2015

THE HABITAT OF EUROPEAN BROWN BEARS IN NORTHERN SPAIN: MAPPING HABITAT FRAGMENTATION AND POTENTIAL CONNECTIVITY

Alma D. Pacheco
The University Of Montana

THE HABITAT OF EUROPEAN BROWN BEARS IN NORTHERN SPAIN:

MAPPING HABITAT FRAGMENTATION AND POTENTIAL CONNECTIVITY

By

Alma Duran Pacheco

Bachelor of Science, Geography, New Mexico State University, Las Cruces, NM, 2011

Thesis

Presented in partial fulfillment of the requirements for the degree of

Master of Science in Geography

The University of Montana
Missoula, MT
May 2015

Approved by:
Sandy Ross, Dean of the Graduate School

David Shively, PhD, Chair

Geography

Anna Klene, PhD

Geography

Christopher Servheen, PhD

Wildlife Conservation

ABSTRACT

Pacheco, Alma D., M.S., Spring 2015 Geography

Committee Chair: David Shively

The European brown bear in northern Spain is considered to be an endangered species whose habitat has been fragmented into two subpopulations due to habitat loss and lack of connectivity. The importance of improving connectivity and preventing more habitat destruction is vital to recover the species in this region. This research looks at spatial and temporal variations of brown bear habitat by mapping the conditions of habitat fragmentation and potential connectivity at a regional extent. This research examines net changes of brown bear habitat fragmentation between 1990-2000, 2000-2006, and overall 1990-2006; and the degree of brown bear habitat connectivity between subpopulations and at a landscape level for 2006. The purpose of this research is to use fragmentation and connectivity geospatial tools to map the spatial relationships among habitat, potential linkages and barriers, and to identify gaps in managed habitats to assist with restoring habitat connectivity. Based on the fragmentation results, high fragmentation occurred in core habitat between 2000-2006. Habitat connectivity is a measure of how diverse the landscape is based on movement resistance and multiple pathways. It's important to analyze connectivity at different scales to determine critical areas of concern. The results showed that connectivity is most constrained by human infrastructure, and this can be viewed as a challenge for brown bear recovery in the study area.

Keywords: European brown bear habitat, northern Spain, Fragmentation, Connectivity

ACKNOWLEDGEMENTS

First and foremost I want to thank my family. To my parents, thank you for your encouragement and support in pursuing this degree. You've always provided words of wisdom which I hold dearly in my heart.

To my dharma teacher, Namchak Khenpo, and Aikido Instructor, Raso Hultgren Sensei, thank you for providing insight along my adventurous journey.

I would like to thank the faculty and staff at the University of Montana. I offer my sincerest gratitude to my advisor, Dr. David Shively, who has supported me throughout my thesis with his patience and encouragement whilst allowing me the room to work on my own way. I would also like to thank my other committee members: Dr. Anna Klene, who has provided knowledge in geospatial science and providing assistance with computer problems; and Dr. Christopher Servheen who has provided knowledgeable background on brown bears. To Nancy Forman-Ebel, thanks for providing departmental assistance and conversations about gardening. Dr. Christiane von Reichert, thank you for providing office space and a computer so I could work on my thesis. Rick Graetz, thank you for lending me a desk in my last semester and inviting me to go with you on Geomorphology field trips to Yellowstone and to the Gallatin area.

In my daily activities I have been blessed with friendly, encouraging, and cheerful people to help me move along the path. Kayde Kaiser, thanks for being a great hiking buddy and going out for an occasional drink. Daniel A. Estrada, my far away friend, thank you for being my anchor and providing thesis advice and humorous conversations via Facebook. Raquel Castellanos, your inspiration and sense of humor has motivated me in more ways I can think of, thank you.

I would like to acknowledge those who provided some financial support of this research: MAGIP/Zuuring GIS Graduate Scholarship.

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1. Introduction

1.1. Problem Statement

Prior to widespread anthropogenic disturbances in northern Spain, a healthy ecosystem provided abundant habitat for European (Eurasian) brown bears (*Ursus arctos arctos)* (Naves et al. 2003). In the last 300 years, the brown bear population was fragmented into subpopulations due to habitat isolation and loss (Naves et al. 2003). In these regions, the brown bear is currently classified as an endangered species partly due to a decline of connectivity (Perez et al. 2010). It is a keystone species whose conservation helps to conserve healthy watersheds and natural functioning ecosystems, and hence broader species diversity (Servheen et al. 1999). Since 1973, conservation efforts to protect the brown bear have been a priority for Spain (Perez et al. 2010).

In Europe and other parts of world, brown bear management has been approached largely through conventional conservation planning efforts, primarily focused on preserving and enhancing ecosystem biodiversity and the creation of protected natural areas at the national level (Perez et al. 2010). While protected areas may be sufficient in the short-term, without linkages the long-term effects of this may include high rates of loss of brown bears and their habitats (Nelson et al. 2003). Therefore, it is crucial to analyze large landscapes across political boundaries (Soulé and Terborgh 1999, Swenson et al. 2000). In terms of analyzing connectivity, geographic extent and scale are important; therefore, broader landscapes should be considered for effective bear management conservation planning (Hilty et al. 2006).

The major problems for brown bear recovery and management in the northern Spain are the lack of identified corridors (one means of achieving connectivity) between subpopulations and barriers (fragmentation-natural or anthropogenic) that divide them (Naves et al. 2003, Hilty et al. 2006). Improvement of connectivity and prevention of more habitat destruction is vital to recovering the species in this region (Swenson et al. 2000).

1.2. Research Need, Questions and Objectives

To help understand the spatial and temporal variations of brown bear habitat connectivity and fragmentation, there is a need for maps which both accurately represent the condition of habitat and are comparable at multiple scales (Soulé and Terborgh 1997, FOP 2014). The application of remotely sensed medium spatial resolution satellite imagery is effective for monitoring landscape patterns and has made full coverage landscape mapping possible at a regional extent (Townsend et al. 2009). The research described here mapped brown bear habitat fragmentation and potential connectivity in montane environments in northern Spain using concepts of large landscape conservation planning and landscape ecology. The essential goal of maintaining connectivity in large landscape conservation is addressed via the spatial configuration of habitat that is important to satisfy the demands of the species.

This research quantified changes in brown bear habitat fragmentation by applying post-classification change mapping techniques to remote sensing-derived multitemporal land-cover maps. Spatio-temporal change analyses were conducted to evaluate brown bear habitat fragmentation identified using Morphological Spatial Pattern Analysis (MSPA) and potential connectivity was analyzed using habitat connectivity geospatial tools. The questions driving this research are:

1. What are the net changes of brown bear habitat fragmentation between 1990 and 2000, between 2000 and 2006, and overall during the period 1990-2006?
2. What is the degree of brown bear habitat connectivity between subpopulations and at a landscape level?

The purpose of this research is to use fragmentation and connectivity geospatial tools to map the spatial relationships among habitat, potential linkages and barriers, and to identify gaps in managed habitats to assist with restoring connectivity.

2. Literature Review

2.1. Theoretical Framework

For this research, concepts of landscape ecology and large landscape conservation planning will be applied to help understand and examine brown bear habitat connectivity and fragmentation in northern Spain. According to Ndubisi (2002, 166), "landscape ecology combines the spatial approach of geographers, which emphasizes spatial analysis, with the functional approach of ecologists, which focuses on the functioning of ecosystems." Large landscape conservation is "regional collaboration—the ability to work across boundaries with people and organizations that have diverse interests yet share a common place" (McKinney et al. 2010, 3).

The theory and application of landscape ecology and large landscape conservation rely on geospatial technologies such as remote sensing, GIS, & models to examine the changing landscape and environment (Naveh and Lieberman 1994, Soulé and Terborgh 1997). The distributions of brown bears in the Cantabrian Cordillera are mainly found in protected areas, but they also extend beyond protected area boundaries. Therefore, it's important to map brown bear habitats at a landscape level to further examine their connectivity and fragmentation.

2.2. European Brown Bear Distribution

European brown bears were historically distributed throughout all of Europe, except on large islands (i.e., Iceland, Gotland, Corsica, and Sardinia); their occurrence in Ireland is still debated (Zedrosser et al. 2001). As the human population increased, brown bear populations began to decrease through over-hunting and the loss of suitable habitats from deforestation and agriculture (Zedrosser et al. 2001). In Europe, there are ~50,000 brown bears (14,000 outside Russia) in 10 fragmented populations (Table 1; Large Herbivore Network 2013, Zedrosser et al. 2001).

Most European bears are found inland and are relatively smaller than those found in coastal regions (i.e., Alaska and Eastern Russia; Zedrosser et al. 2001; Arts 1993). Due to human alteration and presence in original brown bear habitats, brown bears are currently found in forested areas and steep terrain with low human density. They are unique creatures and a keystone species whose conservation helps to conserve healthy watersheds and natural functioning ecosystems, and hence broader species diversity (Servheen et al. 1999). In addition, these ecosystems provide clean water, air, and genetic resources - the basic resources people need to survive (Servheen et al. 1999).

Table 1: European Brown Bear Population by Region. Adapted from Large Herbivore Network (2012) and Fundacion Oso Pardo, (2013).

Region	Brown Bear Population
North Eastern Europe	37,000
The Carpathians	~8,100
Alps-Dinaric-Pindos	~2,600
Scandinavia	~2,000
Rila-Rhodope Mts	~520
Stara Ranina Mts	~200
Apennine Mts	~40-50
Western/Eastern Cantabrian	~190/30
Western/Central Pyrenees	<20
Italian Alps	~8

Since the 16th century, brown bears populations in northern Spain have been severely reduced due to habitat destruction and overexploitation by humans (Naves and Nores 1997). The Iberian Peninsula contains a small isolated population in the Cantabrian Cordillera that is considered to be endangered (Zedrosser et al. 2001), and it has been fragmented into two subpopulations which have been found to be genetically different (Perez et al. 2010). Between the 1950s and 1970s, brown bears in these regions had very low population numbers and were almost at the brink of extinction. In the last 30 years, the number of individuals has slowly grown in the western and eastern subpopulations of the Cantabrian Cordillera (Table 2).

Most of the brown bears in these regions are found within *Natura 2000* protected areas. *Natura 2000*, is an European Union (EU) wide network of nature protection areas; however, it is not a system of strict protection where all human activities are excluded (European Commission 2013). There is evidence that the distribution of brown bears extend beyond the Natura 2000 network for the Cantabrians (Martin et al. 2012), so it is crucial for habitat to be assessed beyond protective boundaries. Brown bears in the study area are endangered in large part due to a loss of connectivity of habitats within it.

Table 2: Brown Bear Populations

Cantabrian		
Year	Western Subpopulation	Source
2013	190 bears	FOP, 2013
2005	100 bears	Martin et al 2012
2000	50-60 bears	Swenson et al 2000
1991	50 bears	Naves & Nores, 1997
Year	Eastern Subpopulation	
2013	30 bears	FOP, 2013
2005	25-30 bears	Martin et al 2012
2000	20 bears	Swenson et al 2000
1991	14 bears	Naves & Nores, 1997

2.3. Landscape Ecology

According to Forman and Godron (1986, 20), landscape ecology, is the study of structure, function, and change in a heterogeneous land area that contains interacting ecosystems. Structure deals with the spatial relationships between the heterogeneous elements that make up the landscape mosaic. Function refers to the interactions among the spatial elements, and change is the alteration of the structure and function of an ecological mosaic over time (Forman and Godron 1986).

