

The collars were located in the wilderness at prepurposed heights in predetermined locations. In order to measure positional accuracy, a high accuracy GPS was used to determine a reference location in order to draw comparisons (D'Eon et al., 2002). In most field locations, spherical densiometers were used to measure canopy closure, which may factor into how well the collar can receive the satellite signal (Wallin et al., 2011). On top of vegetation density, vegetation type can also be recorded in order to determine its effect on fix rate bias (Di Orio et al., 2003).

Fix success rates were determined by calculating the proportion of possible fixes obtained for the time span of a deployed radiocollar on a fixed schedule for attempts (Cain et al., 2005). These collars would often have a max time to collect a signal before the location attempt was deemed "unsuccessful" in order to preserve battery life (Cain et al., 2005).

Computer analytical methods take place in a laboratory environment. One of the analyses can be correcting for the different kinds of error found after the GPS data has been extracted. One recent attempt was to remove multipath error, the error caused by satellite signal reflection, was by post-processing the data to infer movement of GPS trackers to improve accuracy (Miura & Kamijo, 2015). Some post processing methods utilized Landsat images and LiDAR data to help correct the data (Zhang & Forsberg, 2007). On studies with collar data, however, computer analysis was often done with ESRI software, where topographic features, such as slope and topography, were extracted using a GIS (D'eon et al., 2002; Cain et al., 2005; Lewis et al., 2007). Many studies created an "available sky" parameter where the unobstructed view of the sky due to topography was quantified per raster cell (Friar et al., 2004; Cain et al., 2005). Vegetation was measured with the densitometer, and was subsequently incorporated into computer analytical methods and factored into land use models (Wells et al., 2011).

After building computer methods, statistical models can be built in order to truly measure the influence of these factors on fix rate. Some studies will build a weighted linear regression model in order to see the effect of certain parameters, such as vegetation type or density (Di Orio et al., 2003; Lewis et al., 2007). T-tests can be used to compare average fix success rates between stationary collars and collars deployed on free-ranging animals (Cain et al., 2005). Moreover, Raleigh's Z-statistic

can be incorporated into models to test for bias of the roving GPS collars, and whether or not the distribution was circular around true locations (Hulbert and French, 2001).

Many of those statistical analyses have yielded results, with some obvious factors like collar orientation (Wells et al., 2011). However, studies have quantitatively shown that topography is both a significant and insignificant factor in fix rate success (Gau et al., 2004; D'Eon et al., 2002). Mountainous terrain has had some effect on collar performance and is linked with satellite signal interference and the rate at which a 2D or 3D fix can be obtained (Cain et Al., 2005). Topography can be used from a DEM to create a visible sky parameter, which was found to be an important predictor for fix rate and positional error (D'Eon et al. 2002). Vegetation has had an effect in numerous ways, including tree height, basal area, and leaf area index in the canopy (Friar et al., 2004). Vegetation type also has been found to have an effect on fix rate (Williams et al., 2012; Di Orio et al., 2003). Locations will be successful from 60% or more of location attempts if there is neither deciduous nor coniferous trees present near the GPS radio receiver (Moen et al., 1996). This was significant in the time of selective availability. There have been recorded observations between tree habitat types, with different tree species showing lower fix rates than others (DiOrio et al., 2003).

Place has an impact on fix rates. For example, collared animals in steep walled canyons will see more multipath error due to signal reflection (Di Orio et al., 2003). When an animal moves, it is moving itself into new locations each time. Changes in cover type, including if an animal seeks rocky shelter, over the course of the day can lead to plenty of error. It has been argued that fix rates should be discussed in terms of habitat types (Lewis et al., 2007). Collar orientation can also have an impact. When moose collars are slanted horizontal, the fix rate is affected enough to fail 5 times out of 800 attempts (Moen et al., 1996).

Results from previous studies

Fix rates have varied over time with 26% 3D fixes occurring in 1996 (Moen et al., 1996) to 64% minimum fix rates in 2011 (Wells et al., 2011). Fix rates have been plotted and modelled in order to find statistical correlation between fix rate and other variables. While some studies have shown fix rate not varying over time of day (D'Eon et al., 2002), fix type (a 2D or 3D fix) is also not affected by land cover type (Moen et al., 1996). There was a significant relationship between positional error and PDOP (D'Eon et al., 2002). Canopy cover and satellite view were good indicators for 2D and 3D fixes, mean location error and PDOP values (Lewis et al., 2007). The fix rate diminished the longer the collar was deployed on the animals, however, fix rates were more successful in the more northern areas of Canada versus other regions of the country (Gau et al., 2004). In certain model analyses multiple linear regressions of

average location error versus terrain and habitat attributes provided a significant relationship, but were not necessarily predictive in their relationships (D'Eon et al., 2002). Antenna angle and height were incorporated into some statistical models and were significant factors within their analysis as up to 78% of missed attempts were due to the animal resting (Graves et al., 2013).

In summary, many methods have been used to assess the performance of GPS collars using models or tests on live animals. Physical parameters like elevation and satellite view; vegetative parameters like tree height, basal areas, and vegetation type; also collar characteristics like orientation (antenna angle) and antenna height can affect fix rates. Further analysis has been called for aspect and its effect on fix rates (D'Eon et al., 2002) and few studies have done so since. Fix rates, since selective availability was removed in 2001, have improved dramatically (Friar et al., 2010). Challenges with radio collar methods are now more focused on animal behaviour with fix rates hovering around 95%.

METHODOLOGY

Table 1: A table of the variables used in the analysis accompanied by authors who utilized these variables in past studies

Variable	Description	Original Dataset	Also Analyzed In
Fix Rate	The proportion of successful fixes to overall attempted fixes.	Fix Attempt Records	D'Eon et al., 2002 ; Cain et al., 2005 ; Friar et al., 2010
PDOP	The effect of satellite geometry on locational precision	Fix Attempt Records	D'Eon et al., 2002 ; Cain et al., 2005 ; Friar et al., 2010
Locational Error	The distance from the location reported in a given fix record to the actual GPS collar location	Fix Attempt Records	D'Eon et al., 2002 ; Cain et al., 2005; Williams et al., 2012
Time of Day	The time at which the fix was attempted	Fix Attempt Records	D'Eon et al., 2002 ; Friar et al., 2004 ; Moen et al., 1996
Densiometer Values	The amount of sky above the GPS receiver that was not blocked by overhead vegetation	Fix Attempt Records	D'Eon et al., 2002 ; Wells et al., 2011 ; Lewis et al., 2007
Land Cover Type	Description of dominant landscape features, such as forest, ice, etc.	Land Cover Classification Raster	Wells et al., 2011 ; Hebblewhite et al., 2007 ; Williams et al., 2012
Elevation	The height above sea level at which the fix was attempted	Digital Elevation Model	Hebblewhite et al., 2007 ; Wells et al., 2011
Available Sky	The proportion of the sky at a given point that is not blocked by the surrounding horizon	Digital Elevation Model	D'Eon et al., 2002 ; Cain et al., 2005 ;
Aspect	The direction of the slope that the GPS was placed upon	Digital Elevation Model	D'Eon et al., 2002 ; Hebblewhite et al., 2007 ; Wells et al., 2011

