All Roads Lead to Fragmentation: Exploring Habitat Connectivity and Wildlife Underpasses through the Florida Panther and the Jaguar

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Carroll Courtenay
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Dr. Salisbury

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I. Introduction

The global transportation system is the "giant now embracing us," and its omnipresent nature influences ecosystems worldwide (Forman, 1998: iv). The diversity of environmental effects associated with transportation systems challenges researchers to focus on concrete aspects of intertwined ecological systems. Examining habitat fragmentation associated with transportation networks, however, exposes some of the most direct impacts of these networks on fauna populations. As transportation networks expand, road corridors hinder habitat connectivity, which can greatly impact habitat health and genetic diversity in ecosystems (Corlatti et al., 2009; Tewksbury et al., 2002). Animal-vehicle collisions, decreased reproductive success, movement constraints, decreased colonization, and increased extinction rates associated with habitat fragmentation due to roads affects population densities, biodiversity, and ecosystem processes (Beckmann & Hilty, 2010). These factors influence direct and indirect habitat loss, which decreases habitat connectivity and isolates small populations (Beckmann & Hilty, 2010; Schwab & Zandbergen, 2011; Goosem et al., 2005). Habitat fragmentation is particularly detrimental for populations of rare, wide-ranging, and low-density species of wildlife that require large amounts of land to meet their ecological needs or for seasonal migratory movements (Beckmann & Hilty, 2010). Current research promotes habitat connectivity in landscapes fragmented by roads to minimize some of these ecological effects (Beckmann & Hilty, 2010; Goosem et al., 2005; Laurance et al., 2004; Colchero et al., 2010).

In tropical rainforests, habitat fragmentation caused by roads is particularly disruptive to ecosystems (Laurance et al., 2009). Fauna in tropical rainforests are adapted to structurally complex habitats that are cool, moist, and relatively stable (Goosem et al., 2005). Clearings for roads, however, are structurally barren, introduce edge habitat, and have intense environmental extremes in terms of temperature, humidity, and wind compared to intact forest (Beckmann & Hilty, 2010; Laurance et al., 2009; Goosem et al., 2005). Many tropical rainforest species therefore avoid clearings and forest edges, and this means even the narrowest road clearings can fragment intact tropical rainforest ecosystems by creating barriers for "the movements of specialized tropical rainforest fauna" (Goosem et al., 2005: 304). This barrier effect is further exacerbated by increased traffic, pollution, and noise, as well as by clearings, cuttings, or embankments associated with roads (Goosem et al., 2005).

Even though road clearings act as barriers, wildlife still attempt to cross roads to access habitat, and with extensive road use and development comes increased vehicle-related wildlife mortality. In 2003 alone, 15,000 animals were killed on highways in the regions of Pantanal and Cerrado in Brazil (Fischer et al., 2003). In order to protect populations of many unique species in the Amazon, habitat connectivity must be maintained to reduce road kill, predation, and hunting opportunities while providing natural habitat corridors to encourage fauna movement and dispersion (Laurance et al., 2009; Goosem et al., 2005). Wildlife underpasses are increasingly popular ways to maintain habitat connectivity in areas divided by transportation systems. It remains to be seen, however, whether these types of connections are effective in tropical rainforests, and if they will influence targeted top predator movement. Using the Florida panther (*Concolor coryi*) and the jaguar (*Panthera onca*) as comparative case studies, this paper explores the potential of wildlife underpasses as effective habitat connections in tropical rainforests, especially related to the construction of future habitat corridors and conservation networks (Colchero et al., 2010; Foster & Humphrey, 1995).

II. Habitat Corridors and Wildlife Underpasses: Background

Habitat connectivity studies show natural habitat corridors facilitate about 50 percent more wildlife movement between core areas of habitat than unconnected areas, which suggests protecting existing habitat connections may be more important than creating connectivity (Gilbert-Norton et al., 2009). Interconnected habitats help alleviate pressures of stochastic processes on populations such as demographic uncertainty, environmental uncertainty, genetic uncertainty, and natural catastrophes (Quigley & Crawshaw, 1992). Road construction, however, bisects intact habitats and typically leaves no way to maintain natural habitat connectivity. Wildlife underpasses help limit barrier effects of roads with artificial connectivity (Goosem et al., 2005; Goosem et al., 2001).