Many animals, such as brown bears, require more than one ecosystem or patch type in order to survive and reproduce (Forman 1987, Zedrosser et al. 2001). Heterogeneity, or diversity, is essential and required for the persistence of animal species. Since landscapes are made up of spatially heterogeneous elements, their structure, function, and modification are dependent on scale (Ndubisi 2002). Scale is especially important in landscape-ecology because the relative importance of factors controlling ecological processes varies with spatial scale (Odum 1989). For example, a forested landscape may be stable at one spatial scale but not at another (e.g., a forest complex vs. a forest stand).

Brown bear habitats in northern Spain are highly fragmented as a result of ongoing development and land-use change (Naves et al., 2003). When humans convert the land, the landscape is fragmented so that it contains smaller and more isolated patches of open space, which greatly alters the way in which natural systems function. Fragmentation increases edge habitat and the isolation between patches while reducing the number and diversity of natural plant and animal species. Habitat fragmentation is considered to be an existing and growing cause of habitat degradation and biodiversity loss in Europe and elsewhere (Bennett, 2003). The process of fragmentation has three recognizable components (Bennett 2003, 13):

> an overall loss of habitat in the landscape (habitat loss); reduction in the size of blocks of habitat that remain following subdivision and clearing (habitat reduction); and increased isolation of habitats as new land uses occupy the intervening environment (habitat isolation).

The importance of connectivity among habitat patches and species' populations across the landscape is widely recognized. Different groups of animals display markedly different levels of mobility and operate in the environment at different scales, which means that there is a need for suitable linkages between resources at a scale relevant to each species (Bennett 2003). There are two primary components of connectivity: i) the structural (or physical) component: the spatial arrangements of different types of habitats or other elements of the landscape; and ii) functional (or behavioral) component: the behavioral response of individuals, species, or ecological processes to the physical structure of the landscape (Bennett 2003, Tischendorf and Fagrig 2000).

Structural connectivity is associated with spatial arrangements of habitat, while functional connectivity requires not only spatial information about habitats or landscape elements, but also some insight on the movement of organisms or processes through the landscape (Crooks and Sanjayan 2007). Landscape connectivity is a combined product of structural and functional connectivity—the effect of physical landscape structure and the species' use of the landscape (Tischendorf and Fahrig 2000).

In short, connectivity within the matrix of habitats enables the movement of individuals between patches and the functioning of the ecological system within a landscape. It is critical to recognize that a landscape is perceived differently by different species, and so the level of connectivity varies between species and between communities (Bennett 2003).

Landscape connectivity must be assessed, and therefore managed, in the context of human land-use changes. When a landscape has high connectivity, individuals of a particular species can move freely between suitable habitats. On the other hand, when a landscape has low connectivity individuals are severely constrained from moving between selected habitats. In the event of low connectivity, it is necessary to identify potential corridors to help restore connectivity. According to Clevenger et al. (1997, 10), "suitable areas for cover and protection are critical to bears in the Cantabrian." And Caussimont and Herrero (1997, 12) noted that "the patchy distribution of forest cover increases the vulnerability of bears when traveling between areas."

2.4. LARGE LANDSCAPE CONSERVATION PLANNING

The role of conservation is to protect tracts of land from development based on their scenic value, to manage the maximum of species diversity, and manage an entire functional ecosystem (Soulé and Terborgh 1997, Soulé 1983). Protected areas are often too small and isolated from other protected areas by fragmentation caused by human activities; studies have shown that small and large protected areas lose species over time, especially larger animals (Soulé and Terborgh 1997). In the long run, species cannot survive in small habitats because smaller areas are incapable of supporting the full spectrum of processes that sustain diversity (Soulé et al. 2006).

The protection of endangered species is a controversial topic because the whole idea is to save a particular species and types of habitat. However, most species need large contiguous areas to accommodate essential movements. According to Soulé and Terborgh (1997, 5),

> To be effective, biological conservation must be planned and implemented on large spatial scales. Conservation biologists have learned that nature and wildness cannot be saved by protecting a piece here and a piece there.

Since brown bears need large contiguous areas of habitat with sufficient availability of preferred foods, escape cover, and den sites, it is important to consider these in the context of analyzing brown bear habitat conservation at a landscape level. At a regional scale (landscape level), the reintroduction of large carnivores becomes practical and problems of trans-boundary conservation (e.g., for the brown or grizzly bear in Canada and the United States, the jaguar and Mexican wolf in Mexico and the United States) become tractable within a regional context (Soulé and Noss 1998). Planning for regions requires the protection of biodiversity and wilderness on a much broader scale, which includes integrating multijurisdictional of land management—county, state, provincial, and national governments (Soulé and Terborgh 1997).

Since most protected areas contain habitats that are too small or isolated to provide sufficient habitats for large animals, it is necessary to plan and implement systems that will restore connectivity. However, it is important to remember that connectivity is not the only goal (Soulé et al. 2006); the main goal is to reverse the consequences of fragmentation of habitat at the landscape level.

Recent studies of multi-scale habitat modeling has revealed preferred habitat of brown bears in Spain consists large landscapes with low human footprint and large extents of forest cover (Mateo-Sanchez et al., 2013). The brown bears in the Cantabrian Range occur in two small and endangered subpopulations (Palomero et al., 2007) with limited gene flow between them (Perez et al., 2009). The brown bears of Spain have been protected for over 30 years (Mateo-Sanchez et al., 2014). Most of their known range is included in European Nature 2000 Network containing natural parks and recovery plans of each of the regional institutions involved in its management (Mateo-Sanchez et al. 2014).Studies have indicated that both subpopulations are growing; loss of genetic diversity is due to small population size and demographic stochasticity has hampered the recovery of the species and continues to threaten its viability (Garcia-Garitagoritia et al., 2007). The importance of having large blocks of protected core areas within a connected network are key to European, national and regional brown bear conservation initiatives (Palomero et al., 2007). The protection of movement corridors, and the incorporation of connectivity in landscape planning, has been top priority and a critical issue for conservation efforts (Palomero et al., 2007).

3. Methods

3.1. Study Area

3.1.1. Physical Characteristics

The research setting for this study is located in a system of adjoining mountain ranges and high country in the northern Iberian Peninsula, the Cantabrian Cordillera (Figure 1). The Cantabrian Cordillera is generally well-forested and stretch (east-west) along the Atlantic coast of northern Spain for 290 kilometers with elevation ranging from 1000 m to over 2600 m and an area of 31,800 km^2. It has three distinct geographic regions: Western (the Asturian Massif in Asturias, Leon, and Cantabria), Central (the Cantabrian Massif, in Cantabria), and the Eastern (Monte Vascos or Basque Mountains in the Basque Country; Way 1962). Forests cover 36% of the overall area (Martin et al. 2012). The north-facing slopes are dominated by oaks, beech, birch, and chestnut trees, whereas the south -facing slopes are dominated by oaks and beech (Martin et al. 2012). Between 1700-2270 meters, subalpine shrubs dominate the landscape. The northern slopes receive heavy rainfall and the southern slopes are in a rain shadow.

3.1.2. Socio-Economic Characteristics

The Cantabrian Cordillera is divided into three geographic regions (Western, Central, Eastern), which contain different types of vegetation, and ethnicities. The cordillera encompasses five provinces in Spain: Asturias, Cantabria, Basque Country, Galicia and Castilla y Leon (Figure 1). These five provinces are part of the Cantabrian to Alps conservation initiative, in which over half of the administrative regions have full political responsibility concerning land-use planning, agriculture, forestry, nature conservation and infrastructure (Worboys et al. 2010). Tourism and livestock (mainly cattle) farming for dairy production are the main economic activities in the Cantabrian Cordillera. The region is also known for iron and coal deposits, and as a source of hydroelectric power for the coastal regions, which brings economic importance to the region but has implications for habitat connectivity (Martin et al., 2012). The human density is 5.2 inhabitants km^2 and road density is 1.2 km^2 (Martin et al. 2012).