The data was derived from three primary sources: spreadsheets of fix attempts for each collar, a digital elevation model, and a vegetation classification raster. Nine

variables used in previous studies which were included in, or could be generated from these three datasets have been included in the analysis. These variables are summarized in the table below.

Whereas most variables were simply extracted from the original data, three were computed. These were the location error, available sky, and aspect. Location error was determined using the Near function in ArcGIS, which calculates the distance in meters between two sets of points. More specifically, we calculated the distance between each fix record and the actual collar location, and then averaged these values for each collar. Available sky was computed from the DEM using the Skyview module in Saga GIS, as it offered an automated process, as opposed to the manual methods used by other authors in ArcGIS (D'Eon et al., 2002 ; Cain et al., 2005). Lastly, aspect was generated from the DEM using the Aspect function in ArcGIS.

Land cover type, elevation, available sky, and aspect were all extracted from their respective raster dataset using the Extract by Points tool in ArcGIS. Next, the values for all variables were merged into Gnumeric, an open source spreadsheet program. This software was chosen as it not only offers all the required statistical functionality, but also the ability to automatically produce box plots, which is a multi-step process in Microsoft Excel.

The first step was to clean the data. Collars were removed from the dataset which had been tampered with by wildlife. Collars which were placed outside

the scope of the land cover classification were also removed. The final component of data cleaning was to determine whether the three different types of collars were similar enough to be analyzed in aggregate, or whether some needed to be removed due to inherent differences in performance. To test whether these differences were significant a Chi Squared test was executed based on both the fix rates and PDOP values for each type of collar. The result of a Chi Squared test is a P value, which describes the "probability of observing a sample statistic as extreme as the test statistic" (StatTrek, n.d.). Typically, a P value of less than 0.05 is required to confirm an alternative hypothesis, therefore a value of less than 0.05 would mean that the differences between collar types were significant, and some data would have to be discarded.

Our results indicated that the differences in fix rates of the Tel Gen 4 SOB collars ($P > 0.99$) and Tel Gen 3 collars were not significant. The same resulted was found between Tel Gen 4 Argos collars ($P > 0.99$) and Tel Gen 3 collars. However, very few samples were taken with the Tel Gen 4 Argos collars (n=9), and even fewer with the Tel Gen 4 SOB collars (n=3). Therefore, we repeated the tests using PDOP values rather than fix rates. In this instance we found that the differences between the Tel Gen 4 Argos collars and Tel Gen 3 collars to be too significant ($P < 0.01$, n=337). Similar values were found using the Tel Gen 4 SOB and the Tel Gen 3 ($P < 0.01$, n=151). Therefore, only Tel Gen 3 collars (n=30) were used for the remaining analysis

to ensure that results were not in any way biased. This also meant that the effect of fix interval on fix rate and PDOP could not be tested, as 29 of 30 Tel Gen 3 collars used 80 minute intervals.

The following stages involved exploring the relationships between variables. To quickly understand these relationships a stage of exploratory data analysis (EDA) prefaced any further statistical testing. Here, continuous variables (location error, densiometer values, elevation, and available sky) were graphed in scatter charts as the independent variable against fix rate and PDOP. Categorical variables (time of day, land cover type, and aspect) were put into box plots, also as the independent variable against fix rate and PDOP.

Regression and ANOVA testing dominated the next stage of analysis. Continuous variables were tested as the independent variable against fix rate and PDOP using regression testing. Among others, two primary results of regression testing include an R2 value, which measures "the proportion of the variance in the dependent variable that is predictable from the independent variable", as well as the P value (StatTrek, n.d.b). Categorical data was also tested as the independent variable against fix rate and PDOP using ANOVA testing. ANOVA testing only provides a single P value which applies to all the categories involved. In this case, a P value of less than 0.05 would indicate that the differences between groups are significant and not likely due to random chance (Laerd Statistics, n.d.).

