11-4-2014

The Influence of the Projected Coordinate System on Animal Home Range Estimation Area

Michael Barr
University of South Florida, michaelbarr@mail.usf.edu

The Influence of the Projected Coordinate System on Animal Home Range Estimation Area

by

Michael R. Barr

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
School of Geosciences
College of Arts and Sciences
University of South Florida

Major Professor: Joni Downs, Ph.D.
Lori Collins, Ph.D.
Elizabeth Walton, Ph.D.

Date of Approval:
November 4, 2014

Keywords: map distortion, GIS, characteristic hull polygon, map projections

ACKNOWLEDGEMENTS

I would like to thank my committee members Dr. Walton and Dr. Collins for all of their valuable feedback and encouragement during this process. I would also like to thank the researchers whose data I have used in this thesis for making their work available. Special thanks to my advisor Dr. Downs for all that I have learned from her and for all of her support and guidance during the writing of this thesis and throughout my time at USF.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Animal home range estimations are important for conservation planning and protecting the habitat of threatened species. The accuracy of home range calculations is influenced by the map projection chosen in a geographic information system (GIS) for data analysis. Different methods of projection will distort spatial data in different ways, so it is important to choose a projection that meets the needs of the research. The large number of projections in use today and the lack of distortion comparison between the various types make selecting the most appropriate projection a difficult decision. The purpose of this study is to quantify and compare the amount of area distortion in animal home range estimations when projected into a number of projected coordinate systems in order to understand how the chosen projection influences analysis. The objectives of this research are accomplished by analyzing the tracking data of four species from different regions in North and South America. The home range of each individual from the four species datasets is calculated using the Characteristic Hull Polygon method for home range estimation and then projected into eight projected coordinate systems of various scales and projection type, including equal area, conformal, equidistant, and compromise projections. A continental Albers Equal Area projection is then used as a baseline area for the calculation of a distortion measurement ratio and magnitude of distortion statistic. The distortion measurement ratio and magnitude calculations provide a measurement of the quantity of area distortion caused by a projection. Results show the amount distortion associated with each type of projection method and how the amount of distortion changes for a projection based on geographic location. These findings show how the choice of map

projection can have a large influence on data analysis and illustrate the importance of using an appropriate PCS for the needs of a given study. Distorted perceptions can influence decision-making, so it is important to recognize how a map projection can influence the analysis and interpretation of spatial data.

CHAPTER 1:

INTRODUCTION

A home range is an estimation of an animal's use of space based on a distribution of observation locations (Powell and Mitchell, 2012). Precise animal home range estimations are essential in determining the resource needs of a species and developing conservation strategies (Carroll and Miquelle, 2006). Land development planning and public land acquisitions are also dependent on accurate home range estimations (Cramer and Portier, 2001). The accuracy of a home range estimation calculated in a geographic information system (GIS) is influenced by the projected coordinate system (PCS) used to project the data (Yildirim and Kaya, 2008). All map projections contain distortion in some aspect, which is why it is important to choose a PCS that meets the needs of the study for which it is being used (Olson, 2006). A study in which preserving area is important, such as determining home range size, would use an equal-area projection. Different methods of projection will distort data in different ways and the large number of projections available in GIS makes it difficult to choose the most appropriate PCS for a study (Usery and Seong, 2001).

This study will examine the distortion in eight projections available GIS by comparing animal home range area calculations. Research objectives include: (1) Calculate and compare the amount of area distortion in animal home ranges when projected into several different projected coordinate systems; (2) Determine how the level of area distortion for a PCS differs based on the geographic region of the study area; (3) Examine the distortion difference between various types of world projections that use different projection methods. This study will attempt to quantify the amount of distortion in each home range area calculation in order to show how the projected coordinate system influences home range estimations and the importance of choosing an appropriate projection for the purposes of a study. Understanding the distortion associated with each type of projection will help in the decision of which PCS to use for analysis.

The literature review in Chapter 2 provides background information on map projections, including methods of projection, evaluating distortion, and the use of projected coordinate systems in GIS. The literature review also discusses animal home range estimation, including the importance of accurate estimations, tracking data collection, and estimation methods in GIS. Chapter 3 contains the research objectives of this study, while Chapter 4 provides information on the data used to conduct the research. Chapter 5 explains the methods used to complete the research objectives, including the calculation of the area of home range estimation and analysis of the results. Chapter 6 contains the results from this analysis and Chapter 7 is a discussion on these findings. Final conclusions and implications of the research are provided in Chapter 8.

CHAPTER 2:

LITERATURE REVIEW

Home Range Estimation

Burt (1943) was the first to define a home range as “that area traversed by the individual in its normal activities of food gathering, mating, and caring for young.” Establishing a home range is a characteristic common to many different types of species (Burt, 1943). According to Powell and Mitchell (2012), “mammals, birds, reptiles, amphibians, and fish all exhibit site fidelity.” Home ranges tend to be distributed based on the availability of resources, but the lack of a precise definition of what constitutes a home range makes it difficult to quantify and analyze individual home ranges (Mitchell and Powell, 2007; Fieberg and Kochanny, 2005).

It is important to be able to quantify home ranges in order to estimate and evaluate the animal’s resource needs, land cover preference, and use of space (Powell and Mitchell, 2012; Mitchell and Powell, 2007). Conservation planners use these estimates to calculate carrying capacity and identify critical habitat for the protection of vulnerable species (Downs et al., 2012; Carroll and Miquelle, 2006). According to Rayfield et al. (2009), home range estimates are critical to the identification of areas with conservation value and the design of nature reserves used to protect the resource needs of certain species. Estimating resource needs also helps planners analyze the long-term viability of a species in its current habitat and determine if conservation is needed (Carroll and Miquelle, 2006). Precise home range estimates are needed for important conservation policy decisions and the development of conservation strategies (Carroll and Miquelle, 2006).

Animal Tracking Data

Animal home range estimations are created based on the analysis of a set of observation points (Selkirk and Bishop, 2002). Radio telemetry has historically been the best method for obtaining observation points in the field (Worton, 1995). In a radio telemetry survey, the animal is fit with a radio transmitter and then a sampling regime of collecting location data is established (Worton, 1995). Location points are identified in the field by triangulation using a radio receiver from at least three fixed locations (Zurita et al., 2012). Radio telemetry allows researchers to follow the movements of individual animals and has led to an increase in literature on home ranges (Powell and Mitchell, 2012). The use of telemetry has been especially helpful in obtaining data on the movements and home ranges of species that are difficult to track, such as snakes (Ward et al., 2013).

Animal tracking points can be obtained remotely using Global Positioning System (GPS) technology or satellite telemetry. Satellite telemetry involves fitting an animal with a transmitter that sends signals to a network of satellites in order to compute a positional fix (Lord-Castillo et al., 2009). With GPS tracking, the animal is fitted with a GPS receiver that receives signals from satellites to localize the position (Pebsworth et al., 2012). GPS tracking is a newer technology that is becoming more widely used to collect animal location data (Pebsworth et al., 2012). GPS technology has several advantages over radio telemetry, including the ability to collect more data points in less time and eliminating the need to travel to close proximity of the animal (Recio et al., 2011). One problem with GPS technology is that line-of-sight errors between the receiver and satellites can lead to location errors or failure to record a point (Pebsworth et al. 2012). Even with these errors, GPS has proven to be more accurate than radio telemetry in recording location points (Recio et al. 2011).

Home Range Estimation Methods

Once location point data has been collected for an individual, there are several methods that can be used to quantify the home range (Blouin-Demers, 2006). The minimum convex polygon (MCP) and kernel density are the two most widely used home range estimators, but there is little consensus on the most accurate method (Blouin-Demers, 2006; Downs and Horner, 2009). The lack of a standard method for estimating home ranges makes it difficult to compare studies (Pebsworth et al., 2012). According to Powell and Mitchell (2012), home range estimations are a statistical approximation and no method will perfectly represent reality. The home range estimation method chosen for analysis will depend on the goals of the study, as each method has advantages and disadvantages (Fieberg and Kochanny, 2005).