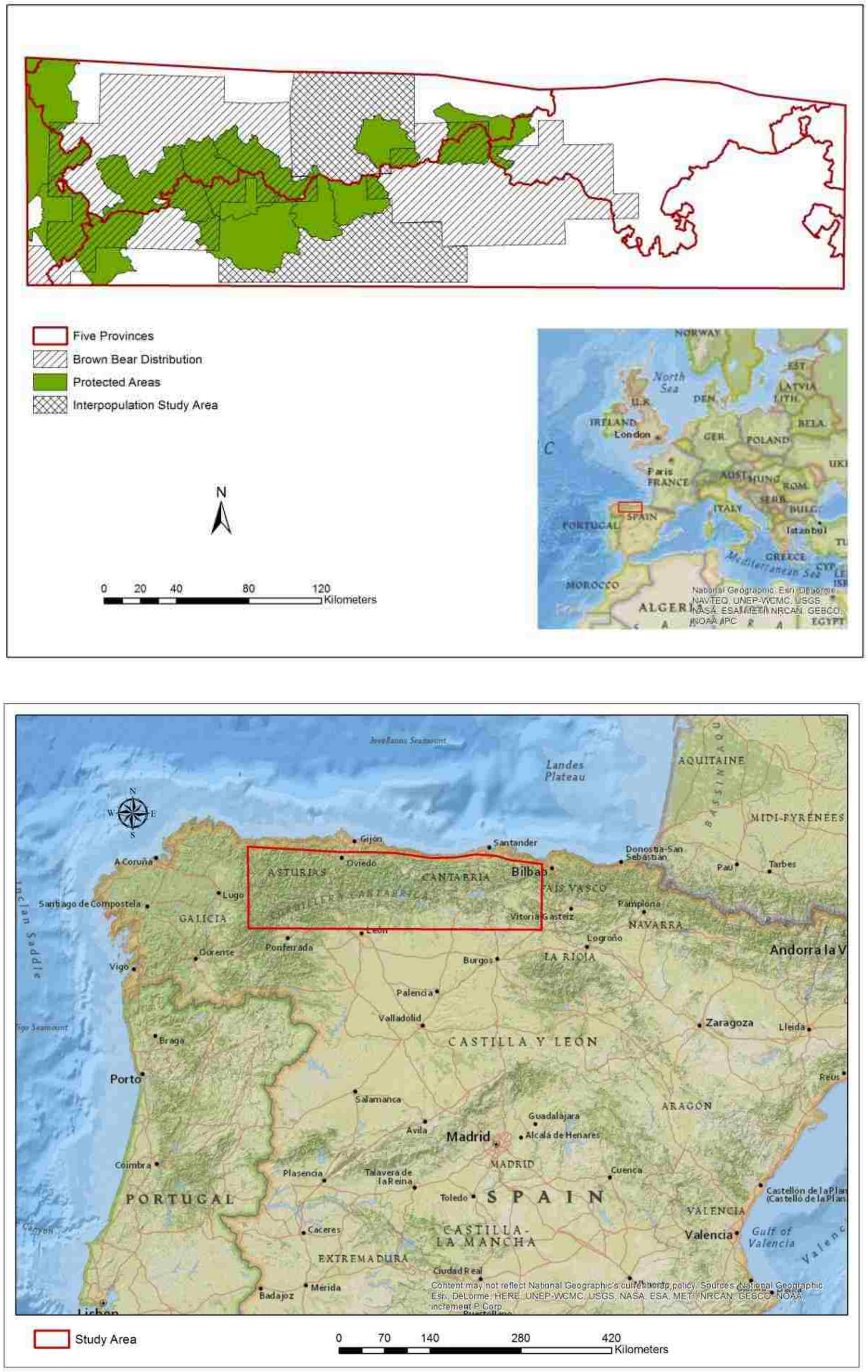

Figure 1: Study Area

3.2. Data Sources

CORINE (Coordination of Information on the Environment) Land Cover (CLC) data produced by European Commission Environment Agency (EEA) Program, for the years 1990, 2000, and 2006, will be used in this study as a principal source of data for the analysis of brown bear habitat, and its fragmentation and connectivity. The CORINE data contain 44 land cover classes and were created using 50-meter spatial resolution Landsat-TM5 (1990) imagery (resampled from 30-meter data), 25-meter spatial resolution Landsat ETM7 (2000) imagery, and 25-meter spatial resolution SPOT (2006) data with ancillary variables (EEA 2007). The 1990 land cover map had an overall accuracy of 85%; the 2000 land cover map had an overall accuracy of 87%; and the 2006 land cover map had an overall accuracy of 85% (EEA 2007). Other sources of data include: protected areas, administrative boundaries, brown bear distribution areas, roads, railways, and human settlements (Table 3). Brown bear datasets, habitat preferences, and modeling parameters were extracted from published articles for this research (Figure 2).

Table 3: Datasets

Datasets	Data Source
Protected Areas	Ministerio de Agricultura Alimentacion Y Medio Ambiente, 2012, Banco de Dataos de la Naturaleza
Brown Bear Distribution Area	www.iucnredlist.org, (McLellan, B.N et al. 2014)
Roads	DIVA_GIS, http://www.diva-gis.org/datadown
Railways	DIVA_GIS, http://www.diva-gis.org/datadown
Human Settlements	CLC 2006 Vector, www.eea.europa.eu

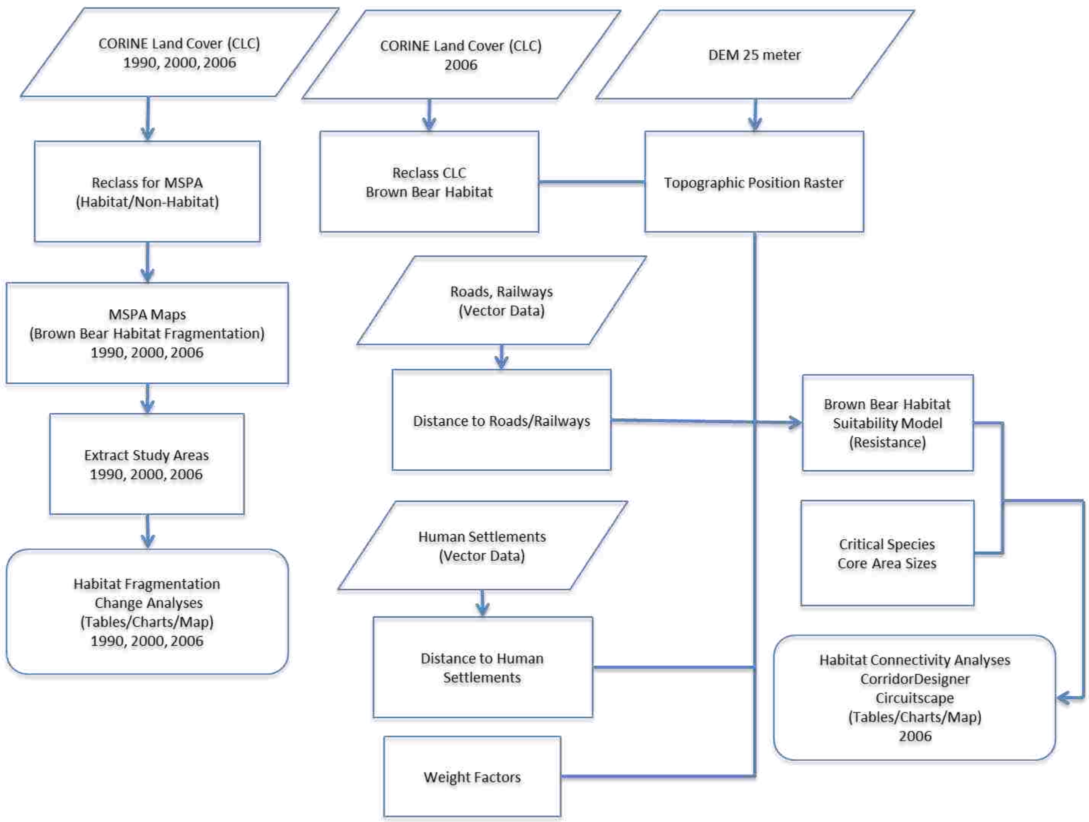

Figure 2: Flow Chart for Data and Methods

3.3. Analytical Methods and Tools

3.3.1. Introduction

This section will discuss the methods used to analyze brown bear habitat fragmentation and potential connectivity. Using the land cover data for 1990, 2000, and 2006, brown bear habitat fragmentation was analyzed for the entire study are for the periods 1990-2000, 2000-2006, and 1990-2006, as well as nine areas of interest within the study area in order to better understand habitat fragmentation at different scales and in different contexts. These nine areas include: Protected Areas, Asturias, Cantabria, Castillia y Leon, Galicia, Basque Country, Western and Eastern Subpopulations, and Fundacion Oso Pardo's (FOP) area of concern (area between subpopulations). The Brown Bear Foundation (Fundacion Oso Pardo-FOP) is a NGO created in 1992 with the aim for conservation projects of brown bears, their habitat, and understanding human-environment interactions (FOP, 2013). The FOP area of concern is located between the two subpopulations and is also known as the "Interpopulation Corridor"; it is about 50 km wide (FOP, 2013). The purpose of this corridor is to join both populations together by collaborating with various agencies, local people, establishing good practices for corridor management (FOP, 2013).

The CORINE land cover datasets were processed using Morphological Spatial Pattern Analysis (MSPA), included in the Guidos Toolbox (Vogt 2012) as discussed below. The resulting MSPA maps were then compared to evaluate changes in brown bear habitat structure for 1990-2000, 2000-2006, & 1990-2006. The tools contained in the IDRISI Selva™ software (Clark Labs 2012) provides an excellent tool for comparing categorical maps based on cross-tabulation at the pixel level.

Potential brown bear habitat connectivity was only modeled and analyzed for the 2006 dataset in order to assess connectivity restoration with the most current data available; more recent (i.e., 2012) data were not available at the time the research was conducted. Circuitscape™ (McRae et al. 2014) was used to analyze potential connectivity for the entire study area. A brown bear habitat suitability model and a focal core model (i.e., for critical species habitat) were created in CorridorDesigner, a GIS toolbox for ArcGIS; these were needed as inputs for Circuitscape™.

3.3.2. Morphological Spatial Pattern Analysis

Habitat fragmentation can be assessed using either a patch-based approach where patch statistics are used to express fragmentation, or by using pixel-level mapping in which each habitat pixel is classified based on the level of fragmentation (Vogt et al. 2007). Patch-based assessments look at habitat patches at the landscape-level to interpret fragmentation using statistics such as the average patch area, number of patches, and patch perimeter (Bogaert et al. 2004). Patch-based approaches can be difficult to implement in large-area assessments due to the huge number of patches involved, the lack of spatially explicit results, and the dramatic effect that changes in the scale of analysis can have on the results (Vogt et al. 2007).

Pixel-level assessment is better suited for fragmentation mapping at the landscape level. Pixel-level mapping is traditionally done using image convolution, a method of using a fixed area window centered on each habitat pixel to classify that pixel based on the type, amount, and adjacency of other habitat pixels (Riitters et al. 2002). Even so, image convolution can misclassify habitat pixels because: (1) it is partially based on percolation theory, which describes the behavior of connected clusters on a random image (however, this only applies to randomly generated images, not real landscapes, which have a higher degree of auto-correlation and stationarity); (2) the thresholds that are used to distinguish between fragmentation classes are user defined and are not directly related to ecological processes, such as edge effects; and (3) the method fails to consider any information outside of the fixed window (Vogt et al. 2007).

Morphological spatial pattern analysis provides an alternative methodology for classifying pixel-level fragmentation. This method classifies habitat pixels based on a series of operations derived from mathematical morphology (Soille 2009). It classifies habitat pixels into one of seven classes to depict the amount of fragmentation on the landscape and the degree of connectivity between habitat areas (Vogt et al. 2007). The classes are: *core, islet, edge, perforated, bridge, branch* and *loop* (Table 4). A unique advantage to using MSPA for pixel-level analysis is that it identifies corridors and connectors in the landscape (Ostapowicz et al. 2008). It has been recognized that MSPA moreand accurately classifies pixels than traditional pixel-level classifications of fragmentation because it considers information from the entire landscape, meaning that changes between classes better reflect landscape level changes and fewer pixels are misclassified (Vogt et al. 2007). Previous studies have found that the greater accuracy of MSPA, compared to other methods of pixel-level classification, allows for greater comparability between summary statistics and trend analysis, making it ideal for monitoring and change detection (Vogt et al. 2007, Wickham et al. 2000).

Morphological Spatial Pattern Analysis is based on concepts from mathematical morphology (Soille 2003), which alter the image using operations such as erosion, dilation and anchoring, based on geometric objects called ‘structuring elements’ (SE) of a predetermined size and shape (Vogt et al. 2009). The shapes of the SEs are determined by the connectivity (either 4 or 8 neighbors), and their size is dictated by their edge widths. Morphological Spatial Pattern Analysis can be used to identify habitat core pixels and linkages of habitat across political boundaries from a single land cover map rather than performing a GIS overlay of several maps (Wickham et al. 2010).

Table 4: Definitions of Morphological Spatial Pattern Analysis Classes

Core	Foreground (habitat) pixels surround on all sides by foreground pixels and greater than the specified edge width distance from background (non-habitat)
Bridge	Habitat pixels that connect two or more core areas
Loop	Habitat pixels that connect an area of core to itself
Branch	Habitat pixels that extend from an area of core, but do not connect to any other areas of cores
Edge	Pixels that form the transition zone between habitat and non habitat
Perforated	Pixels that form the transition zone between habitat and non habitat for interior regions of the habitat
Islet	Habitat pixels that do not contain core and are unconnected

Before discussing the process of MSPA, it is important to note the type of habitat selected for analyzing brown bear habitat fragmentation. For this section of the analyses, natural habitat (i.e., preferred habitat as in Mateo-Sanchez et al., 2013) was identified based on published research about brown bears (Table 5). The selection of natural habitat is to understand how much habitat has been lost due to fragmentation over a sixteen-year time period. The CORINE land-cover datasets were reclassified into nine categories representing brown bear natural habitat.