Table 2

Table 1: Detailed values of the variables associated with each collar

Frequency	Serial	Year	Overall Fix Rate	Fix Rate 3D	Fix Rate 2D	Avg. PDOP	Locational Error (m)	Elevation (m)	Aspect	Avaliable Sky	Vegetation
148.38	535807	2009	100.00%	95.77%	4.23%	4.04	5.79	476	Northeast	96%	Low Shurb Tundra
148.56	547911	2009	100.00%	98.57%	1.43%	4.46	5.55	307	North	96%	Moist Cottongrass tussock
148.58	547912	2009	100.00%	78.46%	21.54%	4.14	5.16	243	North	94%	Shurb Thicket
148.62	547916	2009	99.05%	98.10%	0.95%	3.75	4.22	65	West	99%	Low Shurb Tundra
148.63	547917	2009	100.00%	92.96%	7.04%	4	7.75	239	East	93%	Moist Cottongrass tussock
148.640A	547918	2009	99.22%	71.49%	27.73%	4.3	6.26	25	Southeast	98%	Low Shurb Tundra
148.640B	547918	2009	100.00%	91.59%	8.41%	3.85	5.27	92	Southwest	99%	Shurb Thicket
148.65	547919	2009	100.00%	91.67%	8.33%	4.26	9.31	243	Southwest	92%	Shurb Thicket
148.70	561421	2009	100.00%	98.53%	1.47%	3.98	4.68	287	Northeast	97%	Moist Tundra with wet inclusions
148.72	561423	2009	98.63%	71.23%	27.40%	4.07	15.89	234	South	92%	Wet Barrens
148.75	561426	2009	100.00%	100.00%	0.00%	4.5	4.92	296	West	98%	Moist Cottongrass tussock
148.76	561427	2009	100.00%	100.00%	0.00%	3.82	3.58	114	Northwest	99%	Moist Cottongrass tussock
148.77	561428	2009	100.00%	97.20%	2.80%	3.79	7.56	357	Southeast	95%	Low Shurb Tundra
148.780A	561429	2009	100.00%	100.00%	0.00%	3.88	5.45	4	Northeast	99%	Dry Partially Vegetated or Barren
148.780B	561429	2009	100.00%	100.00%	0.00%	3.77	4.36	369	Southwest	99%	Moist Cottongrass tussock
148.82	561430	2009	100.00%	97.18%	2.82%	4.23	10.53	276	Northwest	89%	Shurb Thicket
148.85	561433	2009	100.00%	100.00%	0.00%	3.62	6.15	226	Northeast	97%	Low Shurb Tundra
148.87	561435	2009	98.57%	98.57%	0.00%	4.22	10.65	592	South	95%	Dry Partially Vegetated or Barren
148.900A	580696	2009	100.00%	100.00%	0.00%	3.65	6.92	0	Flat	99%	Dry Partially Vegetated or Barren
148.900B	580696	2009	100.00%	100.00%	0.00%	3.19	4.16	55	Northwest	99%	Low Shurb Tundra
148.91	580697	2009	100.00%	97.92%	2.08%	4.34	0.90	366	North	92%	Low Shurb Tundra
148.92	580698	2009	100.00%	92.96%	7.04%	3.98	6.86	488	West	93%	Dry Partially Vegetated or Barren
148.38	535807	2010	100.00%	96.74%	3.26%	4.16	5.90	6	North	99%	Ice
148.58	547912	2010	100.00%	94.44%	5.56%	4.41	7.23	238	North	79%	Low Shurb Tundra
148.72	561423	2010	100.00%	93.41%	6.59%	4.12	6.37	32	East	95%	Wet Barrens
148.75	561426	2010	100.00%	98.59%	1.41%	4	3.62	119	Northeast	98%	Low Shurb Tundra
148.86	561434	2010	100.00%	100.00%	0.00%	4.13	4.84	0	Flat	99%	Moist Tundra with wet inclusions
148.56	547911	2010	100.00%	97.80%	2.20%	4.21	4.07	29	Flat	99%	Moist Cottongrass tussock
148.77	561428	2010	94.74%	40.35%	54.39%	4.82	15.86	157	Southeast	92%	Dry Partially Vegetated or Barren
148.91	580697	2010	100.00%	94.74%	5.26%	4.44	14.49	158	Southwest	91%	Wet Barrens

Table 3

Table 3: A table of eight statistical results comparing fix rates for regression and ANOVA testing

Fix Rate			
	R Squared	P Value (Regression)	P Value (ANOVA)
PDOP	0.181	0.019	N/A
Locational Error	0.358	0.000	N/A
Elevation	0.000	0.925	N/A
Available Sky	0.019	0.466	N/A
Densiometer	0.382	0.000	N/A
Fix Time	N/A	N/A	0.910
Aspect	N/A	N/A	0.241
Vegetation	N/A	N/A	0.387

Table 4

Table 4: The statistical results comparing PDOP to 8 variables

PDOP			
	R Squared	P Value (Regression)	P Value (ANOVA)
Fix Rate	0.181	0.019	N/A
Locational Error	0.163	0.027	N/A
Elevation	0.031	0.350	N/A
Available Sky	0.229	0.008	N/A
Densiometer	0.173	0.022	N/A
Aspect	N/A	N/A	0.374
Vegetation	N/A	N/A	0.892