Minimum Convex Polygon

MCP is the simplest method for estimating home ranges (Pebsworth et al. 2012; Worton, 1995) and has traditionally been the most widely used (Seaman et al., 1999). The MCP is the smallest convex polygon that contains all location points collected for an individual (Pebsworth et al., 2012). Regardless of the distribution of inner data points, outlying points have the greatest influence on the MCP estimation (Worton, 1995). These outliers could be the result of infrequent explorations from the normal range and can exaggerate the true size of the home range (Worton, 1995; Burt, 1943). Some studies have addressed this problem by calculating 95% minimum convex polygons to remove the outer 5% of points (Schrecengost et al., 2009; Holzman et al., 1992). MCP is not well suited for home ranges that have a non-convex shape because the estimation will most likely contain areas that are not utilized by the individual (Worton, 1995). MCP has well-noted weaknesses but continues to be widely used due to its simple calculation and so estimations can be easily compared to previous and future studies (Seaman et al. 1999). MCP is viewed as the best estimate of the maximum home range of an individual animal (Blouin-Demers, 2006).

Kernel Density Estimation

Although MCP is the traditional method for home range estimation, kernel density estimation (KDE) has become the most popular method in recent years (Ward et al., 2013; Pebsworth et al., 2012). Kernel estimates define the probability of finding an individual in a given location throughout the study area based on the density of observation points (Pebsworth et al., 2012; Worton, 1989). The KDE will have the highest density at locations with the highest concentration of tracking points (Worton, 1989). According to Steury et al. (2010), KDE has become the most popular method because it is able to estimate multiple activity centers and is nonparametric. Nonparametric techniques are based on density and have no assumption on the shape of the home range (Selkirk and Bishop, 2002).

There are some doubts on the reliability of KDE because of the large influence that the smoothing factor has on the accuracy of the estimation (Hemson et al., 2005; Stuery et al., 2010; Downs et al., 2012). Low smoothing factor, or bandwidth, values give the greatest influence to nearby tracking point locations, while wider bandwidths will allow distant points to have more influence on the estimation (Seaman and Powell, 1996; Blouin-Demers, 2006). The lack of a standard KDE smoothing factor makes it difficult to compare studies (Pebsworth et al., 2012), and an inappropriate smoothing factor can lead to an inaccurate estimation of the size and shape of the home range (Hemson et al., 2005). The smoothing factor choice depends on the intended use of the home range estimation (Worton, 1989). The influence of the smoothing factor makes KDE an inconsistent estimator of home range sizes, and should rather be used as a probabilistic model of an animal's use of space (Blouin-Demers, 2006).

Characteristic Hull Polygon

Due to the inaccuracies associated with MCP and KDE, a number of alternative home range estimation methods have been proposed, including a convex hull peeling-based method (Worton,

1995) and the characteristic hull polygon (CHP) (Downs and Horner, 2009). The CHP is constructed by removing a certain percentage of the largest triangles in terms of perimeter from a Delauney Triangulation created from a set of animal tracking points (Downs and Horner, 2009; Olsen et al., 2011). Unlike MCP, CHP estimation can have a concave boundary and unused space within the boundary with the hope of eliminating area that the animal does not use (Downs and Horner, 2009).

Map Projections

A map projection is a system of transforming the Earth's spherical points to a flat plane (Olson, 2006). Transforming 3-dimensional, spherical data onto a 2-dimensional plane will result in distortion of some aspect of the map (Battersby, 2009). All projections will distort area, shape, distance and angle (Laskowski, 1997; Battersby and Kessler, 2012). Distortion is unavoidable, especially at a global scale (Battersby, 2009), but can minimized for the specific purpose of a map (Laskowski, 1997). With the large number of map projections available, it can be difficult for cartographers to assess the amount of distortion in a projection and select the appropriate projection for a certain purpose (Battersby and Kessler, 2012; Robinson, 1951).

Projection Methods

There is no 2-dimensional map that is free of distortion, but the amount and type of distortion will vary depending on the method used for projection (Robinson, 1951). There are four main categories of projection: equal-area, conformal, equidistant, and compromise (Battersby, 2009; Olson, 2006). Equal-area, or equivalent, projections will preserve area, but will significantly distort the shape of landmasses (Olson, 2006). Conformal projections preserve angle and direction, while equidistant projections preserve distances between points on the map (Brainerd and Pang, 2001).

Compromise projections preserve neither area nor angle, but attempt to minimize distortion in multiple aspects (Battersby, 2009). A projection cannot preserve both area and angle at the same time (Olson, 2006).

Within these four categories of projection, there are many methods for projecting coordinates including cylindrical, conic, pseudoconic, and azimuthal projections (Tobler, 1962; Yildirim and Kaya, 2008). A cylindrical projection is produced when Earth's coordinates are projected onto the surface of a cylinder (Brainerd and Pang, 2001). Conic projections are created by projecting real-world coordinates onto a cone-shaped flat surface (Brainerd and Pang, 2001). The most widely used conic projections are the Albers equal area and Lambert's conformal projections (Tobler, 1962). Tobler (1962) characterizes pseudoconic projections as having "curved meridians and concentric circular arcs as parallels." Azimuthal projections are constructed using a centrally located point and typically preserve distances, but can also be equal area depending on the spacing of parallels (Tobler, 1962). There are an unlimited number of possible projections, and each may be well suited for a specific function (Tobler, 1962; Robinson, 1951).

Evaluating a Map Projection

According to Usery and Seong (2001), the decision of which projection to use can be difficult due to the large number of projections available and a lack of information on the best application for each projection. This decision has long been a problem for cartographers (Robinson, 1951), and it is difficult for even experts to evaluate and measure the distortion in a projection (Battersby and Kessler, 2012). Laskowski (1997) states that simply recognizing that distortion exists is not helpful when making precise measurements and it would be helpful if there were a way to measure the distortion associated with a projection. Laskowski (1997) calls this procedure of measuring distortion the "distortion measure," and proposes that a different measure is needed for each type of distortion. There are many methods to represent and visualize how a map is distorted

(Tobler, 1962; Laskowski, 1997; Battersby, 2009), such as Tissot's Indicatrix, but it can be difficult to calculate the magnitude of distortion (Robinson, 1951; Brainerd and Pang, 2001).

It can be especially difficult to evaluate the suitability of world map projections (Robinson, 1951; Jenny et al., 2010). Jenny et al. (2010) state that cartographers see equal area as the most important aspect of a projection, although there is not an agreement on which method creates the best equal area world projection. Usery and Seong (2001) found that distortion has a large impact on data due to the large areas associated with world projections. There is a large number of projections in use today, so even if you know you need an equal area world projection and eliminate the other options, there are still a sizeable selection of projections to choose from (Brainerd and Pang, 2001; Robinson, 1951). Researchers need to be able to evaluate projections in order to choose the one that meets the needs of a certain project because the projection will impact results and influence policy decisions (Olson, 2006; Battersby, 2009).

Projected Coordinate Systems in GIS

In a geographic information system (GIS), calculations such as distance and area are made based on coordinates (Yildirim and Kaya, 2008). Some surveys will collect spatial data using local, assumed coordinates (Khalil, 2013), or geographic coordinates that have not been projected (Yildirim and Kaya, 2008). There is not a tool in GIS to make area calculations based on ellipsoidal geographic coordinates, so before measurements such as distance and area can be made the coordinates must be converted into a projected coordinate system (PCS) (Khalil, 2013; Yildirim and Kaya, 2008). Yildirim and Kaya (2008) state that the accuracy of data analysis conducted in GIS will be highly influenced by the projection that is chosen. According to Usery and Seong (2001), more research is needed on how a projection influences the accuracy of spatial data in GIS. Calculations in GIS will have errors based on the type of distortion associated with the projection (Yildirim and

Kaya, 2008), so the decision on which PCS to use should be based on the data analysis objectives (Olson, 2006).

CHAPTER 3:

RESEARCH OBJECTIVES

The purpose of this study is to quantify and compare the amount of map distortion in the area of animal home range estimations when projected into a number of projected coordinate systems available in GIS. A map projection that minimizes area distortion should be used when making calculations in which area information is important, such as home range estimations. Accurate home range estimations are critical to analyzing the resource needs of a species and developing conservation strategies. Choosing the most appropriate projected coordinate system for a specific study area can be difficult because different methods of projection will distort the data in different ways. Therefore, it would be useful to quantify and compare the amount of area distortion in different projected coordinate systems in order to help researchers in selecting a PCS for analysis.