Table 5: Brown Bear Natural Habitat for MSPA

Variables	CORINE Label	Description	Literature
Forests and Semi-Natural Areas	Forest	Broad Leaf	Martin et al. 2012
Forests and Semi-Natural Areas	Forest	Conifer	Martin et al. 2012
Forests and Semi-Natural Areas	Forest	Mixed	Martin et al. 2012
Forests and Semi-Natural Areas	Scrub	Natural Grasslands	Marquinez et al. 1997
Forests and Semi-Natural Areas	Scrub	Moors and Heartland	Marquinez et al. 1997
Forests and Semi-Natural Areas	Scrub	Transitional Woodlands	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Bare Rocks	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Sparsely Vegetated Areas	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Burnt Areas	Stewart et al. 2012

The natural brown bear habitat maps were then reclassified into binary classes of foreground (habitat) and background (non-habitat). Guidos software utilizes the binary maps and converts the foreground (area of interest) into seven spatial pattern elements: core, islet, bridge, loop, branch, edge, and perforation (Figure 3). The MSPA output maps were then brought into ArcGIS to extract the nine areas of interest from the main study area for the three time periods and prepared for the Land Change Modeler in IDRISI Selva (Clark Labs 2012). The Land Change Modeler (LCM) evaluated net changes in brown bear habitat corresponding to each period using the MSPA categories.

Also two maps were created in the Land Change Modeler to show the most changes and losses/gains of brown bear habitat fragmentation for Cantabria, Spain, 2000-2006. The rationale for creating these two maps for Cantabria is because it had the most change in habitat. However, to make the maps readable, only MSPA classes with transitions greater than 1000 ha were selected for analyses and representation.

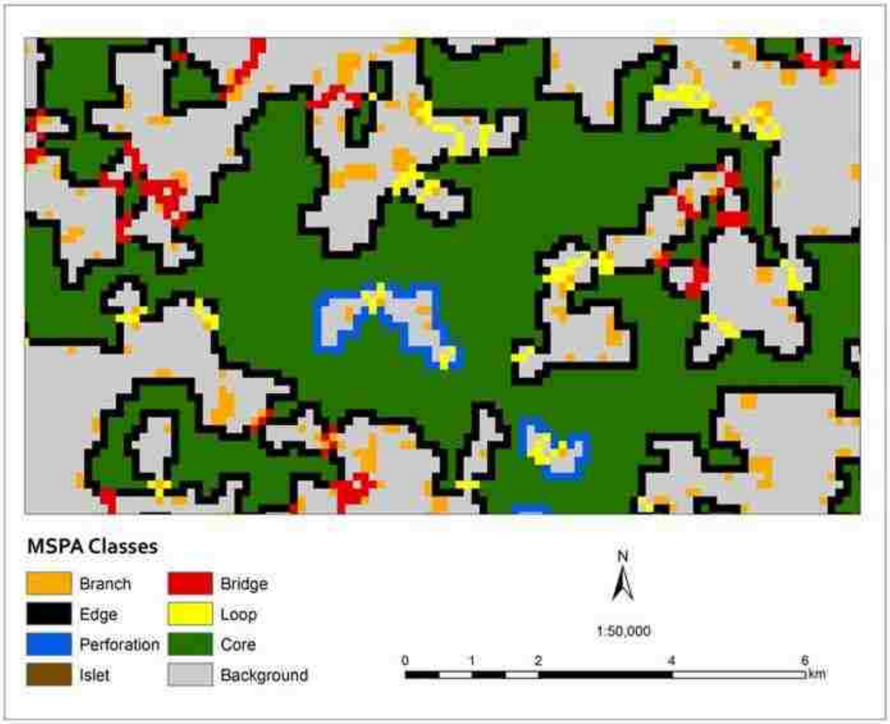

Figure 3: MSPA Detail of Study Area

3.3.3. Connectivity Modelling

According to Cantwell & Forman (1993), it is important to find a good modeling method for understanding connectivity in heterogeneous landscapes. Three types of ecological models have been used to quantify habitat connectivity: graph theory, network theory, and circuit theory. Cantwell and Forman (1993) used graph theory to help identify three key ecological criteria: 1) spatial configuration of patches, corridors, and matrix; 2) the interactions of flow between elements of the landscape; 3) comparing the first two characteristics at multiple scales in any landscapes. Graph theory is based on finite set of nodes (points, vertices), and a finite set of linkages (edges and lines; Cantwell & Forman 1993).

Network theory incorporates least-cost path modeling, where species are restricted to single and optimal pathways (Rayfield et al. 2011) based on either node size or link weight. Network theory applies graph theory to help understand real-world networks, structural dynamics, and the relationship between their structure and function (Rayfield et al. 2011).

Circuit theory applies network theory to quantify connectivity in circuited systems that respond positively to the presence of alternative pathways (Rayfield et al. 2011) or resistors, in the case of electrical circuits (McRae 2006, McRae and Beier 2007, McRae et al. 2008). The foundation of circuit theory is based on two primary factors. 1) resistance consists of current flow between two nodes; 2) current flow gives net passage probabilities for random walkers (McRae et al. 2008). In other words, circuit theory describes flows of random walkers across a network of resistors, or “habitat” grid cells. Circuit theory and analysis also uses a binary of node (habitat) and linkage in a network perspective (McRae & Beier, 2007). As a network approach, it is similar to graph theory, and includes directionality and degree of connectivity between nodes. Circuit theory can be used to quickly analyze large landscapes and datasets (Beier et al. 2011).

Circuits can operate across multiple pathways (McRae & Beier, 2007) and can be analyzed to predict movement patterns and probabilities of successful dispersal or mortality of random walkers moving across complex landscapes; this can generate measures of connectivity or isolation of habitat patches, populations, or protected areas, and identify important connective elements (e.g., linkages) for conservation planning (McRae & Beier 2007).

3.3.4. Corridor Modelling

CorridorDesigner is an ArcGIS extension toolbox for creating habitat and corridor models. It contains a three-step process that applies least-cost modeling for multiple focal species. The core input is the habitat suitability model which allows assessing the quality of habitat for a species within the study area or a modeled corridor and masking out any unsuitable habitat.

The habitat suitability model is comprised of several raster-based layers, such as land cover, elevation, topographic position, human disturbance, or other relevant data. Using these data, and a habitat suitability threshold that ranks habitat quality for breeding, a single species corridor can be modelled.

This section will discuss the two-step process of creating a habitat suitability model (HSM) and critical core habitat model relevant to brown bears in the Cantabrian Cordillera. The following pre-modelling steps were considered in order to advance to the next stages: data collection of habitat variables (CORINE 2006 Land Cover, Digital Elevation Model - DEM, roads, railways, human settlements) and evaluating literature reviews/expert opinion-based habitat suitability models to determine weights and habitat factors for brown bears. The choice of habitat in GIS suitability models are based on one to five factors, including land cover, one or two factors related to human disturbance, and one or two topographic factors (Favilli et al., 2013).

For the analyses of connectivity, suitable brown bear habitat classes from the CORINE land cover dataset (Table 6) are different from those utilized in the fragmentation analyses. For MSPA, only natural habitat classes were chosen in order to identify loss of habitat and fragmentation due to non-habitat factors. For habitat models, land cover is considered the most important factor because it is related to food, hiding cover, thermal cover, and (for urban/rural land use) human disturbance (Favilli et al., 2013). The CORINE land cover dataset was reclassified into six classes: Forest, Scrub/Open, Water Bodies, Wetlands, Agriculture, and Artificial. These classes were chosen because brown bears are generalists and opportunistic species which have a bigger adaptation to different habitat types and to human activities (Favilli et al., 2013).

Table 6: Brown Bear Habitat for Connectivity Analyses

Variables	CORINE Label	Description	Literature
Forests and Semi-Natural Areas	Forest	Broad Leaf	Martin et al. 2012
Forests and Semi-Natural Areas	Forest	Conifer	Martin et al. 2012
Forests and Semi-Natural Areas	Forest	Mixed	Martin et al. 2012
Forests and Semi-Natural Areas	Scrub	Natural Grasslands	Marquinez et al. 1997
Forests and Semi-Natural Areas	Scrub	Moors and Heartland	Marquinez et al. 1997
Forests and Semi-Natural Areas	Scrub	Transitional Woodlands	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Bare Rocks	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Sparsely Vegetated Areas	Marquinez et al. 1997
Forests and Semi-Natural Areas	Open	Burnt Areas	Stewart et al. 2012
Agriculture	Arable Land	Non-Irrigated Arable Land	FOP, 2014
Agriculture	Arable Land	Permanently Irrigated Land	FOP, 2014
Agriculture	Permanent Crops	Fruit Trees and Berry Plantations	FOP, 2014
Agriculture	Pastures	Pastures	FOP, 2014
Agriculture	Permanent Crops	Olive Groves	FOP, 2014
Agriculture	Heterogeneous	Annual Crops w/ Permanent Crops	FOP, 2014
Agriculture	Heterogeneous	Land Occupied by Ag.	FOP, 2014
Agriculture	Heterogeneous	Agro-Forestry	FOP, 2014
Artificial	Urban Fabric	Continuous Urban	FOP, 2014
Artificial	Urban Fabric	Discontinuous Urban	FOP, 2014
Artificial	Industrial, Commercial	Road/Rail Networks	FOP, 2014
Artificial	Mine, dump, Construction stites	Mineral Extraction	FOP, 2014
Wetlands	Inland wetlands	Inland Marshes	FOP, 2014
Water Bodies	Inland Waters	Water Courses	FOP, 2014
Water Bodies	Inland Waters	Water Bodies	FOP, 2014

The first step is to create a topographic position raster from a DEM. CorridorDesigner creates a topographic position raster relevant to cost of movement, in this case for the brown bear, that is correlated with moisture, heat, cover and vegetation (Beier et al., 2008). Topographic position can be estimated by classifying pixels into any number of classes such as steep slope, ridge top, drainages/canyons, or valley bottom (Beier et al. 2008). Other data such as roads, railways, and human settlements were processed to determine Euclidian distance to keep species from certain human disturbances.

The second step is to create a habitat suitability model. This iteration of habitat suitability modelling uses pixels to determine survival and reproduction of a focal species. The habitat suitability model needs six inputs which consist of five habitat factors with their assigned weights and a table of habitat suitability scores for each habitat factor (Figure 4 and Table 7). For each class of the habitat factors, a particular suitability score was assigned based on literature about brown bear habitat use (Favilli et al., 2013). The assignments of suitability scores for each class within each factor were based on a fixed scale between 0 (no suitability) and 100 (maximum suitability). The biological interpretation is as follows:

- 100: best habitat, highest survival and reproductive success
- 50: sub-optimal habitat, food availability and passage
- 25: occasional use and passage
- 0: avoided/barrier (Favilli et al. 2013)

This approach is not predictive but probabilistic; it focuses on potential threats wildlife may encounter in their daily movements based on assumptions conditioning the identification of the most probable paths for wildlife dispersal. This helps to formulate management recommendations to overcome future threats due to the expansion of human infrastructure (Favilli et al. 2013).