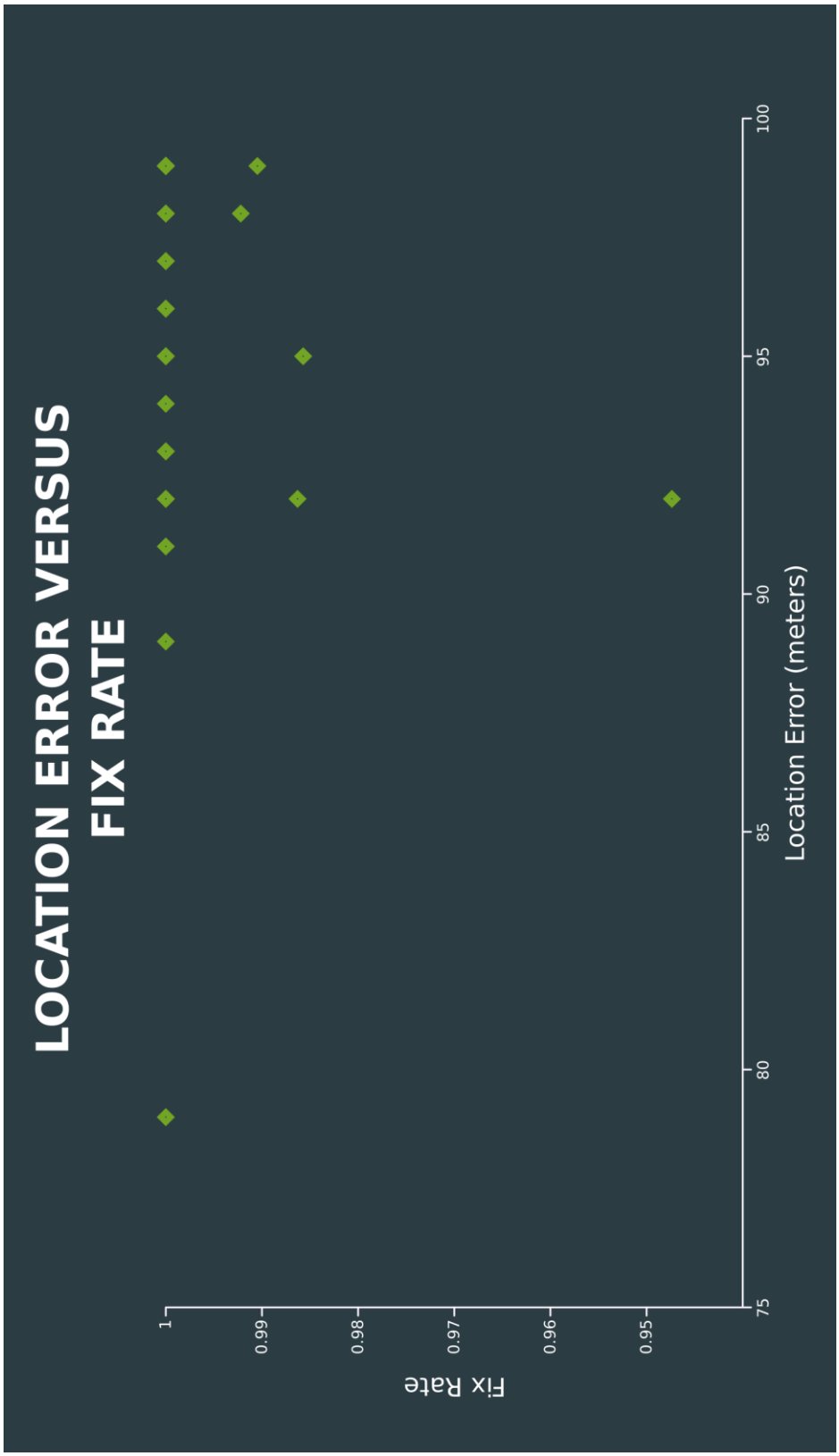


Figure 1: Scatterplot of the location error versus PDOP

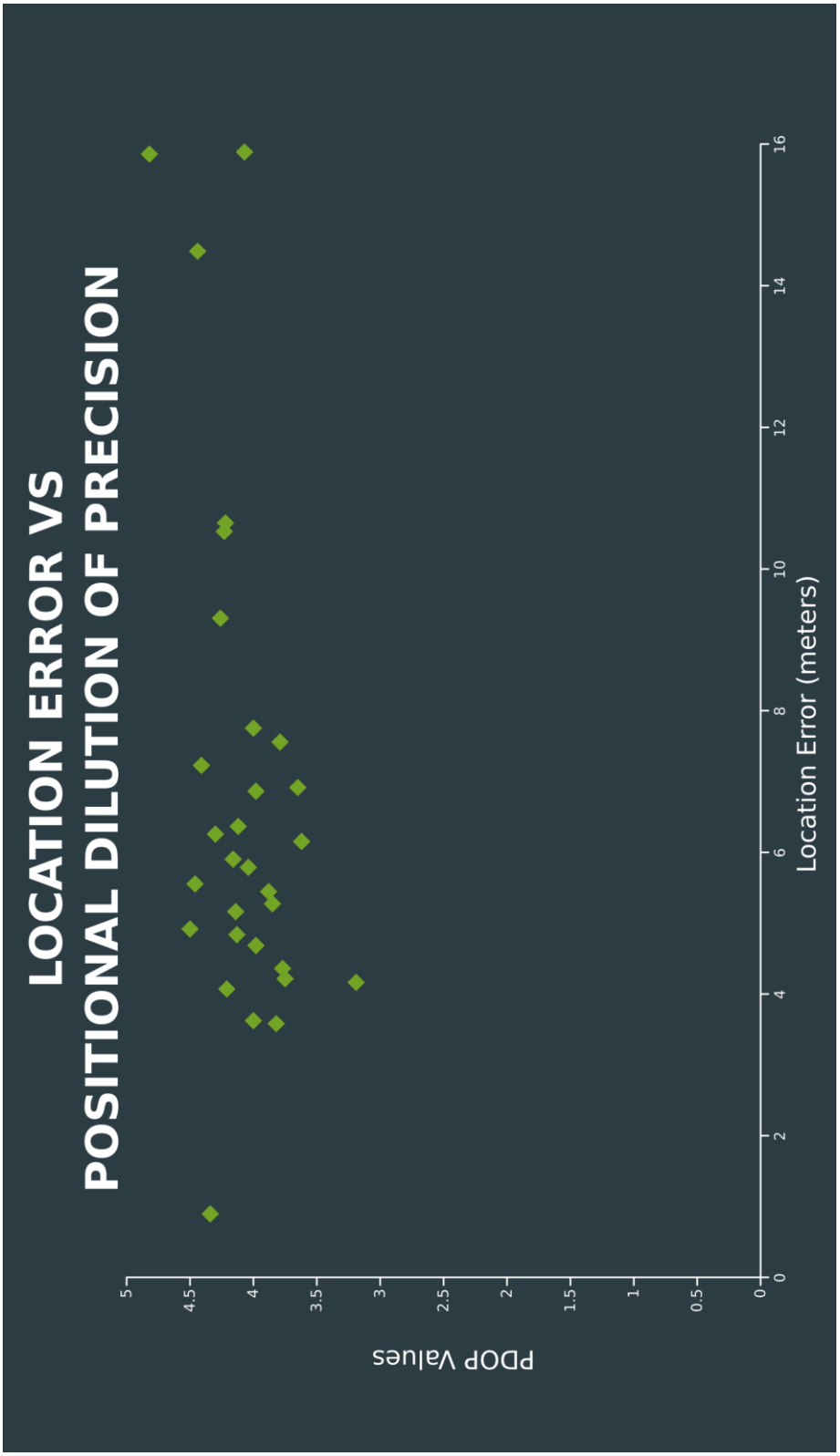