Many wildlife underpasses incorporate natural components of ecosystems to facilitate species movement. Research shows maintaining unobstructed views of habitat on the far side of underpasses and locating underpasses where wildlife naturally cross roads are two of the most important variables in determining the effectiveness artificial connections (Foster & Humphrey, 1995). Most wildlife underpasses have natural footing, along with other natural components, such as leaves, rocks, or logs, to encourage species movement (**Figure 1**) (Goosem et al., 2005). Fencing along roads is used to funnel species to underpasses and restrict road access (Foster & Humphrey, 1995). Natural habitat corridors leading to the mouths of underpasses, called revegetated corridors, are also used to encourage the use of underpasses by species from forest interiors (Goosem et al., 2005; Foster & Humphrey, 1995). Even with these infrastructural modifications, species require time to adapt to artificial movement structures and must learn how to use these habitat connections (Clevenger & Waltho, 2000). Human or predator activity and other landscape characteristics, however, may discourage species use of underpasses (Clevenger & Waltho, 2000). “Once adaptation has occurred, the dynamics of human activity and attributes of landscape heterogeneity, [rather than structural attributes], may play a larger role” in determining which species use underpasses (Clevenger & Waltho, 2000: 54).

Figure 1. An underpass with natural components to facilitate species movement (Goosem et al., 2005).

Wildlife underpasses are relatively new ways to create artificial connectivity under roads, and it is difficult to determine how heavily these road crossings are used (Corlatti et al., 2009; Goosem et al., 2005; Foster & Humphrey, 1995). Most studies assessing the use of wildlife crossings are observational and rely on sand tracking, trapping and remote photography around wildlife under- and overpasses (Corlatti et al., 2009; Goosem et al., 2005; Clevenger & Waltho, 2000). The detection of rare species may be difficult because of low abundance, and many tracks found at mouths of wildlife underpasses are unidentifiable. It is also hard to distinguish unique “small species” from more common mammals in both photographs and sand trapping, which can make rare-species identification difficult (Goosem et al., 2005: 313). Consequently, it is difficult to establish accurate samples of fauna that use wildlife crossings because extensive funding is required to finance fine-scale tracking methods or remote photography and monitoring (Goosem et al., 2005). These methodological issues make studying the use of wildlife underpasses in the Amazon even more difficult, as there is often limited funding for conservation initiatives and frequent rains make tracking difficult. Habitat corridors and underpasses, however, are a conservation solution easily understood by the public and government officials (Simberloff et al., 1992). Underpasses are fairly obvious infrastructure projects and this visibility makes governments and the public believe they are "doing something for conservation" (Simberloff et al., 1992: 500). It may be possible to use this motivation to tap into funding for artificial connections, especially as more research and case studies evaluate the usefulness of underpasses to promote habitat connectivity.

III. The Florida Panther (*Concolor coryi*)

Wildlife underpass use by Florida panthers has been widely studied, and findings from this research can be applied to a number of different species. Originally found throughout the southeastern United States, Florida panthers' current range consists of about 10,000 square kilometers south of Lake Okeechobee in south Florida (**Figure 2**) (Schwab & Zandbergen, 2011; Kautz et al., 2006). The Florida panther's habitat is constricted because of habitat constraints from habitat fragmentation, human development expansion, and road construction. Florida panthers are one of the most highly publicized endangered species in the United States, and there are only 70 to 100 individuals left in the wild (Schwab & Zandbergen, 2011; Kautz et al., 2006; Foster

Figure 2. Historic and current range of Florida panther (New York Times Company, 2006)

& Humphrey, 1995). In 1995, eight Texas panthers were released in south Florida to offset inbreeding depression, however the small Florida panther population is still subject to continued genetic problems without range expansion and reintroduction in other parts of Florida (Schwab & Zandbergen, 2011; Jansen et al., 2010).