The overall suitability of each pixel is assigned with a weight for each factor according to their relative importance for the species' ecological needs (Favilli et al., 2013). To calculate the pixel's suitability value, the habitat factor class scores are multiplied with habitat factor weights to obtain a final score between 0 and 100 for each pixel. Therefore, a weighted geometric mean algorithm was applied to the model in order to reflect a better situation in which one habitat factor limits suitability in a way that cannot be compensated by other factors (Beier et al. 2008). For instance, if urban areas are poor habitat under all circumstances, one would combine factors in a way that a pixel of urban habitat doesn't get a high score because it has ideal elevation, topography, and distance to a road (Favilli et al., 2013). Suitability values and factor weights are essential for modelling of behavior of the focal species as it moves through the landscape (Beier et al. 2008).

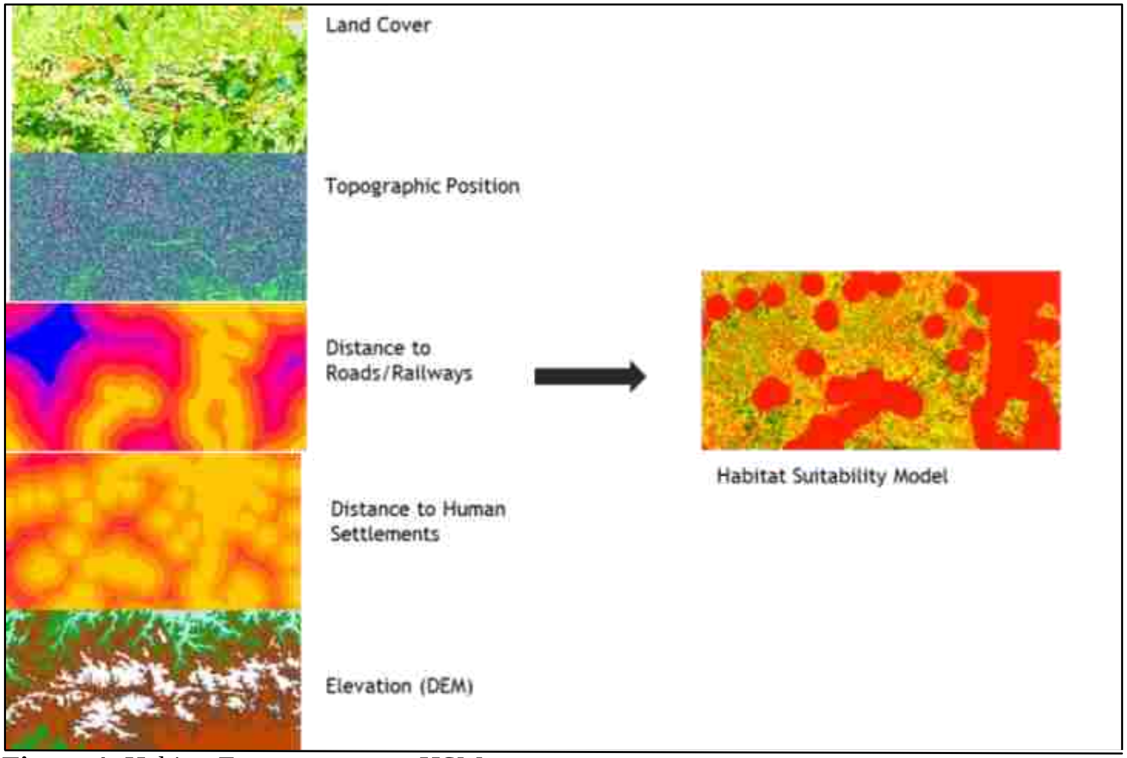

Figure 4: Habitat Factors to create HSM

Table 7: Brown Bear Habitat Factor Scores/Weights for HSM (Favilli et al. 2013)

Land Cover	Scores %	Distance to R/R (m)	Scores %	Topographic	Scores %	Elevation (m)	Scores %	Distance to Human Impact (m)	Scores %	Factor Weights	Scores %
Urban	0	0-3900	0	Drainages/Canyons	0	0-500	50	0-3700	0	Land Cover	30
Agriculture	25	3900-15200	50	Bottom-Gentle Slope	50	500-1000	75	3700-15000	50	Distance to Human Impact	10
Forests	100	>15200	100	Steep Slope	100	1000-1500	100	15000-20000	100	Elevation	10
Scrub/Open	50			Ridge Tops	25	1500-2000	100	>20000	100	Topographic	30
Waterbodies	25					2000-2500	100			Distance to RR	20
						>2500	50				

The next step in step two is to use the model to produce a habitat patch map in order to determine breeding habitat, population patches, and smaller than breeding patches. Population patches are areas that estimated to be large enough to support European brown bear breeding for 10 or more years, even if they were isolated from interaction with other populations of the species (Majka et al. 2007). As for breeding patches, they have a smaller area than the population patches, but large enough to support a single breeding event (Majka et al. 2007). Parameters for creating a habitat patch map include: habitat suitability map, minimum threshold of habitat quality, 50%, (an assigned suitable score for breeding and non-breeding habitat), minimum breeding patch size, 5000 ha, and a minimum population patch size, 30000 ha (Favilli et al., 2013).

3.3.5. Connectivity

Circuitscape is an open-source program, based on circuit theory that can be used to model habitat connectivity. To do this, it uses a habitat suitability raster dataset for an entire study area that is coded for resistances (high values denote greater resistance to movement) or conductances (reciprocal of resistance; higher values indicate greater ease of movement; McRae 2011) and focal nodes (points or regions between which connectivity is to be modeled). When a grid cell has a finite resistance it will be represented as a node in a graph, and is connected to its eight second-order neighboring habitat cells (McRae 2011). Grid cells with infinite resistance (zero conductances) are dropped. Habitat patches, or collections of cells, can be assigned zero resistance (infinite conductance) (McRae 2011).

Resistance is used to measure connectivity by incorporating multiple pathways while connecting nodes (McRae et al. 2008). Resistance distance is both the minimum movement distance and the availability of other pathways. Currents are considered as random walkers flowing through resistors connecting any pair of nodes (MacRae et al. 2008) (Figure 5). There are four modes in which Circuitscape operates: pairwise, one-to-all, all-to-one, and advanced. For this study, pairwise mode was selected because it produces calculations much faster than the other three modes and recommended for large datasets and multiple habitat patches (McRae 2011). In pairwise mode, Circuitscape connects one focal node to ground and all remaining focal nodes to 1-amp current sources (McRae 2011). It then repeats the process for each focal node; if there are *n* focal nodes, there will be *n* calculations (McRae 2011). Cirucitscape generates output maps that show the current density at each grid cell in the landscape under each configuration (McRae 2011).

The focal nodes (destination sites) for the study area are habitat patches that have a minimum of 5000 ha of breeding patch size and a minimum of 30000 ha for population patch size (Favilli et al. 2013); these are not inclusive of one another owing to the specific habitat types assigned by the HSM. The rationale for using these parameters for the focal nodes is to have a limit of focal nodes in order for the model to work properly. In previous iterations, having all focal nodes based on the habitat patches less than 5000 ha, produced problems, and Circuitscape failed to work. The habitat patches serve as starting and ending points for linkages to indicate the location of the modeled corridor.

Circuitscape is used to calculate expected flow of animals between each pair of nodes within a species-specific threshold of each other. It works in similar fashion to ordinary least-cost path analysis, but instead of returning a single least-cost path or corridor, it calculates the expected flow of the target across all of the different pathways from one node to the other, treating the nodes as electrodes and the landscape as a circuit board matrix with varying levels of resistance (Braaker et al 2014). Pathways that are expected to receive lots of dispersing animals are scored with high current density values, whereas cities and roads between the nodes tend to get low density values.

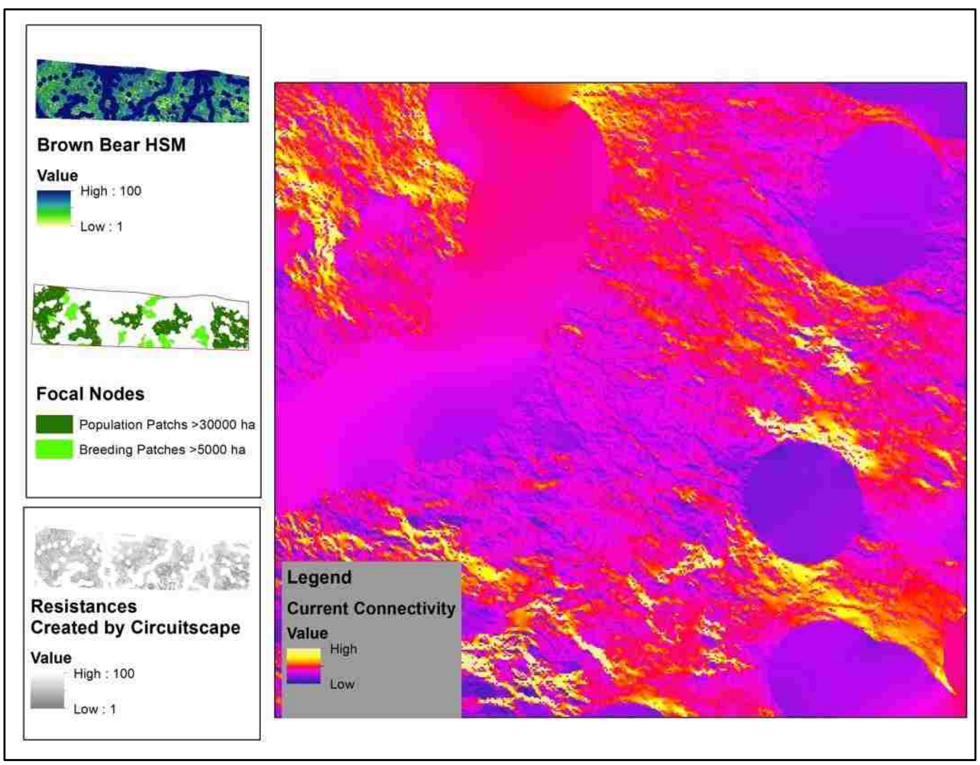

Figure 5: Current Connectivity Map with Detail and inputs

4. Results

4.1. HABITAT FRAGMENTATION

In the main study area, within the two different time periods considered (1990-2000 and 2000-2006), the biggest net change of MSPA categories happened between 2000 and 2006, even given the shorter time increment. This was especially evident for islets, with a 2.32% gain, and loops, with a 2.39% gain (Table 8). The total (1990-2006) net change indicates a loss of 10,951 ha (-0.75%) of core habitat and a gain of 3,762 ha (0.85%) of non-habitat. The biggest total net changes occurred in edge (3,928 ha or 2.08%), bridge (840 ha 2.77%), islet (146 ha 2.59%), edge (3928 ha 2.08%) and loop (492 ha 2.16%).

Figure 6, gives an idea how much habitat there is for each MSPA class per year for the entire study area. Core habitat has the highest amount in hectares followed by background (non-habitat). Based on results, the amount of core habitat slowly declined and non-habitat gained as the years progressed overtime.