Figure 2 Scatterplot of Locational error versus positional dilution of precision

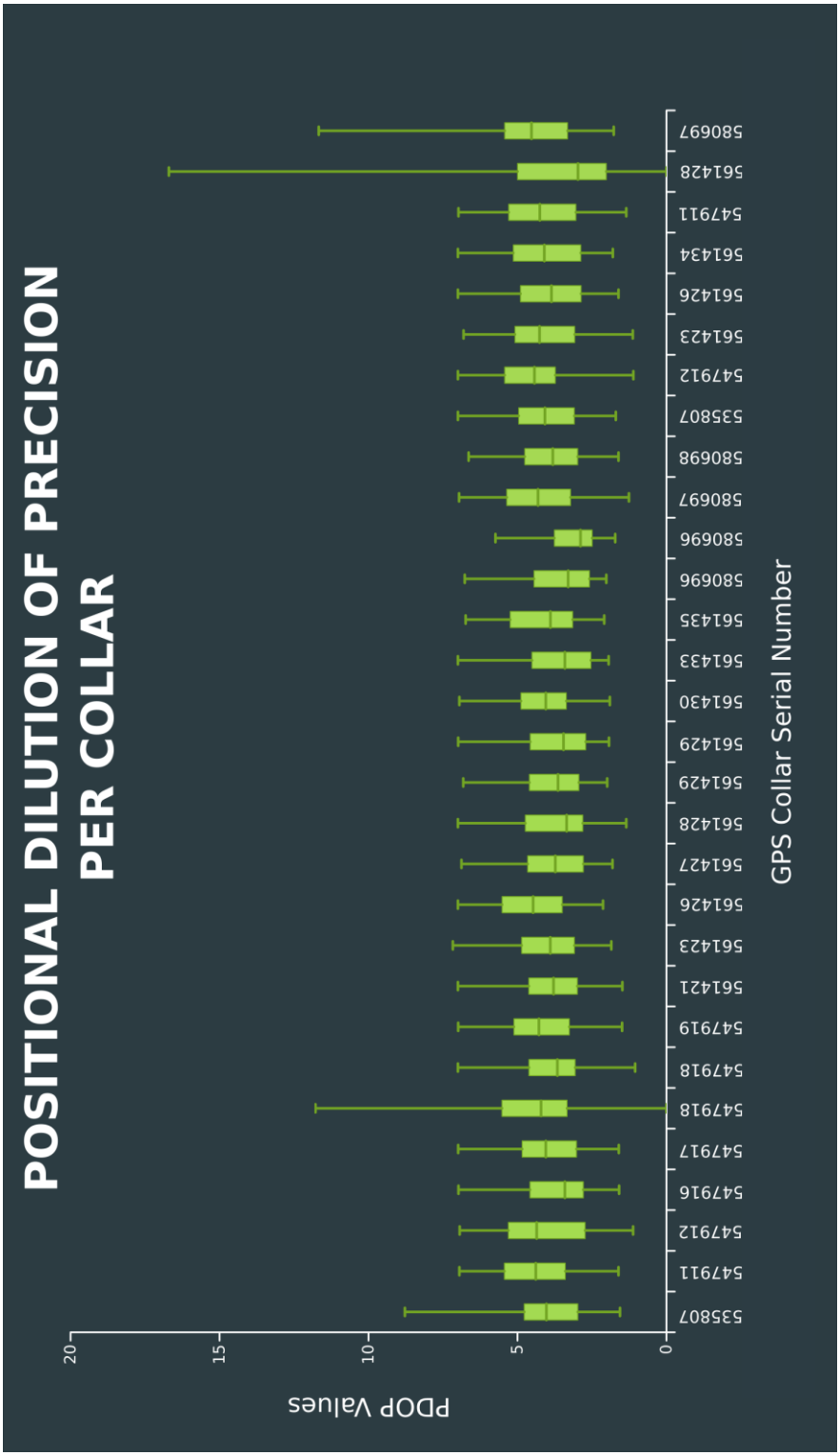