Home range analysis of species that have large home ranges might require a world projection rather than a projection that minimizes distortion for a specific area. World projections are also useful for comparing studies from different regions, such as the home range estimation of migratory birds that travel between North and South America. Different projection methods will likely distort data differently based on the latitude and geographic region of the study area. Also, the results of studies are most directly comparable when projected into the same coordinate system. For these reasons, it would be beneficial to examine the difference in area distortion between different types of world projections and how area distortion differs for a PCS when used in various geographic regions.

The research objectives of this study include:

1. Calculate and compare the amount of area distortion in animal home ranges when projected into several different projected coordinate systems.

2. Determine how the level of area distortion for a PCS differs based on the geographic region of the study area.

3. Examine the distortion difference between various types of world projections that use different projection methods.

CHAPTER 4:

ANIMAL TRACKING DATA

The analysis in this study was performed using the tracking point data of four species: Florida panther (*Puma concolor coryi*), waved albatross (*Phoebastria irrorata*), long-tailed duck (*Clangula hyemalis*), and the oilbird (*Steatornis caripensis*). These four species were chosen because they have varying home range sizes and are found in different regions of North and South America. The waved albatross, long-tailed duck, and oilbird datasets were obtained from the Movebank Data Repository.

The Florida panther data was collected in southern Florida between the years 1981 to 2001 to study the dispersal and habitat preference of the endangered population (Meegan and Maehr, 2002). Tracking points for 108 individual panthers were obtained using radio telemetry by the Florida Fish and Wildlife Conservation Commission and National Park Service (Meegan and Maehr, 2002). The Florida panther is a highly endangered species, making panther habitat conservation an important issue in Florida (Cramer and Portier, 2001; Benson et al., 2011).

The waved albatross dataset tracks the movements of 28 individuals as they travel from the Galapagos Islands to the coast of Peru in South America to forage for food (Cruz et al., 2013; Dodge et al., 2013). Data was collected in 2008 using GPS tracking devices. The waved albatross is classified as critically endangered, so protecting foraging and breeding areas is crucial to conservation (Awkerman et al., 2014).

The long-tailed duck data was collected in the Yukon-Kuskokswim Delta of western Alaska. The long-tailed duck is a declining in population in Alaska, which is thought to be the result of environmental problems in their molting area (Petersen et al., 2003). The survey combined radio and satellite transmitters to identify the preferred habitat for molting (Petersen et al., 2003). Data was available for 14 female ducks between the years 1998-2000.

The oilbird tracking data was collected in northeastern Venezuela using GPS/acceleration loggers (Holland et al., 2012). Oilbirds were once thought to spend the majority of their lives in caves and only leave at night to find fruit (Holland et al., 2009). This study found that oilbirds only spend one out of every three days in a cave and are significant seed dispersers in the forests of this region (Holland et al., 2009). Tracking data was collected for 40 birds from 2007-2009.

The Florida panther, long-tailed duck, and oilbird datasets are located in the Northern Hemisphere, while the waved albatross dataset is located in the Southern Hemisphere. The long-tailed duck data was collected the farthest north of the four datasets and the waved albatross is located the farthest south. The oilbird and waved albatross data are positioned nearest to the Equator. Figure 1 shows the locations of the tracking points for each of the four datasets within North and South America. A number of long-tailed duck tracking points are located outside of North America and are not included in this map (Figure 1).

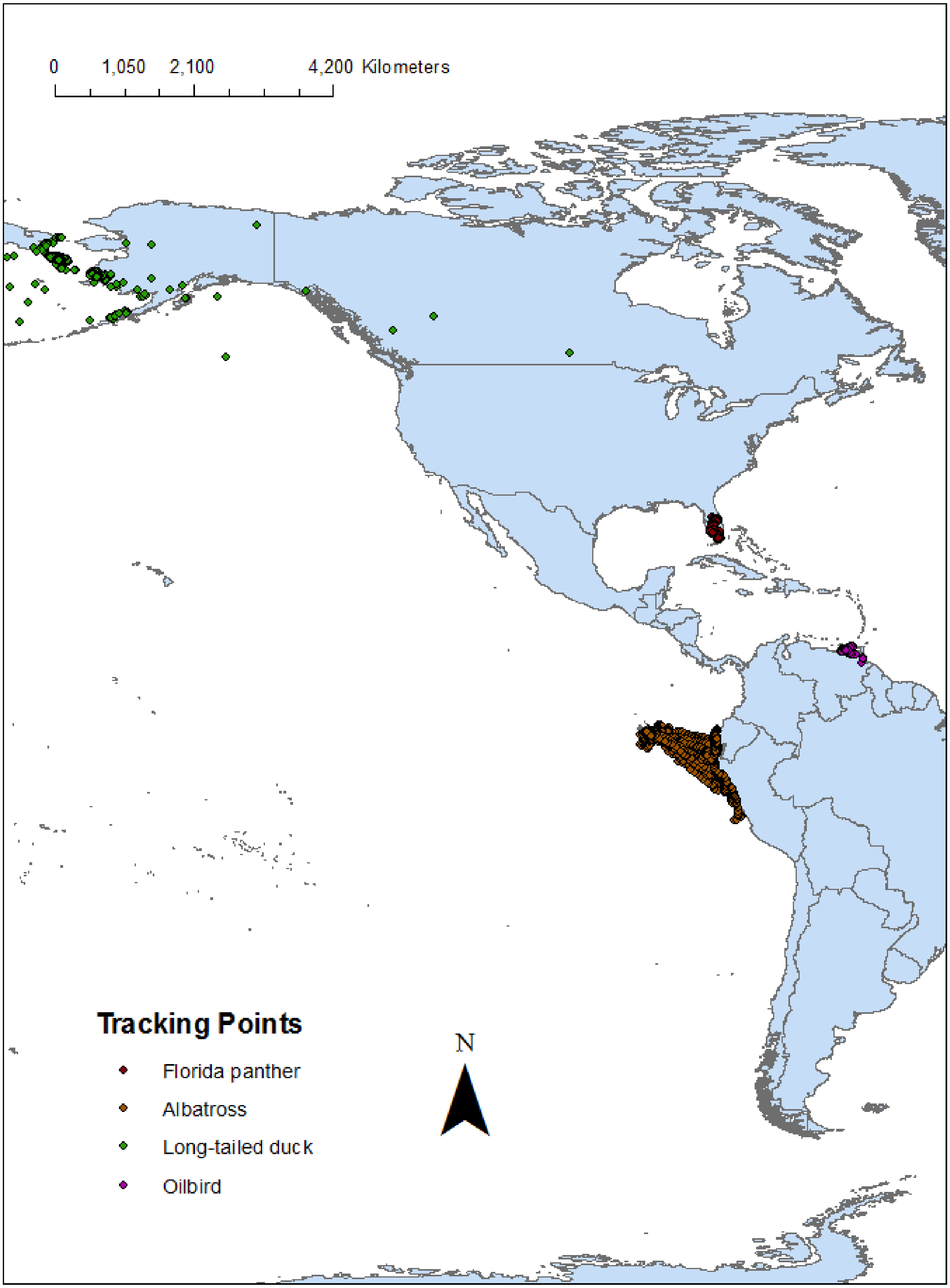

Figure 1. Animal Tracking Point Locations.

CHAPTER 5:

METHODS

The research objectives in this study are accomplished by comparing the area of home range estimations when projected into different projected coordinate systems. The home ranges of all individuals from each of the four species datasets were estimated and then projected into eight different projected coordinate systems. For every individual animal, the area from each PCS was calculated and used to measure and compare the amount of distortion associated with each projection method. Analysis of the datasets was conducted using ArcGIS 10.1.

GIS Analysis

The home range for each individual animal is calculated using the Characteristic Hull Polygon method for home range estimation. The CHP method was chosen for analysis due to the weaknesses associated with MCP and KDE estimations. CHP provides useful home range estimations by eliminating area not utilized by the animal. A custom ArcGIS tool was used to calculate the CHP of all individuals in a dataset at once. The tool removed a few of the individuals with the lowest number of tracking points from the Florida panther, waved albatross, and oilbird datasets. The individual home ranges were then projected into eight different projected coordinate systems. The area of each home range was then calculated for comparison. Statistics on the tracking data, including the number of individuals, the number of tracking points, and tracking duration, for each of the four species are summarized in Table 1.

Table 1. Species Datasets Statistics.