Table 8: Study Area MSPA Results

MSPA Study Area Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	198	0.33	66	0.11	264	0.44
Edge	1214	0.65	2714	1.43	3928	2.08
Perforation	-675	-0.69	-807	-0.83	-1481	-1.53
Islet	15	0.28	131	2.32	146	2.59
Bridge	284	0.95	557	1.83	840	2.77
Loop	-52	-0.23	544	2.39	492	2.16
Core	-2530	-0.16	-8421	-0.54	-10951	-0.7
Background	1545	0.2	5217	0.66	6762	0.85

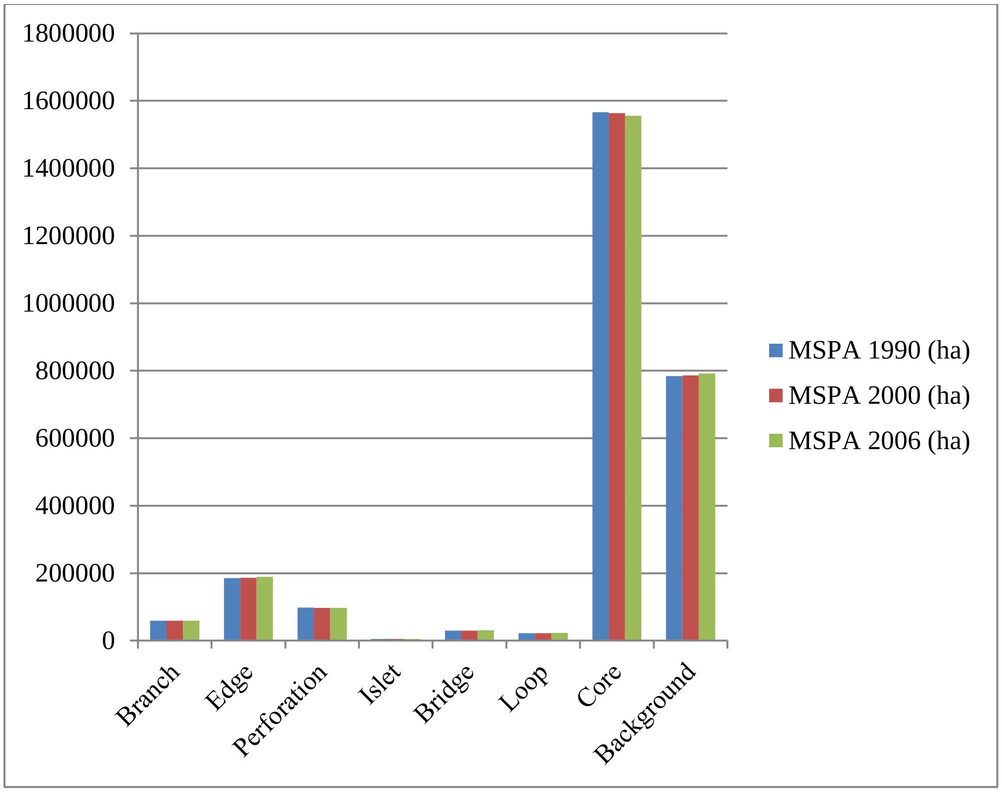

Figure 6: Total Hectares For Each MSPA Class For Entire Study Area

The protected areas have a total net change gain in core (417 ha, 0.09%) and a loss in non-habitat of (305 ha, -0.29%). However, most of that core gain happened in 1990-2000 (933 ha) and loss of 516 ha in 2000-2006 (Table 9).

Table 9: MSPA Results for Protected Areas

MSPA Protected Areas Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	77	0.94	-131	-1.62	-53	-0.66
Edge	-488	-1.92	-291	-1.16	-779	-3.1
Perforation	190	0.5	337	0.88	527	1.37
Islet	18	8.39	8	3.73	27	11.8
Bridge	91	2.37	63	1.61	155	3.94
Loop	-35	-0.6	46	0.78	11	0.19
Core	933	0.21	-516	-0.11	417	0.09
Background	-787	-0.75	482	0.46	-305	-0.29

During 1990-2000, Cantabria gained 1,158 ha of core, and then in the following six years (2000-2006) it lost 9,778 ha of core (total loss of 8,620 ha). It's important to note that Cantabria had minimal net change loss for most categories in 1990-2000 (Table 10). However, in 2000-2006, these losses became large gains. The biggest gains in net change for 2000-2006 include: edge (2,944 ha 11.14%), bridge (427 ha 8.11%), loop (332 ha 7.22%) and non-habitat (6,376 ha 4.88%).

Table 10: MSPA Results for Cantabria

MSPA Cantabria Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	-76	-0.68	291	2.54	215	1.88
Edge	-22	-0.1	2944	11.14	2922	11.05
Perforation	-66	-0.41	-592	-3.84	-658	-4.27
Islet	-83	-5.73	-1	-0.1	-84	-5.83
Bridge	-101	-2.09	427	8.11	326	6.19
Loop	-53	-1.25	332	7.22	278	6.06
Core	1158	0.44	-9778	-3.83	-8620	-3.37
Background	-756	-0.61	6376	4.88	5620	4.3

Asturias has the most protected area; therefore brown bear habitat isn't as fragmented. In 1990-2000, there was a loss of 3,594 ha of core and a gain 193 ha in 2000-2006 with a total net change -0.71% (Table 11). As for non-habitat, there was a gain of 2,786 ha in 1990-2000, and a loss of 219 ha in 2000-2006, with a total net change of 1.21%. The highest gains and losses in total net change are edge (1345 ha 2.14%), perforation (-1341 ha -4.16%), islet (86 ha 4.09%) and bridge (384 ha 3.07%). The gain of core and loss of non-habitat in 2000-2006, though quite small, may indicate the possibility of establishment of protected areas and management policies becoming more effective.

Table 11: MSPA Results for Asturias

MSPA Asturias Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	297	1.39	14	0.07	311	1.45
Edge	1627	2.58	-282	-0.45	1345	2.14
Perforation	-1418	-4.41	77	0.24	-1341	-4.16
Islet	46	2.82	39	2.34	86	5.09
Bridge	235	1.9	149	1.19	384	3.07
Loop	21	0.27	30	0.37	51	0.64
Core	-3594	-0.75	193	0.04	-3401	-0.71
Background	2786	1.32	-219	-0.1	2566	1.21

The highest total net changes for the western and eastern subpopulations are islets. The total net change of islets for the western subpopulation is 16.17%, and for the eastern subpopulation is 43.57% (Table 12). The eastern subpopulation has high gains in edge (950 ha 12.2%), branch (261 ha 6.37%) and non-habitat (2,236 ha 3.87%). As for the western subpopulation, gains are high in bridge (364 ha 6.05%) and edge (1,203 ha 3.65%). The main difference between the two subpopulations is the amount of protected areas found in the western subpopulation and its relationship with Asturias.

Table 12: MSPA Results for the Western and Eastern Subpopulations

MSPA Eastern Population Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	80	2.04	181	4.42	261	6.37
Edge	209	2.97	741	9.51	950	12.2
Perforation	-264	-1.22	-18	-0.08	-282	-1.31
Islet	25	18.56	60	30.71	86	43.57
Bridge	37	2.68	28	2.02	65	4.64
Loop	-45	-1.97	129	5.35	84	3.49
Core	-1040	-0.36	-2360	-0.83	-3400	-1.19
Background	998	1.76	1238	2.14	2236	3.87
MSPA Western Population Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	278	2.5	-21	-0.19	257	2.32
Edge	1795	5.36	-592	-1.8	1203	3.65
Perforation	-1071	-3.3	160	0.49	-911	-2.79
Islet	52	9.14	48	7.74	100	16.17
Bridge	200	3.41	164	2.73	364	6.05
Loop	72	1.25	-30	-0.52	42	0.74
Core	-3817	-0.98	145	0.04	-3672	-0.95
Background	2492	2.11	125	0.11	2617	2.22

The area of concern (Fundacion Oso Pardo's area of interest for connectivity) between the two subpopulations has interesting results (Table 13). Unlike other portions of the study area discussed above, this area has a total net gain of core (4,746 ha 1.65%) and a loss of non-habitat (-4105 ha 2.89%). The highest loss was islets (-7.79%) and highest gain was bridges (2.44%).

Table 13: MSPA Results for the FOP Area of Concern

MSPA FOP Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	-135	-1.18	-39	-0.35	-174	-1.53
Edge	-447	-1.07	112	0.27	-334	-0.8
Perforation	-167	-1.1	-14	-0.09	-181	-1.2
Islet	11	1.17	-80	-9.06	-69	-7.79
Bridge	38	0.55	135	1.91	173	2.44
Loop	-38	-0.91	-17	-0.4	-55	-1.32
Core	3556	1.24	1190	0.41	4746	1.65
Background	-2818	-1.97	-1287	-0.91	-4105	-2.89

As for Castilla y Leon (Table 14), the islet class has the highest gain at 155 ha (7.75%). During 1990-2000, there were core losses of 389 ha, however, in 2000-2006, the core class gained 928 ha. As for non-habitat, there was total net loss of 904 ha.

Table 14: MSPA Results for Castilla y Leon

MSPA Castilla y Leon Net Change						
Category	1990-2000 (ha)	% Change	2000-2006 (ha)	% Change	1990-2006 (ha)	% Change
Branch	-84	-0.4	-155	-0.74	-239	-1.14
Edge	885	1.08	86	0.1	971	1.18
Perforation	-458	-1.12	-312	-0.77	-770	-1.9
Islet	53	2.82	101	5.07	155	7.75
Bridge	70	0.76	53	0.57	124	1.33
Loop	73	0.94	52	0.66	125	1.6
Core	-389	-0.05	928	0.13	538	0.07
Background	-150	-0.04	-753	-0.19	-904	-0.23

Since Cantabria experienced the most net change for 2000-2006, two maps were created to show the amount of brown bear habitat fragmentation change and core habitat losses and gains (Figure 7). In 2000-2006, most change of brown bear habitat fragmentation came from core as it lost 7,004 ha to background (non-habitat); 3,969 ha to edge, and 3,446 ha to perforation. Habitat fragmentation is based on how much core has been lost to the all classes, and habitat loss is based on how much core has been lost to background (non-habitat). The amount of core habitat gain for Cantabria was 5,523 ha and a loss of 15,301 ha.