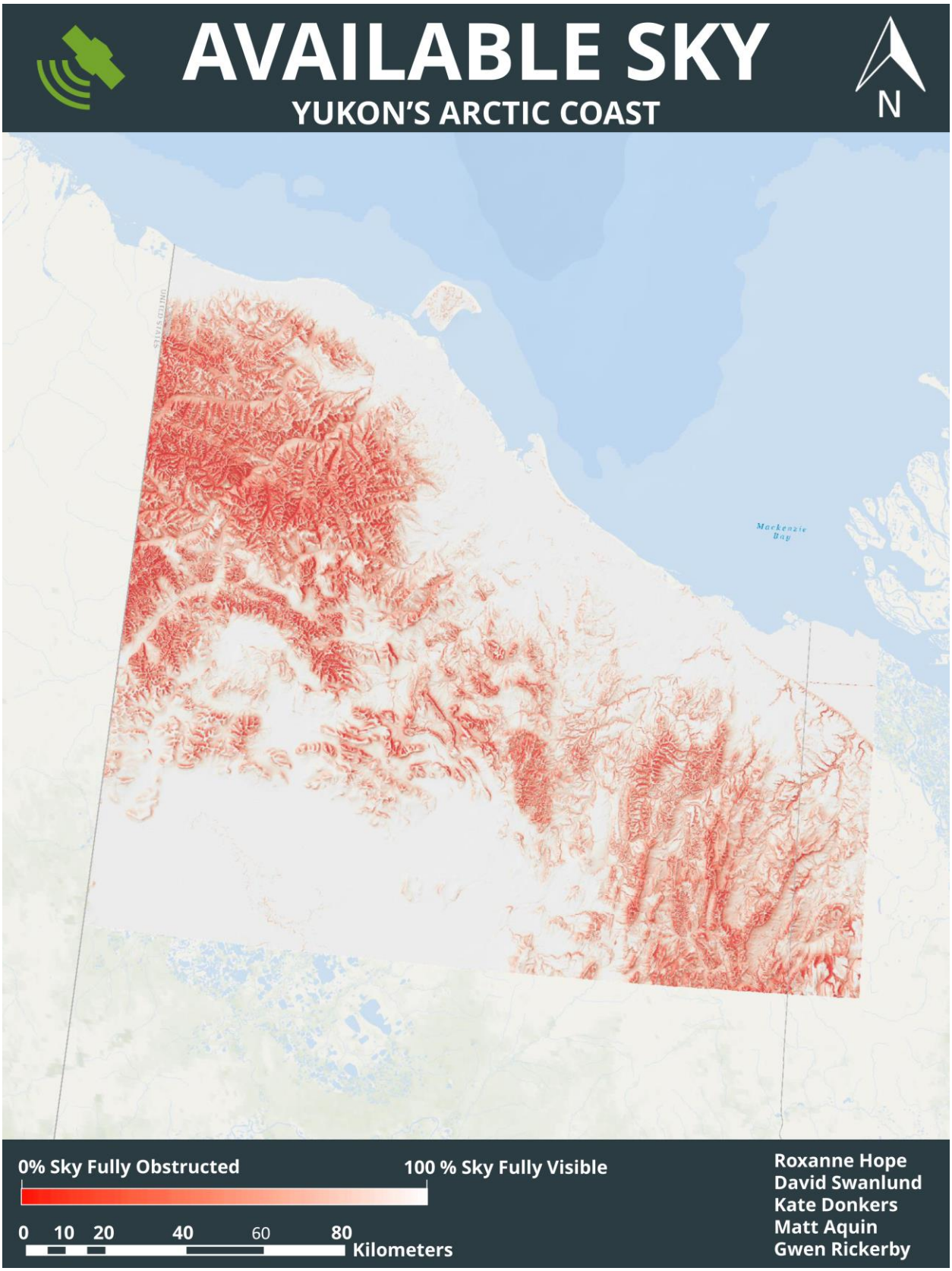
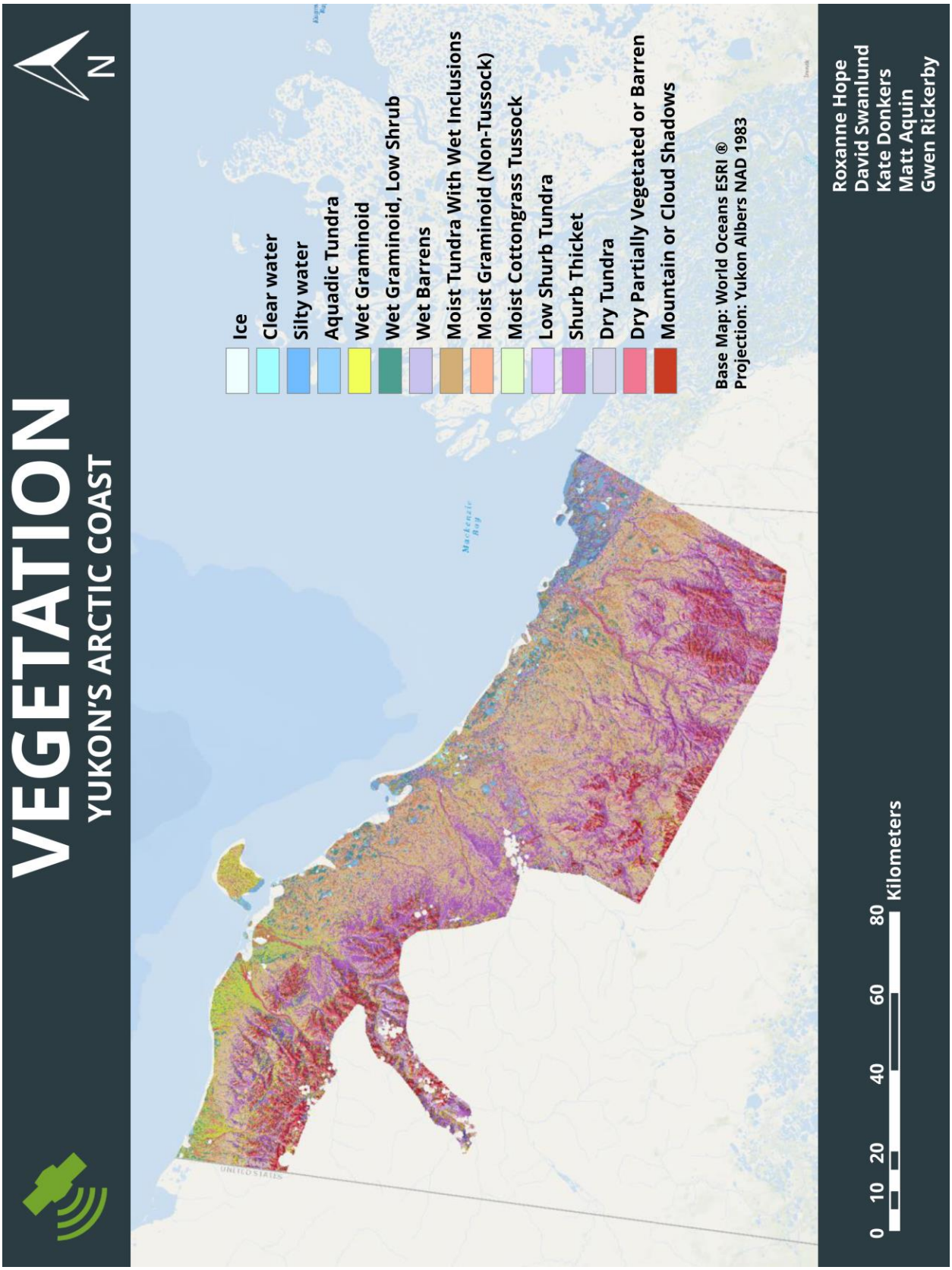
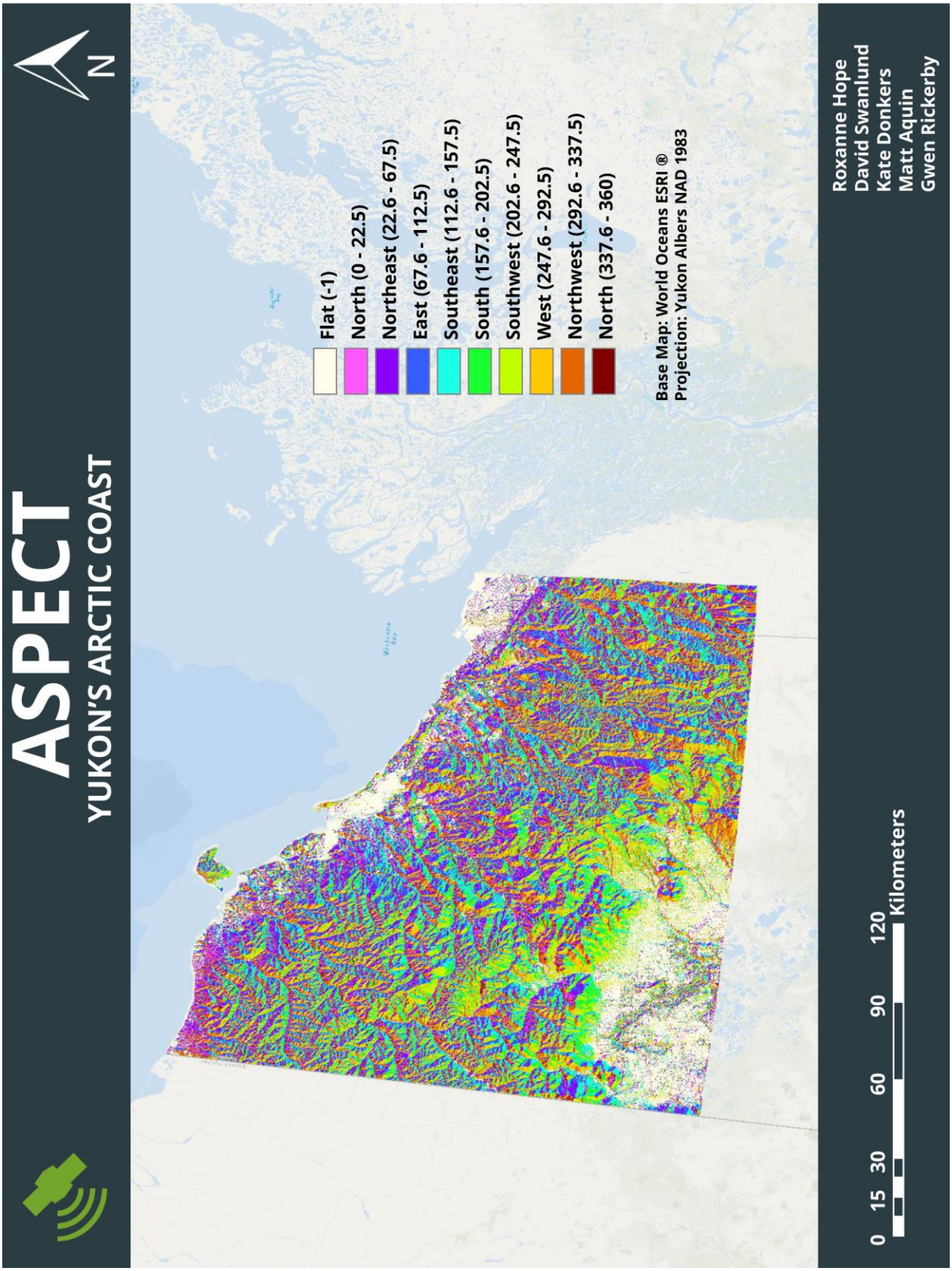