Species	n	Min. Points	Max. Points	Mean Points	Min. Duration	Max. Duration	Mean Duration
Florida panther	105	7	2872	489.85	1 year	16 years	3.90 years
Waved albatross	17	58	2339	884.35	4 days	147 days	57.53 days
Long-tailed duck	14	19	172	102.64	109 days	537 days	199.07 days
Oilbird	32	11	264	106.5	1 day	168 days	85.00 days

Projected Coordinate Systems

The first projection selected for analysis is a continental Albers equal area PCS that is specific to the continent or region where the animal tracking data was collected. The continental Albers equal area PCS will minimize distortion for the specific study area and is the most localized equal area projection available for this study. A more specialized PCS, such as Florida Geographic Data Library's (FGDL) Albers projection for Florida, could be obtained from outside sources or customized within ArcGIS using specific coordinates, but only projections that come standard with ArcGIS 10.1 are used in this study. A specialized PCS could provide a more accurate area calculation for certain regions, but were not available for each of the animal tracking study areas. For this reason, the continental equal area PCS available in ArcGIS was used in order to remain consistent between the datasets.

The next projection used for analysis in this study is a conformal projection specific to each species' study area. The third PCS is a Universal Transverse Mercator (UTM) Zone specific to the study region for each species. UTM Zone projections are not equal area, but are specialized for specific regions and often used in GIS analysis. The long-tailed duck dataset crosses multiple UTM zones, so the zone that contained the majority of the tracking points was chosen for analysis. The waved albatross tracking points are located in three UTM zones, so the center zone was chosen. The final five projections are world projections and are used for the analysis of each of the species datasets. The "World" versions of these five projections were selected for analysis, as opposed to the "sphere" versions that can also be found in ArcGIS. The five world projections include each type of the main projection methods, including a conformal projection, two equal-area projections, an equidistant projection, and a compromise projection. The Bonne projection, a pseudoconical projection, and the cylindrical projection were chosen in order to compare two different methods for preserving equal area in a world PCS. The Mercator projection and certain other types of non-equal area projections have become widely used in Google Maps and other online mapping applications (Battersby, 2009). Table 2 lists the projections that are utilized in this study. The table shows the projection type and the specific PCS that are used to analyze each of the animal datasets. The continental equal area, continental conformal, and UTM projections are different for each dataset, but the five world projections remain the same for all datasets.

Distortion Measurement

Once the area of each home range was calculated, the results were then compared to measure the amount of distortion in each PCS. A distortion measurement ratio is created for each individual home range by dividing the areas calculated in each PCS by the area from the continental Albers projection. The continental Albers PCS will not be free of distortion, but is the most localized equal-area projection available for this study and was used to obtain a baseline area calculation for each home range. The mean home range area differs greatly between the four species, so the ratio calculated in this analysis is useful as a standardized measurement for comparing the level of distortion of each projection across each of the datasets. The seven projections can then be compared based on which has the least amount of distortion, or which is the least different from the continental Albers PCS. A magnitude of distortion was also calculated for each home range by subtracting the continental Albers area from the area of each of the other projections, showing the difference between each projection and the baseline projection in terms of area. This magnitude serves as another measurement of distortion and shows the amount change in home range area between the different types of projections. Conclusions regarding the research objectives are made based on this distortion comparison and how the distortion associated with each PCS changes between the species datasets and study regions.

Table 2. Projected Coordinate Systems.

Projection Type	Florida panther	Waved albatross	Long-tailed duck	Oilbird
Continental Equal Area	North America Albers Equal Area Conic	South America Albers Equal Area Conic	Alaska Albers Equal Area Conic	South America Albers Equal Area Conic
Continental Conformal	North America Lambert Conformal Conic	South America Lambert Conformal Conic	North America Lambert Conformal Conic	South America Lambert Conformal Conic
UTM	WGS 1984 UTM Zone 17N	WGS 1984 UTM Zone 17S	WGS 1984 UTM Zone 3N	WGS 1984 UTM Zone 20N
World—Conformal	Mercator	Mercator	Mercator	Mercator
World—Equal area	Cylindrical Equal Area	Cylindrical Equal Area	Cylindrical Equal Area	Cylindrical Equal Area
World—Equal Area	Bonne	Bonne	Bonne	Bonne
World—Compromise	Robinson	Robinson	Robinson	Robinson
World—Equidistant	Azimuthal Equidistant	Azimuthal Equidistant	Azimuthal Equidistant	Azimuthal Equidistant

CHAPTER 6:

RESULTS

Visual comparison of home ranges when projected into the eight coordinate systems shows that different projection methods result in different home range shapes and sizes (Figure 2). The statistical results of analysis are reported in Tables 3-6. Included in the table for each species dataset are the minimum, maximum, and mean home range area, magnitude of difference, and distortion measurement ratio calculations for each PCS. There are two ways of evaluating these home range analysis results that are relevant to the research objectives to this study. First, in order to compare the amount of distortion associated with each PCS, it will be necessary to compare the ratio calculations within the individual species datasets. Second, each PCS will be compared individually across each of the datasets in order to determine how the area distortion of that projection changes between the four study regions.

The continental Albers Equal Area Conic projection serves as the baseline home range area for the distortion ratio and magnitude calculations. Using the North America Albers PCS for analysis, the Florida panther dataset has a minimum home range area of 5.240 km^2, a maximum of 4019.586 km^2, with an average home range of 412.092 km^2. The South America Albers projection was used as the baseline calculation for the waved albatross, and oilbird datasets. The minimum home range area for the waved albatross is 1.530 km^2, the maximum is 167,946.405 km^2, and the mean area is 40,009.446 km^2. For the oilbird dataset, the minimum is 0.705 km^2, the maximum is 3,377.531 km^2, and the mean home range area is 603.259 km^2. The Alaska Albers projection was used as the baseline calculation for the long-tailed duck data and resulted in a minimum home range area of 137.678 km^2, a maximum of 892,807.206 km^2, with a mean of 115,430.707 km^2.

When evaluating individual species datasets in terms of mean distortion ratio, the highest ratio for the Florida panther is the Azimuthal Equidistant at 1.4491 and the lowest was the Robinson at 0.8830. The Cylindrical Equal Area and Bonne were the closest to the baseline Albers calculation with mean ratios of 1.0 for the Florida panther home ranges. For the waved albatross, the highest mean ratio was the Azimuthal Equidistant at 1.4900 and the lowest was the Robinson at 0.8202. The Cylindrical Equal Area and Bonne were again the closest to baseline calculation with ratios of 1.0 and 1.0001, respectively. For the long-tailed duck, the mean ratio for every PCS was greater than 1.0 with the Mercator as the highest at 4.4715 and the UTM as lowest and closest to the baseline calculation at 1.0001. For the oilbird home ranges, the South America Lambert Conformal Conic has the highest mean ratio at 1.2688 and the Robinson has the lowest at 0.8202. The Cylindrical Equal Area at 1.0 and the Bonne at 0.9999 gave the calculations closest to the Albers calculation for the oilbird dataset. The minimum and maximum ratios show that some of the projections have a wide variation in ratios within a dataset. Some of the projections gave area calculations that were both above and below the baseline area for different individual home ranges within the same dataset. For instance, the WGS 1984 UTM Zone 3N has a minimum ratio of 0.9654 and maximum ratio of 1.0267 in the long-tailed duck dataset.

Next, the mean distortion ratio for an individual PCS is compared across each of the four species datasets. The highest mean ratio for the continental Lambert Conformal projection was for the oilbird data at 1.2688. The lowest mean ratio was 0.9405 for the Florida panther home ranges, the only dataset in which the Lambert has a mean ratio less than 1.0. The continental Lambert Conformal was the closest to the baseline Albers calculation for the long-tailed duck and waved albatross with mean ratios of 1.0292 and 1.0269, respectively. The UTM projection has the highest mean ratio for the waved albatross at 1.0083 and the lowest for the oilbird and Florida panther with both having a mean ratio of 0.9992. The UTM was the closest to the baseline calculation for the long-tailed duck dataset at 1.0001. The Mercator projection is has the highest mean ratio for the long-tailed duck at 4.4715. The Mercator has the lowest mean ratio and is the closest to the baseline calculation for the waved albatross dataset at 1.0043. The Cylindrical Equal Area has a mean ratio of 1.0 for all datasets except the long-tailed duck with a ratio of 1.0163. The Bonne projection has the highest mean ratio for the long-tailed duck at 1.0048, while the mean ratios for the other three datasets range from 0.9999 to 1.0001. The Robinson projection has the highest mean ratio for the long-tailed duck at 1.2296. The other three species datasets have mean ratios of 0.8830 and below for the Robinson projection. The Azimuthal Equidistant projection has the highest mean ratio for the long-tailed duck dataset at 2.2849 and the lowest for the oilbird at 1.2422.