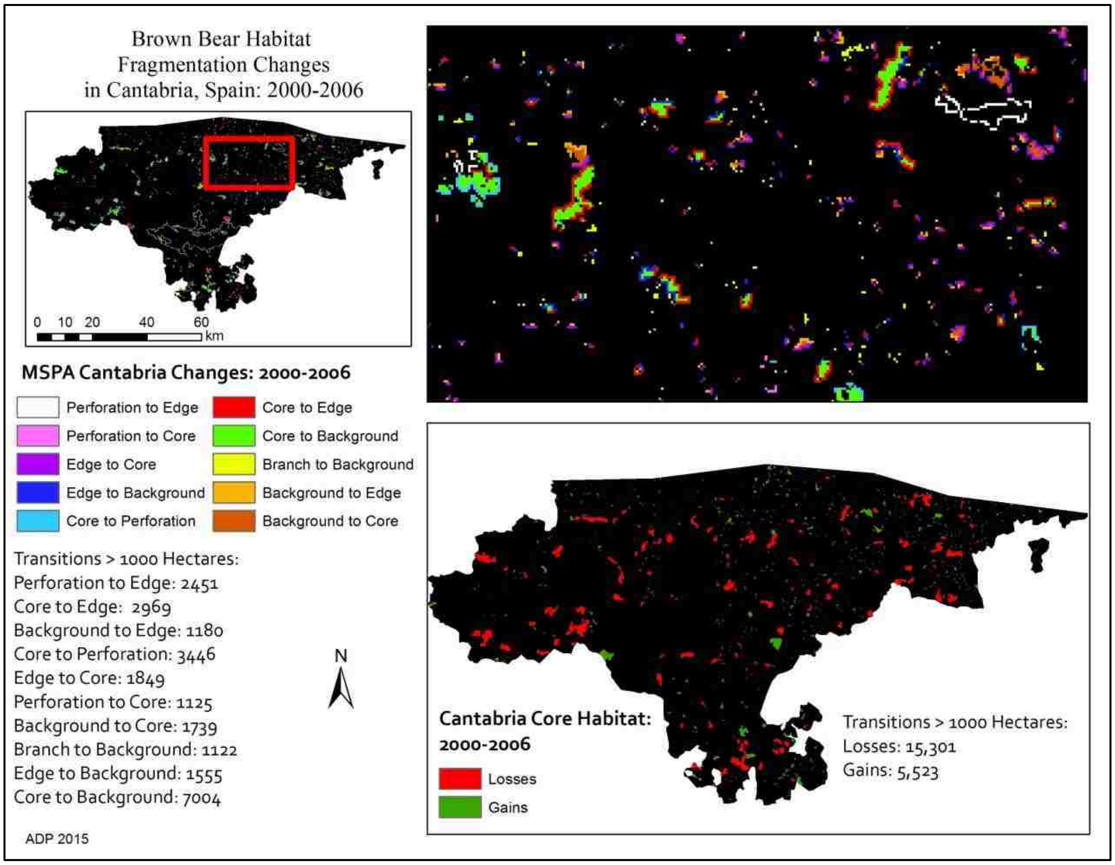

Figure 7: Brown Bear Habitat Fragmentation Change for Cantabria, Spain, 2000-2006

4.2. HABITAT CONNECTIVITY

Current maps are created for every pair for focal nodes in the pairwise mode, and will be identical due to symmetry. However the study area was still too large, and Circuitscape failed to create all 250 output maps for all the focal patches due to memory issues. Circuitscape only produced ninety-four output maps for five focal patches (three breeding patches and two population patches). However, most of the output maps had similar patterns; to avoid redundancy, two Circuitscape output maps will be discussed.

For the connectivity maps, yellow represents areas of high current flow (connectivity) and dark purple represents low current flow. Bright yellow areas highlight pinch points and indicate essential connectivity areas. As important note, areas with little or no current flow can be interpreted as less important for connectivity, but only for the node pairs used. Note the highest current density values tend to be found at the nodes themselves, which is an artifact of the way current flow is calculated.

In Figure 8, currents are flowing from a breeding patch to a population patch across the entire study area. At this scale it's hard to interpret important areas of concern; however, most of the connectivity tends to flow across the center of the map, west to east (or vice versa). Since the breeding patch is located at the western end of the map, current density is low when it reaches the far eastern population patch. Current density is still prominent in high resistance places and connectivity is happening between the subpopulations.

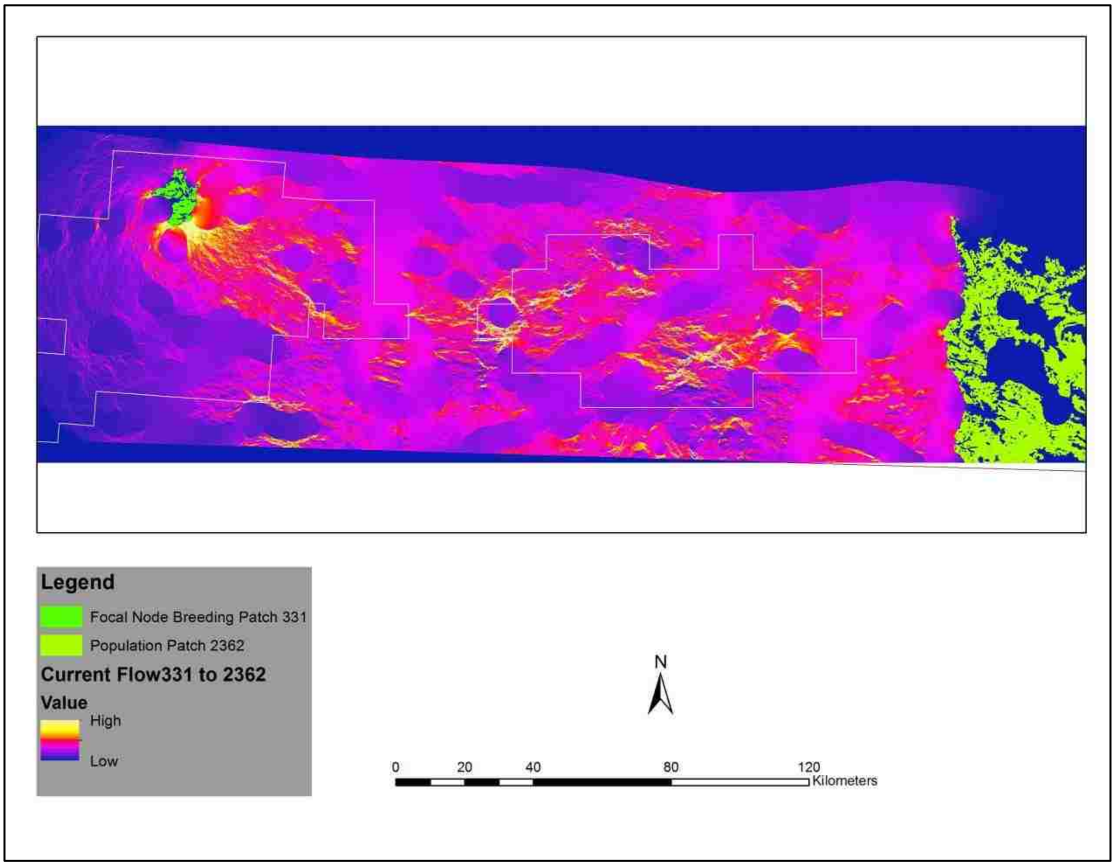

Figure 8: Potential Connectivity for Entire Study Area

In Figure 9 we see connectivity happening between two population habitat focal nodes. Analyzing connectivity at different scales is very crucial for determining critical areas of concern. By looking at the images, pinch points and high connectivity are present between the subpopulations, which indicate possible passageways for brown bear dispersers. As a reminder, circuit connectivity works when currents pass through focal core habitats in which can be used to predict expected net movement probabilities (MacRae et al. 2008). Current density can be used to identify landscape corridors or "pinch points," areas in which dispersers have a high likelihood of passing (MacRae et al 2008). When there is high connectivity in the landscape, the current has a high value. The more alternative pathways that exist to move between core habitats, the broader is the random walker distribution, and therefore, the lower the current flowing along any single path. The fewer alternative pathways exist, the higher the current flowing through the existing paths (Braaker et al. 2014). Circuitscape is based on electrical circuit theory; therefore, both minimum movement cost and alternative pathways are taken into account to predict movements (McRae et al. 2008).

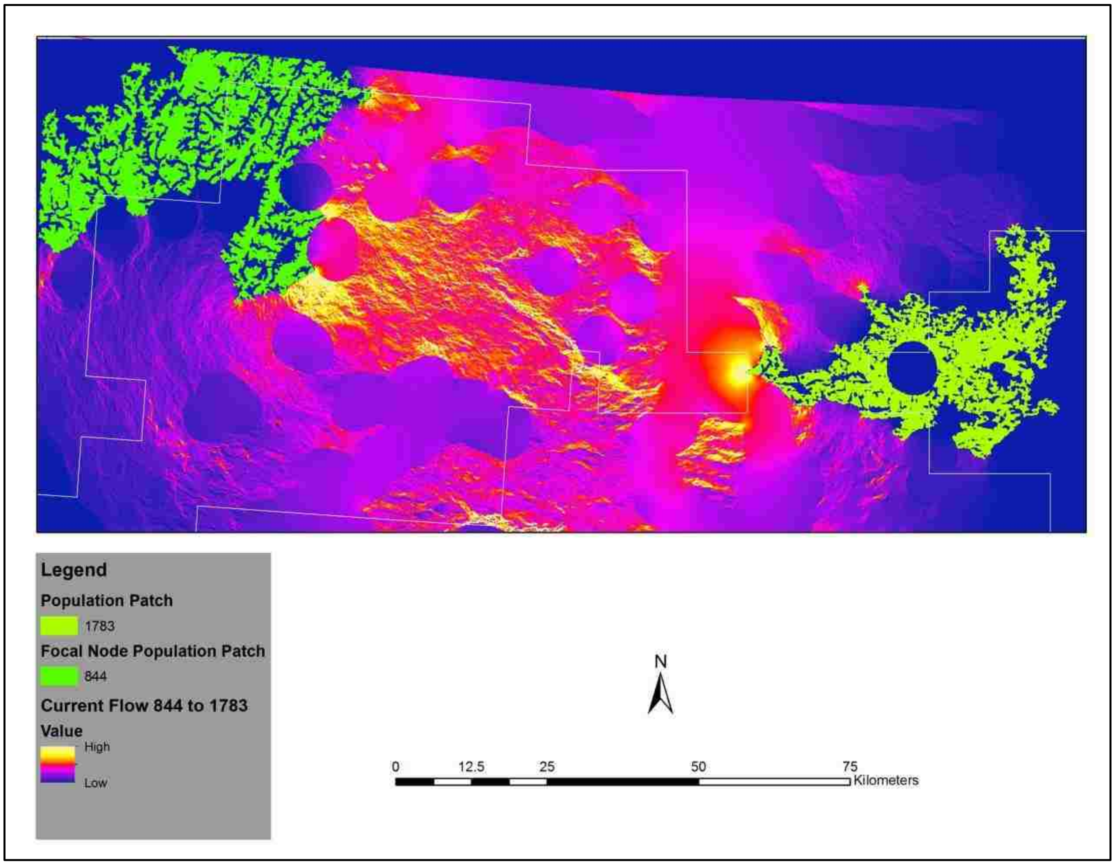

Figure 9: Potential Connectivity between Subpopulations (i.e., near the middle of the study area).

5. Discussion

Based on the MSPA results for the entire study area, high fragmentation occurred in core habitat between 2000 and 2006. The province of Cantabria suffered the most of this loss due to development found mostly in its center. However, the eastern subpopulation distribution area lies in the southwestern portion of Cantabria along the Cantabrian Cordillera, where there seems to be more habitat with less fragmentation (Figure 10). But since the eastern subpopulation lies within three provinces, brown bear management policies are different, which leads to possible gaps in management practices. Therefore, it's important to implement large landscape conservation management practices to insure integration of multijurisdictional land management.