Florida panthers can disperse between 20 and 68 kilometers at one time (Kautz et al., 2006). The wide-ranging nature of Florida panthers makes it difficult to target specific locations for protection, therefore, one of the most important conservation strategies for the species is to maintain connectivity between populations (Schwab & Zandbergen, 2011). Two major roads in south Florida, I-75 and SR29, however, act as major barriers to the dispersal of Florida panthers (Schwab & Zandbergen, 2011; Jansen et al., 2010; Kautz et al., 2006; Foster & Humphrey,). About six Florida panthers die in vehicle-related accidents each year, which greatly impacts the already small panther population. Radio telemetry tracking shows roads create a “cage effect” and panthers’ home ranges follow length of roads, “much as a captive animal paces the length of its cage,” but rarely cross the roads (**Figure 3**) (Schwab & Zandbergen, 2011: 865). Adult females are more deterred by roads than adult males, who often have large home ranges, and juveniles, who are searching for their own home ranges, who are more likely to cross roads (Schwab & Zandbergen, 2011; Kautz et al., 2006; Meegen & Maehr, 2002; Foster & Humphrey, 1995).

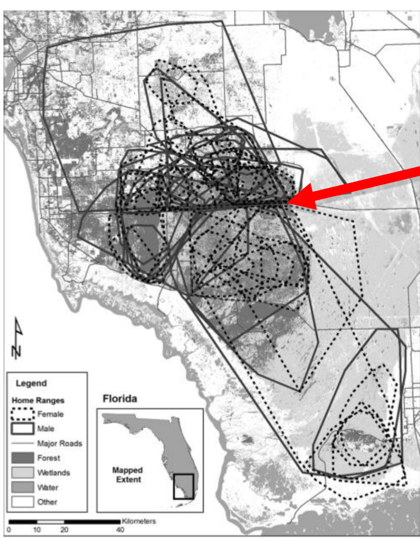

Figure 3. Florida panther’s home ranges influenced by the “cage effect” due to I-75 (Schwab & Zandbergen, 2011).

In 1993, 23 underpasses were completed under I-75 in order to facilitate Florida panther movement and reduce road kill (Foster & Humphrey, 1995). Most previous research on the effectiveness of highway underpasses for wildlife focuses on ungulates, and the construction of the I-75 underpasses was largely experimental (Foster & Humphrey, 1995). Each underpass consists of two bridges constructed of concrete under the four-lane divided highway (Foster and Humphrey, 1995). The underpasses offer an unobstructed view of habitat on the other side, and concrete offers some soundproofing from traffic above (Jensen et al., 2010). Chain-link fencing with barbed wire funnels animals to underpasses and excludes them from I-75 (Foster and Humphrey, 1995). The underpasses were sited in areas of known panther movement or in areas where panthers were previously killed by vehicles, which were identified as potential crossing zones for panthers (Jensen et al., 2010; Meegan & Maehr, 2002). They also connect appropriate habitats for the Florida panther, as forests are important diurnal resting areas for panthers and "stepping stones" of small, forested habitats are important to promote Florida panther range expansion (Schwab & Zandbergen, 2011; Kautz et al., 2006; Meegan & Maehr, 2002). Studies conducted after construction was completed showed Florida panthers use underpasses and the underpasses appear to reduce panther mortality along the fenced section of I-75 (Meegan & Maehr, 2002; Foster & Humphrey, 1995). In this way, underpasses successfully prevent roads from becoming demographic sinks for Florida panthers and aid in their dispersal and range expansion (Foster & Humphrey, 1995).

Even though underpasses encourage some panther movement, many panthers still do not use these artificial connections. Forty-eight percent of males and 83 percent of females monitored within 1.6 kilometers of I-75 have still not crossed the road, although research attributes hesitation to a period of adaptation for panthers (Jensen et al., 2010; Clevenger & Waltho, 2000). Panthers are often scared away by human use of underpasses and do not seem to use artificial connections that are also used by humans (Foster & Humphrey, 1995; Jenson et al., 2010). Other habitat and species characteristics, such standing water and shyness, also influence panther use of underpasses (Foster & Humphrey, 1995; Jenson et al., 2010). Only 64 kilometers of the I-75 is fenced off from wildlife, however, and Florida panthers continue to be killed on other areas of I-75 (Jensen et al., 2010). Nonetheless, these underpasses greatly reduce the number of panthers killed on the highways, and many researchers support the replication of this type of underpass design to increase habitat connectivity (Jensen et al., 2010).