The magnitude of distortion statistic reported in Tables 3-6 represents how these distortion measurement ratios translate into actual home range area differences in terms of km^2, where ratios less than 1.0 have negative magnitudes and ratios greater than 1.0 have positive magnitudes. For each projection, the magnitude shows how much greater or less than an area calculation is compared to the area from the continental Albers projection. Ratios translate differently into magnitude for each dataset due to differences in home range size. For instance, a mean ratio of 1.2390 for the Mercator projection translates into a distortion magnitude of 99.403 km^2 in the Florida panther dataset, whereas in the long-tailed duck dataset, a mean ratio of 1.2296 for the Robinson projection translates into a magnitude of 28,499.451 km^2.

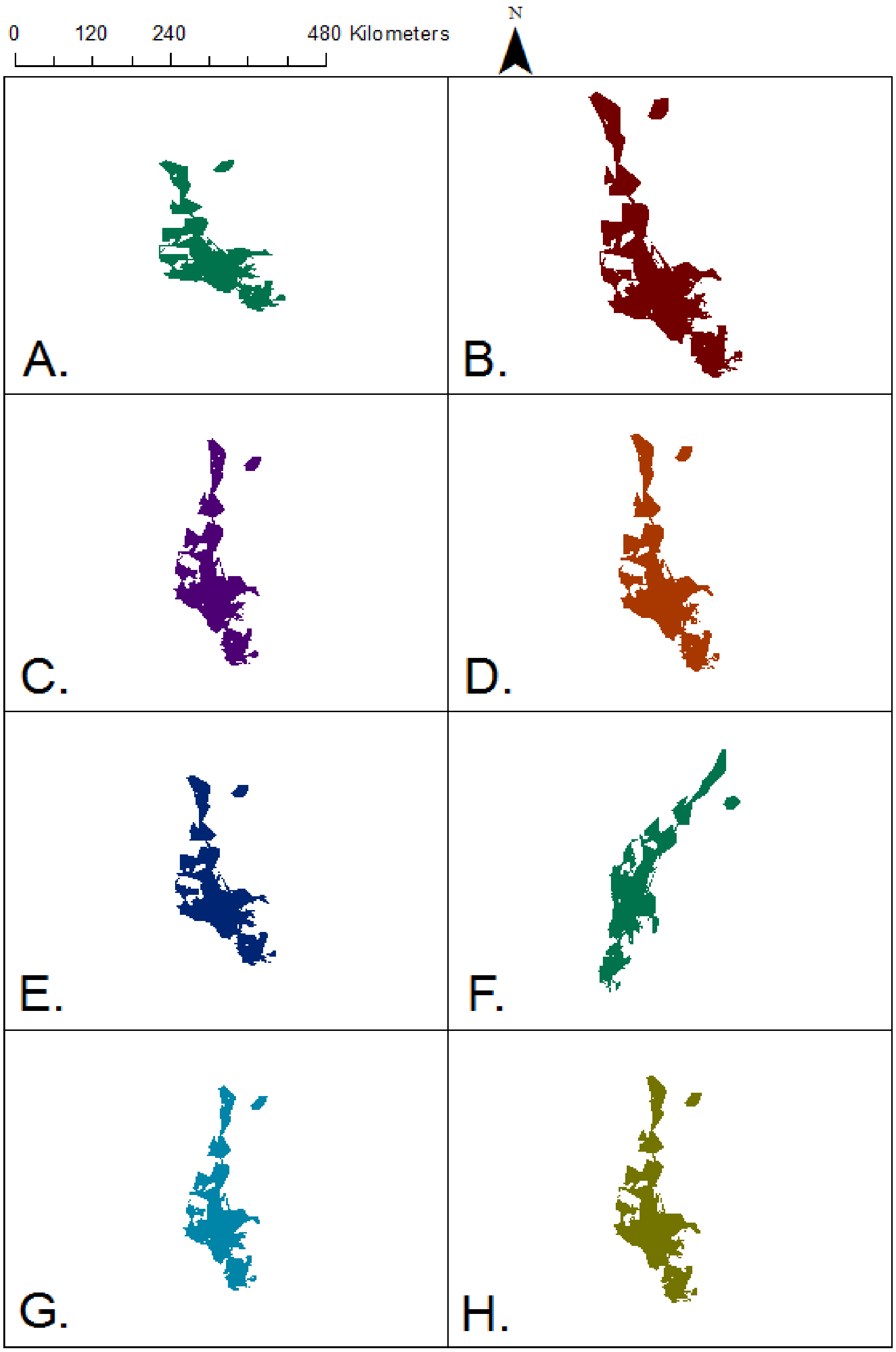

Figure 2. Florida Panther Home Range Estimations.*

**A. North America Albers Equal Area Conic, B. South America Lambert Conformal Conic, C. WGS 1984 UTM Zone 17N, D. Mercator, E. Cylindrical Equal Area, F. Bonne, G. Robinson, H. Azimuthal Equidistant.*

Table 3. Florida Panther Home Range Analysis Results.

Florida panther												
Projection	Area (km^2)				Magnitude (km^2)				Ratio			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
North America Albers Equal Area Conic	5.240	4019.586	412.092	527.089	0.000	0.000	0.000	0.000	1.0000	1.0000	1.0000	1.0000
North America Lambert Conformal Conic	4.924	3743.464	387.296	493.091	-276.122	-0.316	-24.796	34.131	0.9313	0.9467	0.9405	0.0025
WGS 1984 UTM Zone 17N	5.236	4016.545	411.767	526.686	-3.041	-0.004	-0.324	0.405	0.9984	0.9993	0.9992	0.0001
Mercator	6.505	5090.516	511.494	661.038	1.264	1070.930	99.403	134.160	1.2232	1.2664	1.2390	0.0067
Cylindrical Equal Area	5.240	4019.607	412.077	527.096	-1.346	0.200	-0.015	0.137	0.9972	1.0001	1.0000	0.0003
Bonne	5.241	4019.721	412.099	527.084	-0.442	1.304	0.008	0.139	0.9994	1.0027	1.0000	0.0003
Robinson	4.630	3576.061	364.096	467.352	-443.525	-0.610	-47.996	59.777	0.8791	0.8897	0.8830	0.0016
Azimuthal Equidistant	7.608	5839.460	597.123	764.675	2.368	1819.874	185.031	237.592	1.4401	1.4538	1.4491	0.0032

Table 4. Waved Albatross Home Range Analysis Results.

Waved albatross												
	Area (km^2)				Magnitude (km^2)				Ratio			
Projection	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
South America Albers Equal Area Conic	1.530	167946.405	40009.446	49802.311	0.000	0.000	0.000	0.000	1.0000	1.0000	1.0000	1.0000
South America Lambert Conformal Conic	1.599	169013.520	40605.034	50463.530	0.069	3583.055	595.588	964.621	1.0047	1.0496	1.0269	0.0169
WGS 1984 UTM Zone 17S	1.565	168921.528	40323.017	50165.753	-2.082	1266.552	313.570	417.324	0.9992	1.0247	1.0083	0.0088
Mercator	1.530	169548.319	40280.338	50172.660	0.001	1601.914	270.892	415.083	1.0003	1.0097	1.0043	0.0037
Cylindrical Equal Area	1.530	167939.493	40008.605	49800.266	-15.136	5.411	-0.841	4.967	0.9998	1.0002	1.0000	0.0001
Bonne	1.530	167910.493	40008.049	49795.271	-56.850	36.875	-1.398	20.565	0.9994	1.0009	1.0001	0.0003
Robinson	1.253	137980.363	32842.510	40889.246	-29966.042	-0.276	-7166.936	8913.229	0.8191	0.8216	0.8202	0.0010
Azimuthal Equidistant	2.404	248709.620	59693.649	74257.779	0.875	80763.215	19684.203	24473.224	1.4331	1.5771	1.4900	0.0497

Table 5. Long-tailed Duck Home Range Analysis Results.