Figure 3 Boxplots showing the range of PDOP values for each collar


ELEVATION
YUKON'S ARCTIC COAST
N
UNITED STATES
Mackenzie Bay
0
4309 Meters
0 10 20 40 60 80
Kilometers
Roxanne Hope
David Swanlund
Kate Donkers
Matt Aquin
Gwen Rickerby


AVAILABLE SKY
YUKON'S ARCTIC COAST
N
Mackenzie Bay
0% Sky Fully Obstructed
100 % Sky Fully Visible
0 10 20 40 60 80
Kilometers
Roxanne Hope
David Swanlund
Kate Donkers
Matt Aquin
Gwen Rickerby


VEGETATION
YUKON'S ARCTIC COAST
N
Ice
Clear water
Silty water
Aquadic Tundra
Wet Graminoid
Wet Graminoid, Low Shrub
Wet Barrens
Moist Tundra With Wet Inclusions
Moist Graminoid (Non-Tussock)
Moist Cottongrass Tussock
Low Shurb Tundra
Shurb Thicket
Dry Tundra
Dry Partially Vegetated or Barren
Mountain or Cloud Shadows
Base Map: World Oceans ESRI ®
Projection: Yukon Albers NAD 1983
Roxanne Hope
David Swanlund
Kate Donkers
Matt Aquin
Gwen Rickerby
0 10 20 40 60 80 Kilometers


ASPECT
YUKON'S ARCTIC COAST
N
Flat (-1)
North (0 - 22.5)
Northeast (22.6 - 67.5)
East (67.6 - 112.5)
Southeast (112.6 - 157.5)
South (157.6 - 202.5)
Southwest (202.6 - 247.5)
West (247.6 - 292.5)
Northwest (292.6 - 337.5)
North (337.6 - 360)
Base Map: World Oceans ESRI ®
Projection: Yukon Albers NAD 1983
Roxanne Hope
David Swanlund
Kate Donkers
Matt Aquin
Gwen Rickerby
0 15 30 60 90 120
Kilometers

The initial proposed methodology included using the results of the EDA and statistical analysis to perform a pairwise comparison such that appropriate weights could be determined, which would then be used to perform a multi-criteria evaluation. This multi-criteria evaluation would have provided a raster which shows the areas which would be most or least likely to obtain a GPS fix. However, the results of the EDA and statistical analysis prevented this. Our results showed only weak relationships in variables that could be extrapolated over the rest of the landscape, such as elevation or available sky. This is largely due to the very high fix rates and very low PDOP values that were obtained. In fact, 25 out of 30 collars achieved a 100% fix rate, and out of a total of 3526 recorded fix attempts, only 13 failed.

Three relationships were found relative to PDOP. These were between available sky and PDOP ($R2 = 0.22$, $P = 0.01$), densiometer values and PDOP ($R2 = 0.17$, $P = 0.02$), and finally locational error and PDOP ($R2 = 0.16$, $P = 0.03$). There were also two relationships found relative to fix rate. These were between densiometer values and fix rate ($R2 = 0.38$, $P < 0.01$), and between locational error and fix rate ($R2 = 0.36$, $P < 0.01$). Lastly, there was a relationship between fix rate and PDOP itself ($R2 = 0.18$, $P = 0.02$).

ANOVA testing of categorical data resulted in very high P values. Relative to fix rate, fix time had the highest P value of 0.91, while aspect had the lowest P value, at

0.24. Relative to PDOP, land cover type had a P value of 0.89, while aspect had a value of 0.37.

Further analysis of the five collars which did not get a 100% fix rate, we find that three were very likely to have been influenced by topography. Field notes included in the collar records indicate that one of these three collars was at "the valley bottom with steep canyon walls" (serial = 561428, fix rate = 94.7%), another was at the "base of 20m high cliff" (serial = 561423, fix rate = 98.6%), while the last was in a mountain saddle (serial = 561435, fix rate = 98.6%). The remaining two collars showed no immediate contributing factors to their lower fix rate. However, it must be emphasized that fix rates were over 99% for each of these two.

PDOP values were also quite consistent, with only three collars experiencing major variability as they recorded some fixes with PDOP values above ten. Two of these collars were in valley bottoms (serial = 561428, 580697), with the other being under tall willow and alder (serial = 547918). Nevertheless, these collars averaged PDOP values of 4.82, 4.44, and 4.30, respectively. Overall, the collars' PDOP had an average of 4.07, a median of 4.10, and mode of 4. Typically a value of less than five is considered to be good, and thus PDOP values among all collars were, on average, near-ideal.

DISCUSSION & LIMITATIONS

The results of our analysis showed no strong predictors of fix rate in the Yukon Territory. The only relationship found between an environmental variable and fix rate was for densiometer readings, which could not be extrapolated across the rest of the landscape. This does suggest, however, that overhead vegetation cover can play a key role in creating fix rate bias, and therefore analyzing leaf area index (LAI) may be a key vector for further research.