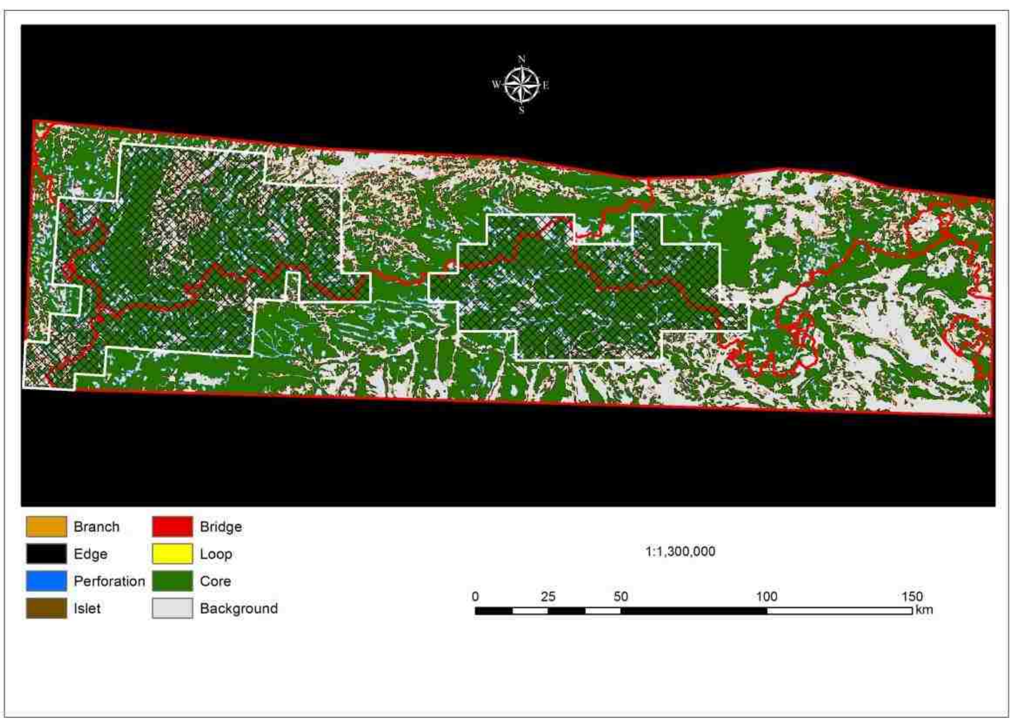

Figure 10: MSPA 2006

What is important to take into consideration about MSPA, it only analyzed the structural landscape of 'natural' brown bear habitat; it did not include weighted factors to evaluate brown bear behavior(this study did not consider species presence-absence data so it is uniformed by data concerning bear distributions and habitat utilization). Such weighting factors are important to analyze functional connectivity in the landscape. The MSPA model shows how fragmented the landscape is based on how many (i.e., 'islets', 'branches', 'core' and 'background') areas there are in the landscape.

There are some discrepancies in the habitat suitability model (HSM) that was created for the corridor modelling performed in Circuitscape. In this HSM, the Euclidian distances determined for roads and railways are not necessarily as fully informative as they should be because these features have tunnels that are not represented in the GIS data; all road and railway segments were included for Euclidian distance analysis (Figure 11). Figure 11 highlights example areas in the study area where there are discrepancies in the HSM (resistance) map (of roads/railways that have tunnels) along with a MSPA map to show that there is actual where those roads/railways are located. For the Circuitscape model, weighting factors were based on expert knowledge from brown bear literature. The resistance map did not affect the connectivity model too much in areas where there is actual habitat based on MSPA results other than the exclusion of high current density flow in these areas (Figure 11). However, there was some current density to indicate the potential for movement of bears across these high resistance areas.

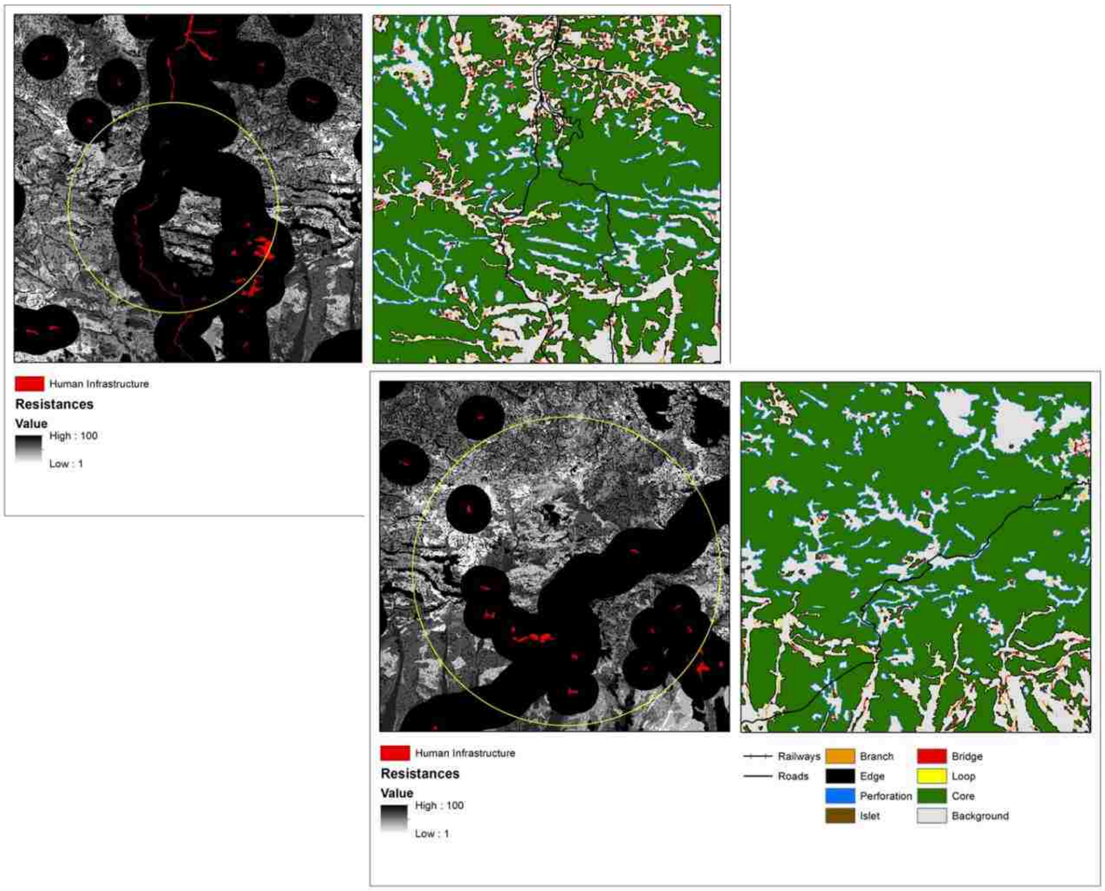

Figure 11: Resistances vs MSPA

Having diverse landscapes provides an opportunity to study the whole range of land cover types and other factors ranging from low to high movement resistance. Circuitscape relies both on resistance surfaces and multiple pathways, which makes it well adapted to modeling connectivity in a complex environment. Connectivity maps produced by Circuitscape highlight pathways crucial to maintain overall connectivity

(McRae et al. 2008). Low current areas, however, can represent either high-resistance areas (barriers) or large swaths of low-resistance cells (large corridors), because both reduce current flow in a single cell (Braaker et al. 2014).

It is important to emphasize connectivity pinch points; because they are narrow corridors leading to high current flow. The distinction between barriers and large corridors is only possible with a corresponding resistance map (Figure 12).

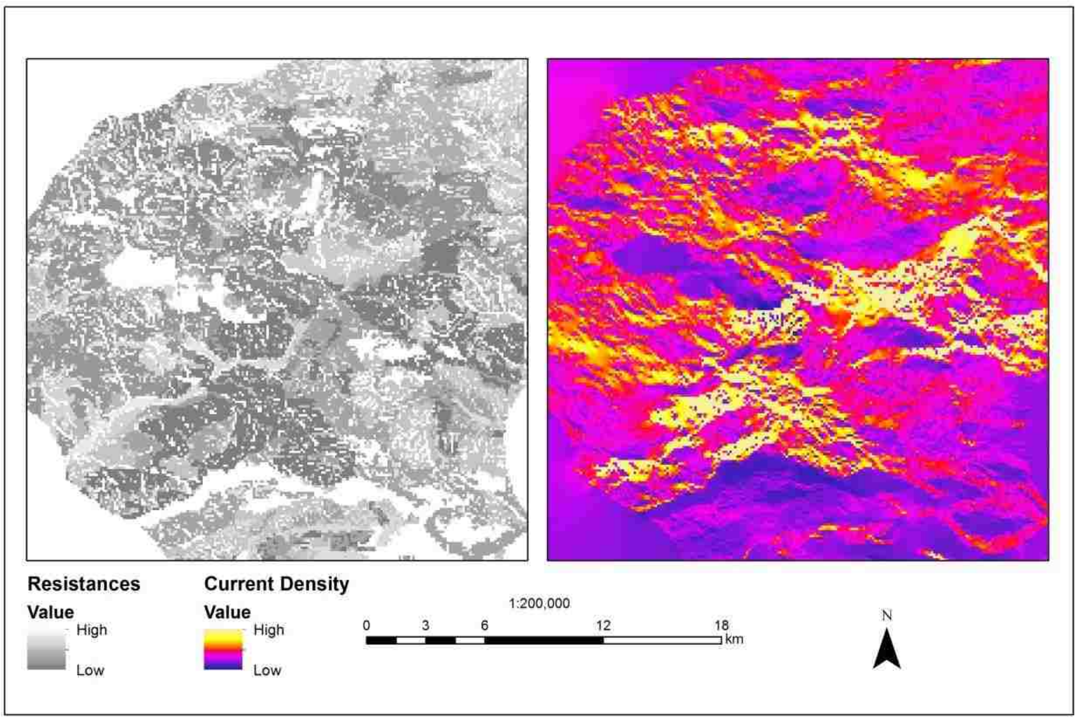

Figure 12: Detail Of Current Connectivity Flow Map With Resistance Map

Data collection is a very critical process in any type of project and acquiring "accurate" and "precise" data of high quality is a necessary requirement for producing acceptable results. However, lack of funding and access to high-quality datasets can affect any study. Because of the extent of the study area, not all roads were included in the study area, only main highways and railways. Also, other road datasets (i.e., private and/or forest roads) were unavailable for in- depth analyses. Other datasets such as livestock were not included for the study, mainly because they were not accessible. There were some discrepancies in the human infrastructure datasets, which created problems when setting buffer distances to meet the needs of the species. Instead of indicating the correct distance for avoiding human infrastructure at 0-500 meters, the processing toolbox set parameters of 0-3900 meters as its minimum avoidance setting. These parameters produced spurious results for the habitat suitability model as well as the final connectivity outputs.

Overall, this research project emphasized the importance of obtaining reliable data. At an international level, this can be difficult without proper funding, available data and important contact information. The connectivity portion of the thesis was challenging, but provided learning experiences for future research possibilities.

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