Long-tailed duck												
Projection	Area (km^2)				Magnitude (km^2)				Ratio			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
Alaska Albers Equal Area Conic	137.678	892807.206	115430.707	246373.094	0.000	0.000	0.000	0.000	1.0000	1.0000	1.0000	1.0000
North America Lambert Conformal Conic	140.577	890209.599	115887.119	245721.455	-4756.377	5797.913	456.412	2412.421	0.9815	1.0898	1.0292	0.0301
WGS 1984 UTM Zone 3N	137.571	861908.229	113523.924	239115.173	-30898.976	3415.734	-1906.783	8394.640	0.9654	1.0267	1.0001	0.0125
Mercator	596.285	3413853.112	460275.036	946741.497	458.607	2521045.907	344844.330	700694.602	3.6787	5.5687	4.4715	0.5325
Cylindrical Equal Area	137.677	1018864.670	126220.992	278741.549	-1878.701	126057.464	10790.285	33861.255	0.9806	1.1412	1.0163	0.0435
Bonne	137.682	916094.850	116849.513	251915.315	-8122.753	23287.645	1418.806	6759.228	0.9683	1.0261	1.0048	0.0132
Robinson	166.259	1138005.231	143930.158	312173.919	28.581	245198.025	28499.451	66333.805	1.1338	1.3187	1.2296	0.0465
Azimuthal Equidistant	318.109	1938822.207	258549.492	540533.049	180.430	1046015.002	143118.785	294410.078	2.1716	2.4082	2.2849	0.0693

Table 6. Oilbird Home Range Analysis Results.

Oilbird												
	Area (km^2)				Magnitude (km^2)				Ratio			
Projection	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
South America Albers Equal Area Conic	0.705	3377.531	603.259	764.143	0.000	0.000	0.000	0.000	1.0000	1.0000	1.0000	1.0000
South America Lambert Conformal Conic	0.889	4290.047	765.509	969.618	0.184	912.516	162.516	205.486	1.2609	1.2747	1.2688	0.0026
WGS 1984 UTM Zone 20N	0.704	3375.626	602.674	763.403	-3.923	0.257	-0.585	0.937	0.9970	1.0020	0.9992	0.0007
Mercator	0.726	3486.743	622.413	788.393	0.021	109.212	19.154	24.265	1.0297	1.0340	1.0318	0.0009
Cylindrical Equal Area	0.705	3377.960	603.158	764.015	-2.176	0.429	-0.101	0.438	0.9983	1.0019	1.0000	0.0005
Bonne	0.705	3379.253	603.050	763.984	-5.267	1.722	-0.209	1.046	0.9960	1.0037	0.9999	0.0010
Robinson	0.583	2796.827	499.366	632.583	-580.703	-0.122	-103.893	131.561	0.8264	0.8295	0.8278	0.0004
Azimuthal Equidistant	0.873	4199.088	749.107	949.210	0.168	821.557	145.848	185.070	1.2382	1.2475	1.2422	0.0019

CHAPTER 7:

DISCUSSION

Results of this study show that the projected coordinate system chosen for analysis can have a large influence on data analysis in a GIS. It is well known that the projection can have an impact on results, but the distortion measurement ratio and magnitude calculations in this study provide a measurement of the quantity of this impact. The ratio calculated in this study provided a simplified distortion measurement that allows for easier comparison of the differences in home range area. The magnitude of distortion calculation is useful for showing how this distortion measurement ratio translates into area and for measuring the amount of area distortion in an individual home range estimation. Animals with larger home ranges will have larger magnitude calculations than those with smaller home range area, making it difficult to compare the amount of distortion based exclusively on differences in area. The distortion measurement ratio addresses this problem by creating a proportion that allows for the comparison of the amount of area distortion associated with different projections and across different datasets. For this reason, the ratio was especially useful when comparing the amount of distortion associated with a particular PCS across the four species datasets of varying home range sizes. Comparison of ratios between and within datasets shows that the projection method has a large influence on home range estimation and that the geographic location of the study area can influence the amount of distortion associated with a projection.

Comparison of ratios within a single dataset shows that home range areas can differ greatly depending on the PCS chosen for analysis. This home range size variation within a dataset can be attributed to differences in projection method. Variation in ratio for a single PCS within the same species dataset, as evidenced by the minimum and maximum ratios, could be due to the geographic distribution and size differences of home ranges within the same dataset. This type of variation is more significant in the long-tailed duck dataset that has the largest home range areas that span across a large distance and can be far away from each other. Wide variation between the projection methods is found within each dataset and shows the importance of choosing an equal area projection when studying animal home range areas.

When examining a particular PCS across the four datasets, change in the distortion measurement ratio can be attributed to change in geographic location. A PCS can be shown to preserve area more accurately at certain locations by comparing ratios from the different datasets. The continental Lambert projection has mean ratios above 1.0 for three of the datasets, but a mean ratio of 0.9405 for the Florida panther home ranges. This shows that the Lambert continental projection tends to give high area calculations, with the exception of the North America Lambert Conformal Conic results in Florida. The UTM projection has a mean magnitude of distortion close to 0 km^2 for all datasets except the waved albatross and long-tailed duck, the two datasets that have the largest mean home range areas and cross multiple UTM zones. However, the mean ratios of the UTM projection for these two datasets are still reasonably close to 1.0, showing how the distortion measurement ratio translates into differences in actual home range area differently for each dataset. UTM Zone mean ratios are generally closer to 1.0 than the ratios for the other non-equal area projections, likely due to the fact that the UTM minimizes distortion for a specific region. The Mercator projection has the highest mean ratio for the dataset nearest the pole with a ratio of 4.4715 for the long-tailed duck, but has lower ratios that are closer to 1.0 for the oilbird, albatross, and Florida panther home ranges that are nearer to the Equator. The Robinson projection resulted in mean ratios of 0.8830 and below for the three datasets closest to the Equator and a mean ratio above 1.0 for the long-tailed duck dataset, which is closest to the pole. This evidence suggests that the Mercator and Robinson projections distort area in a way in which far northern landmasses are larger than reality and landmasses become much smaller nearer to the Equator. The Azimuthal Equidistant projection resulted in mean ratios of 1.2422 and above for all four datasets, which is evidence that this PCS has a tendency to give high area calculations in all locations. These changes in distortion level at different geographic locations are likely due to the methods of projection. A projection can be more accurate for certain areas depending upon how the coordinates are projected from a sphere to a flat surface. Distortion change at different locations is more pronounced for the non-equal area projections in this study because it is not possible for a PCS to preserve all aspects of a map, including area, shape, direction, and distance, at the same time.

A world projection may be required for analysis depending on the scale of a specific study. The five world projections chosen for this study are the most comparable because they were used in the analysis of all four datasets. The UTM Zone and continental conformal projections are different depending on the study area and have different coordinate system axes, so tendencies for these projections are less conclusive. A number of different scales were chosen for analysis because choosing an appropriate PCS depends on the needs of the research as well as the scale of the study. The results of this study show that the mean ratios associated with the Mercator, Robinson, and Azimuthal Equidistant projections differ greatly depending on the geographic location of the dataset. Analysis of a dataset with a large study area or datasets from multiple locations will be significantly impacted if the PCS used for analysis varies greatly in the amount of distortion from location to location. As the two equal-area world projections, the Cylindrical Equal Area and Bonne projections were the most accurate for calculating home range area. The Cylindrical Equal Area PCS has a mean ratio of 1.0163 for the long-tailed duck and a ratio of 1.0 for the other three datasets. The Bonne projection has mean ratios ranging from 0.9999 to 1.0048. The Bonne and Cylindrical

Equal Area projection both have mean ratios farthest from 1.0 for the long-tailed duck dataset, which could be a result of the long-tailed duck having the largest mean home range area and being located the farthest north of the four datasets. Visual comparison of these two projections (Figure 2) shows that the shape and orientation of home range estimations are different despite both being equal area world projections. This difference in shape illustrates how these projection methods can both preserve area in different ways. Since these two equal area world projections mostly remain consistent in preserving area for all four datasets, this is evidence that they could be used with confidence in animal home range studies located in North and South America.