Some results were quite contradictory to that which would be expected. For example, aspect was predicted to be a major environmental factor given the northern latitude of the study area combined with the relatively southern latitude of GPS satellite orbits. However, of the nine aspect categories the three which did not obtain a perfect fix rate were on south, southeast, and west facing slopes. These were areas that were predicted to have very high fix rates. However, the sample size in each of the categories was quite low, reducing the integrity of the results.

Another unexpected result included the relationship between fix rate and available sky. This was a variable that was expected to have a major effect on fix rate, as it embodies the obstructions caused by varying terrain. However, while available sky showed a relationship with PDOP, it appeared to have little effect on overall fix rate. This result is also in contradiction to D'Eon et al. (2002), who found that available sky was "an important predictor of location accuracy and fix rate bias."

Collars, which failed to attain 100% fix rate, were mostly positioned in areas that would have an obvious and significant effect on fix rates, such as in canyons or under heavy vegetation cover. These are small features that are not fully captured in the data. Though expensive, accurate LiDAR data would likely capture such features, and thus would provide a better foundation for analysis of fix rate bias. Nevertheless, fix rates were extremely high, and thus the necessity of correcting data is minimal.

There were a number of limitations in the analysis. First, given the number of variables that can influence GPS performance, the sample size was relatively low, making the isolation of variables difficult. The effects of this low sample size were compounded in the categorical data, such as vegetation and aspect, as the samples were divided further into small groups. For example, aspect was divided into nine categories, which resulted in two categories containing two samples (east and south), and three categories containing only three samples (west, northwest, and flat). Therefore, a small data set was made smaller still. Additionally, two of the three collar types were removed from the data set (Gen 4 SOB and Gen 4 ARGOS) as Chi squared testing revealed that differences seen between the collars were not random but due to technology. In previous studies, researchers collected data from over 500 sites to ensure that the error could be modelled, whereas in this study only 30 samples were used after cleaning the data (Wells et al. 2011).

A second major limitation to modeling the fix rate bias was that the sample variance was too low. The median and mode for fix rate between the 30 collars was 100%, with a standard deviation of 1%. This further limited the analysis, not only due to the difficulty of determining relationships using the five collars below 100% fix rate, but also because a single failed fix in many of the collars would have met, or exceeded the standard deviation. This only serves to increase the uncertainty of relationships, as relatively significant deviations could have been caused due to random device failure rather than environmental factors.

The data provided was collected through the method of stationary testing where collars were mounted to stands and oriented towards the sky at bear height. However, when GPS collars are positioned on bears, elevation and orientation will be constantly changing as they move through the landscape. This may affect the ability of the collars to obtain fixes, reducing accuracy and potential data collection. Additionally, bears traditionally spend a large portion of time in cave systems (Gau et al. 2004). In the sub-surface dwellings GPS signal may be weak or non-existent (Gau et al. 2004). Therefore, the results should be used cautiously in studies where GPS collars are mobile. While in this study GPS success was found to be extremely high, there are real-world factors, which would likely degrade GPS signal quality (Gau et al. 2004).

Vegetation has been found to pose a significant effect on fix rate accuracy and positional accuracy (the greater the canopy density, the larger impact vegetation has on fix rate success and PDOP) (Friar et al. 2004). It is important to note that during different times of the year, vegetation cover changes (Friar et al. 2004). Unfortunately, data collection for this study took place only during the summer months when much of the vegetation was in full bloom (Friar et al. 2004). Since the data was collected only during the summer months, our analysis could not take seasonality into account. For example, fix rate may improve during the winter as canopy density decreases, but it also may become less reliable due to snow cover. This is an area that requires further analysis.

In future studies using a higher number of collar locations would also be recommended. A larger sample size over the desired study area would increase the reliability of statistical tests in determining if environmental variables affect fix rate. With a larger and more varied pool of data to analyze, relationships can be stated with more confidence that they are indeed correlative, rather than due to random or outlying data. Moreover, it is suggested that one brand of collar be used for analysis to reduce the chance of performance being affected by differences in the underlying technology, such as receiver strength.

CONCLUSION

This study assessed fix rate bias and PDOP on Yukon's Arctic coast. Through stationary testing collars were placed throughout the landscape and left through the summers of 2009 and 2010 to collect data. The GPS collars were very successful, obtaining a low PDOP average of 4.07, as well as successfully getting a fix 99.7% of the time. The low PDOP values suggest satellite triangulation was good despite the satellite orbits not having prominence over the Yukon's North Coast. Given the high fix success average and low PDOP average, as well as the low variation between the two, it is safe to assume that the Telonics Gen 3 collars are a suitable choice for further GPS research.

However, analysis indicated that there was no strong predictors affecting fix rate. The small data set did not reveal any meaningful relationships from which further analysis could be drawn, although collars placed in heavily vegetated areas and canyons did experience lower fix rates. Some results were also unexpected, and even contradictory to previous studies, as was the case for available sky. Moreover, low-performing collars had relatively high fix rate success coupled with low overall variance, which made the identification of patterns difficult. This was one of a number of limitations that was imposed due to the small dataset, as isolating variables which affect GPS performance proved to be difficult.

Collecting data from collars in stationary positions at predetermined heights also brought limitations to the analysis. As bears move through their surroundings, the collars will likely continuously change in orientation and elevation, affecting their ability to receive GPS signals and record their locations. Results from this study should be taken with caution as stationary collars may not behave the same way as mobile collars, which would affect studies concerning mobile collars.

Vegetation was identified as an important factor affecting GPS signals, and has been confirmed in other studies (Friar et al. 2004). Depending on the time of year the foliage varies, with vegetation blooming in the summer and going dormant in the winter. GPS collars may have less difficulty receiving satellite signals in the winter as there is less vegetation interfering. Future studies could explore GPS communication success by placing control collars in various locations during the winter.

Ultimately, this study found that the Telonics Gen 3 collars suffer from minimal fix rate bias in the Yukon's Arctic Coast. Furthermore, the overall PDOP and locational accuracy was quite strong, indicating that minimal corrections to future studies would be required. On the other hand, the study also found that this very high fix rate success made modelling the low level of fix rate bias based on environmental predictor variables extremely difficult, especially given the low sample size. It would be strongly recommended that should these marginal corrections be required, that more data be gathered to ensure statistically reliable results.

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