CHAPTER 8:

CONCLUSION

This research evaluated the area distortion of projections from each of the four major types of projection methods—equal area, conformal, equidistant, and compromise—at various scales, from UTM zone to continental and global. Different methods of projection result in data being distorted in different ways. The ratio calculated in this study allowed for that distortion to be quantified and compared, including a comparison of the distortion associated with each type of projection method and how the amount of distortion changes for a projection based on geographic location. The research objectives were accomplished using this distortion comparison. In addressing these research objectives, this study found that: (1) The area calculation of an individual animal home range can vary greatly depending on the PCS chosen for analysis, (2) the amount of area distortion associated with a particular PCS can fluctuate based on the geographic region of the study area, and (3) equal-area projections can give accurate home range area calculations across large distances, while other types of projection methods do not remain consistent in the amount of distortion across different regions.

Implications

These findings show how the choice of map projection can have a large influence on data analysis and illustrate the importance of using an appropriate PCS for the needs of a given study. All map projections inevitably have distortion that can impact how we perceive the world (Battersby, 2009). For example, the widespread use of non-equal area projections in popular online mapping programs can influence the user's understanding of the presented spatial data and view of the world (Battersby, 2009). The influence of the map projection is not something that is widely thought about, so a researcher or user of spatial information may be unaware of what PCS is being used to project data. During analysis and when presenting spatial data, researchers should record and report the projection used in order to bring greater awareness to possible influences on data. Distorted perceptions can influence decision-making, so it is important to recognize how a map projection might be influencing the analysis and interpretation of spatial data.

Conservation planning is one field where it is necessary to recognize how animal home range estimations might be affected by the projected coordinate system chosen for analysis. Having accurate home range estimations is vital for critically endangered species, such as the waved albatross and Florida panther, due to the large-scale conservation efforts to protect these species. A study by Main et al. (1999) found that the mean price for public lands purchased for Florida panther conservation was $1291 per hectare, and the mean value of panther habitat on privately owned land was between $4744 and $7401 per hectare due to the agricultural and residential development potential of the land. In rapidly growing and developing southern Florida, the high cost of land acquisition and habitat maintenance puts importance on having accurate area calculations (Main et al., 1999). Even small variations in area calculations due to map distortion can result in a difference that may not be large, but turns out to have significance in terms of monetary value. In this study, the minimum ratio for the UTM projection in the Florida panther is 0.9984, which translates into a difference of 3.041 km^2 between two commonly used projection types. This slight variation can potentially influence resource planning and land acquisition decisions. Results of this study show that the PCS chosen for analysis can distort the size and shape of spatial data. This type of distortion can also potentially impact land acquisition by shifting the boundaries between public land and private property. This research demonstrates how miscalculations in data analysis due to map distortion could lead to errors in significant conservation planning decisions, such as identifying and purchasing critical panther habitat in southern Florida or protecting enough resources to maintain waved albatross feeding grounds in Peru.

This study shows the importance of choosing a projected coordinate system that meets the needs of analysis, which in this case is to give accurate animal home range area calculations. The scale of the research is another factor that affects the decision of which PCS to use for analysis. The results of this study establish that the non-equal area projections do not have the same amount of area distortion in all geographic regions, illustrating the need to recognize how the scale of a study may influence data analysis. Distortion change may be negligible at smaller scales and more profound at larger scales as datasets cover greater distances (Battersby, 2009). The results also suggest that the two equal-area world projections, the Bonne and Cylindrical Equal Area, remain consistent in preserving area for the regions in this study with the exception of the long-tailed duck, which is the dataset with the largest mean home range area and located the farthest north. Knowing that these projections will give accurate area calculations for North and South America could be valuable for the home range analysis of species that travel between the two continents or combining and comparing datasets from different regions.

When choosing a PCS for analysis, researchers should evaluate the objectives, scale, and geographic location of the research. The objectives, or what information is being pursued by the research, would determine the type of projection required. A study evaluating animal home range area would require an equal area projection, while other types of studies might require a conformal or equidistant projection. The scale of the study determines when it would be appropriate to use a world, continental, or a more localized PCS, such as a State Plane coordinate system or UTM zone. Datasets that cover large distances might cross UTM zones or continents and require a larger scale continental or world projection. A world projection would be necessary for the home range analysis of migrating birds and marine animals that are not limited to one continent. The geographic location of the study area is another factor that must be considered when choosing a PCS. World projections may be more accurate in certain regions depending on how ellipsoidal coordinates are projected. More research on this topic could help to determine how each PCS is best applied. Researchers should ensure that the PCS being used to project data is appropriate for the needs of the study.

Limitations

The number of datasets and locations is a limitation to the application of the results of this research. Results show the amount of distortion for each dataset and projection, but interpretations can only be made about the four study areas chosen for analysis. Home range area differences in the world projections across the four datasets show distortion tendencies for North and South America, but cannot be assumed to be true for other continents. There is also a lack of evidence to make conclusions about any particular UTM zone or continental Lambert Conformal projection because they are different for each dataset. Also, a UTM projection might not be best applicable to the long-tailed duck or waved albatross datasets since the tracking points span multiple zones. Results of this study show for certain that the chosen projection has a large influence on data analysis, but more tracking data in more locations could support or refute the trends regarding changes in distortion level across geographic regions for each projection.

The fact that the exact area of each home range was unknown is a possible limitation to the accuracy of distortion measurement calculations. A home range estimation using the continental Albers Equal Area Conic for analysis was used as a baseline area calculation for the distortion measurements. The distortion associated with the Albers projection likely varied slightly depending on the location of tracking points. For instance, it is unknown how much distortion change there might be in the PCS between the oilbird and waved albatross datasets, which both used the South America Albers projection as the baseline calculation despite the great distance between the two study areas. Also, it is possible that a world projection may be more appropriate for analysis of the long-tailed duck dataset rather than the Alaska Albers projection due to great distance covered by the tracking points. The continental Albers was the smallest scale equal area projection available for this study, however no projection can be completely free of distortion, so it is unknown how much influence the baseline calculation might have had on results.

Future Work

The large number of projections available and lack of information on the best application of each projection has made choosing a PCS for analysis a difficult decision for researchers (Usery and Seong, 2001). This is especially true for large-scale studies, such as home range analysis of migrating animals, where a world projection might be best applied. The ratio calculated in this study provides a way to measure and evaluate the distortion associated with a projected coordinate system. Future work could expand upon this research by analyzing more animal home ranges from different locations in North and South America and other continents. Analysis of more regions would provide more quantifiable data on the worldwide distortion tendencies of each projection. Future analysis could also include more equal area and commonly used projections at various scales that are available in ArcGIS. A more complete set of data that includes more geographic regions and projections could serve as a guide for choosing a PCS in large-scale studies based on the location of the study area.

Methodology changes, such as customizing the center coordinates of a PCS to the mean center of a tracking point dataset, could possibly result in a more accurate baseline area calculation. The ideal baseline calculation for assessing distortion would be the real-world area of the home range rather than one calculated in a GIS. A study by Yildirim and Kaya (2008) measured the distortion error caused by a map projection by calculating the true area of parcels using ellipsoidal geographic coordinates rather than projected coordinates. Area calculation based on geographic coordinates is not possible within ArcGIS, but since the CHP method of home range estimation uses triangles that have points at set coordinates, it is possible to calculate the true area. The Yildirim and Kaya (2008) study used parcels that are set in dimensions rather than highly complex animal home ranges. This method may be more useful in studies that are purely attempting to measure distortion differences in map projections instead of examining their impact on home range estimations.

LITERATURE CITED

Awkerman, J., Cruz, S., Proaño, C., Huyvaert, K., Uzcátegui, G., Baquero, A., . . . Anderson, D. (2014). Small range and distinct distribution in a satellite breeding colony of the critically endangered Waved Albatross. *Journal of Ornithology, 155*(2), 367-378.

Battersby, S. E. (2009). The Effect of Global-Scale Map-Projection Knowledge on Perceived Land Area. *Cartographica, 44*(1), 33-44.

Battersby, S. E., & Kessler, F. C. (2012). Cues for Interpreting Distortion in Map Projections. *Journal of Geography, 111*(3), 93-101.

Benson, J. F., Hostetler, J. A., Onorato, D. P., Johnson, W. E., Roelke, M. E., O'Brien, S. J., . . . Oli, M. K. (2011). Intentional genetic introgression influences survival of adults and subadults in a small, inbred felid population. *Journal of Animal Ecology, 80*(5), 958-967.

Blouin-Demers, G. (2006). Kernels Are Not Accurate Estimators of Home-Range Size for Herpetofauna. *Copeia*(4), 797.

Brainerd, J., & Pang, A. (2001). Interactive map projections and distortion. *Computers and Geosciences, 27*, 299-314.

Burt, W. H. (1943). Territoriality and Home Range Concepts as Applied to Mammals. *Journal of Mammalogy*(3), 346.

Carroll, C., & Miquelle, D. G. (2006). Spatial viability analysis of Amur tiger Panthera tigris altaica in the Russian Far East: the role of protected areas and landscape matrix in population persistence. *Journal of Applied Ecology, 43*(6), 1056-1068.

Cramer, P. C., & Portier, K. M. (2001). Modeling Florida panther movements in response to human attributes of the landscape and ecological settings. *ECOLOGICAL MODELLING, 140*(1-2), 51-80.

Cruz S, Proaño CB, Anderson D, Huyvaert K, Wikelski M. (2013). Data from: The Environmental-Data Automated Track Annotation (Env-DATA) System: Linking animal tracks with environmental data. Movebank Data Repository.

Dodge S, Bohrer G, Weinzierl R, Davidson SC, Kays R, Douglas D, Cruz S, Han J, Brandes D, Wikelski M. (2013). The Environmental-Data Automated Track Annotation (Env-DATA) System—linking animal tracks with environmental data. Movement Ecology 1:3.

Downs, J. A., Heller, J. H., Loraamm, R., Stein, D. O., McDaniel, C., & Onorato, D. (2012). Accuracy of home range estimators for homogeneous and inhomogeneous point patterns. *Ecological Modelling, 225*, 66-73.

Downs, J. A., & Horner, M. W. (2009). A Characteristic-Hull Based Method for Home Range Estimation. *Transactions in GIS, 13*(5/6), 527-537.

Fieberg, J., & Kochanny, C. O. (2005). Quantifying home-range overlap: The importance of the utilization distribution. *JOURNAL OF WILDLIFE MANAGEMENT, 69*(4), 1346-1359.

Hemson, G., Johnson, P., South, A., Kenward, R., Ripley, R., & McDonald, D. (2005). Are kernels the mustard? Data from global positioning system (GPS) collars suggests problems for kernel home-range analyses with least-squares cross-validation. *Journal of Animal Ecology, 74*(3), 455-463.

Holland, R. A., Wikelski, M., Kümmeth, F., & Bosque, C. (2009). The Secret Life of Oilbirds: New Insights into the Movement Ecology of a Unique Avian Frugivore. *PLoS ONE, 4*(12), 1-6.

Holland RA, Wikelski M, Kuemmeth F, Bosque C. (2012). Data from: The secret life of oilbirds: new insights into the movement ecology of a unique avian frugivore. Movebank Data Repository.

Holzman, S., Conroy, M. J., & Pickering, J. (1992). Home range, movements, and habitat use of coyotes in southcentral Georgia. *The Journal of Wildlife Management*(1), 139.

Jenny, B., Patterson, T., & Hurni, L. (2010). Graphical design of world map projections. *International Journal of Geographical Information Science, 24*(11), 1687-1702.

Khalil, R. (2013). The Accuracy of GIS Tools for Transforming Assumed Total Station Surveys to Real World Coordinates. *Journal of Geographic Information System, 5*(5), 486-491.

Laskowski, P. (1997). Part 1: Distortion-Spectrum Fundamentals. *Cartographica, 34*(3), 3.

Lord-Castillo, B. K., Mate, B. R., Wright, D. J., & Follett, T. (2009). A Customization of the Arc Marine Data Model to Support Whale Tracking via Satellite Telemetry. *Transactions in GIS, 13*, 63-83.

Main, M. B., Roka, F. M., & Noss, R. F. (1999). Evaluating Costs of Conservation. *Conservation Biology, 13*(6), 1262-1272.

Meegan, R. P., & Maehr, D. S. (2002). LANDSCAPE CONSERVATION AND REGIONAL PLANNING FOR THE FLORIDA PANTHER. *Southeastern Naturalist, 1*(3), 217.

Mitchell, M. S., & Powellt, R. A. (2007). Optimal use of resources structures home ranges and spatial distribution of black bears (English). *Animal behaviour, 74*(2), 219-230.

Olsen, J., Downs, J. A., Tucker, T., & Trost, S. (2011). Home-Range Size and Territorial Calling of Southern Boobooks (Ninox novaeseelandiae) in Adjacent Territories. *The Journal of Raptor Research*(2), 136.

Olson, J. M. (2006). Map Projections and the Visual Detective: How to Tell if a Map is Equal-Area, Conformal, or Neither. *Journal of Geography, 105*(1), 13-32.

Pebsworth, P. A., Morgan, H. R., & Huffman, M. A. (2012). Evaluating home range techniques: use of Global Positioning System (GPS) collar data from chacma baboons. *PRIMATES, 53*(4), 345-355.

Petersen, M. R., McCaffery, B. J., & Flint, P. L. (2003). Post-breeding distribution of Long-tailed Ducks (*Clangula hyemalis*) from the Yukon-Kuskokwim Delta, Alaska. *Wildfowl*(54), 129-139.

Powell, R. A., & Mitchell, M. S. (2012). What is a home range? *Journal of Mammalogy, 93*(4), 948-958.

Rayfield, B., Moilanen, A., & Fortin, M. J. (2009). Incorporating consumer-resource spatial interactions in reserve design. *ECOLOGICAL MODELLING, 220*(5), 725-733.

Recio, M. R., Mathieu, R., Denys, P., Sirguey, P., & Seddon, P. J. (2011). Lightweight GPS-Tags, One Giant Leap for Wildlife Tracking? An Assessment Approach. *PLoS ONE, 6*(12), 1-11.

Robinson, A. H. (1951). THE USE OF DEFORMATION DATA IN EVALUATING WORLD MAP PROJECTIONS. *Annals of the Association of American Geographers, 41*(1), 58-74.

Schrecengost, J. D., Kilgo, J. C., Ray, H. S., & Miller, K. V. (2009). Home Range, Habitat Use and Survival of Coyotes in Western South Carolina. *American Midland Naturalist, 162*(2), 346-355.

Seaman, D. E., Millspaugh, J. J., Kernohan, B. J., Brundige, G. C., Raedeke, K. J., & Gitzen, R. A. (1999). Effects of Sample Size on Kernel Home Range Estimates. *The Journal of Wildlife Management*(2), 739.

Seaman, D. E., & Powell, R. A. (1996). An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology*(7), 2075.

Selkirk, S. W., & Bishop, I. D. (2002). Improving and Extending Home Range and Habitat Analysis by Integration with a Geographic Information System. *Transactions in GIS, 6*(2), 151.

Steury, T. D., McCarthy, J. E., Roth, T. C., Lima, S. L., & Murray, D. L. (2010). Evaluation of Root-n Bandwidth Selectors for Kernel Density Estimation. *JOURNAL OF WILDLIFE MANAGEMENT, 74*(3), 539-548.

Tobler, W. R. (1962). A CLASSIFICATION OF MAP PROJECTIONS. *Annals of the Association of American Geographers, 52*(2), 167-175.

Usery, E. L., & Seong, J. C. (2001). All Equal-Area Map Projections Are Created Equal, But Some Are More Equal Than Others(*).(Statistical Data Included). *Cartography and Geographic Information Science*(3).

Ward, M. P. m. i. e., Sperry, J. H., & Weatherhead, P. J. (2013). Evaluation of Automated Radio Telemetry for Quantifying Movements and Home Ranges of Snakes. *Journal of Herpetology, 47*(2), 337-345.

Worton, B. J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology*(1), 164.

Worton, B. J. (1995). A Convex Hull-Based Estimator of Home-Range Size. *Biometrics*(4), 1206.

Yildirim, F., & Kaya, A. (2008). Selecting Map Projections in Minimizing Area Distortions in GIS Applications. *Sensors*(12), 7809.

Zurita, G., Pe'er, G., Bellocq, M. I., & Hansbauer, M. M. (2012). Edge effects and their influence on habitat suitability calculations: a continuous approach applied to birds of the Atlantic forest. *Journal of Applied Ecology, 49*(2), 503-512.