IV. The Jaguar (*Panthera onca*)

The jaguar is another threatened large cat species found in the Americas with populations greatly reduced due to habitat fragmentation. The jaguar's historic range stretches from the southern United States to northern Patagonia (Quigley & Crawshaw, 1992). Currently, however, jaguars occupy only 33 percent of their former range in Central America and 62 percent of their former range in South America (**Figure 4**) (Quigley & Crawshaw, 1992). Jaguars occur in very low densities throughout their range and are consider 'near-threatened' by the International Union for Conservation of Nature (IUCN) (IUCN Red List, 2011; Quigley & Crawshaw, 1992). Although this threatened status is mostly attributed to habitat fragmentation, hunting for fur trade and persecution of livestock predation also contribute to declining numbers of jaguars in the Americas (Rabinowitz & Zeler, 2010).

Figure 4. Historic and current range of jaguar (New Junkie Post, 2012)

Like Florida panthers, jaguars have large home ranges and can also disperse between 20 and 64 kilometers (Rabinowitz & Zeller, 2010). They can also travel up to 15 kilometers in one night (Rabinowitz & Zeller, 2010). These types of wide-range dispersal patterns make jaguar habitat corridors and underpasses feasible options for increasing habitat connectivity (Rabinowitz & Zeller, 2010). The Amazon Basin is the largest contiguous area of jaguar range, containing 88 percent of the jaguars' occupied range, because jaguars prefer to move through dense forest (Rabonwitz & Zeller, 2010). Regional differences in habitat and prey availability, however, make it difficult to determine "prime" jaguar habitat (Colchero et al., 2010; Rabionwitz & Zeller, 2010; Quigley & Crawshaw, 1992). "Because jaguars as a species range across many different nations and habitat types, small-scale conservation efforts selected ad hoc and focused over narrowly defined areas have not succeed in stemming the tide of jaguar extirpation" (Sanderson et al., 2002: 59). Large-scale conservation plans connecting important habitats and breeding areas are therefore important to maintain jaguar population health (Rabinowitz & Zeller, 2010; Sanderson et al., 2002; Quigley & Crawshaw, 1992).

Roads, however, act as major barriers for jaguar dispersal and fragment large-scale conservation plans. Although males cross road with higher frequency than females, jaguars generally avoid roads and are "reluctant to cross man-made 'boundaries'" (Quigley & Crawshaw, 1992: 154; Colchero et al., 2010). Roads also inevitably increase human access to remote areas and encourage human settlement and infrastructure development (Beckmann & Hilty, 2010). This causes jaguars to change their behavior and ranges, as jaguars avoid even small densities of human settlement (Colchero et al., 2010; Rabinowitz & Zeller, 2010). Human encroachment associated with roads therefore leads to indirect habitat loss and fragmentation (Colchero et al., 2010; Rabinowitz & Zeller, 2010). The success of wildlife underpasses in southern Florida for the Florida panther, a large cat species with similar behavioral characteristics, however, demonstrates how underpasses might maintain connectivity in larger jaguar conservation plans fragmented by roads.

V. Focus on Charismatic Megafauna

The comparison in this paper focuses on two of the most charismatic megafauna in the Americas—the Florida panther and jaguar. While funding and infrastructure development associated with habitat connectivity and wildlife underpasses may focus on specific species, these conservation initiatives are likely to have cascading effect on non-target species (Clevenger & Waltho, 2000). Conservation initiatives and planning centered on large predators, such as the Florida panther and jaguar, offers protection for entire "functioning ecosystems," as the wide-ranging and low-density nature of these felines promotes protection and connectivity of large amounts of land (Quigley & Crawshaw, 1992: 155; Beckmann & Hilty, 2010; Meegan & Maehr, 2002; Clevenger & Waltho, 2000). In this way, these top predators are important diplomats for promoting conservation ideals associated with habitat connectivity because of the public's fascination with these species.

VI. The Complexities of Roads

The proliferation of roads in existing core habitat complicates developing conservation networks to protect, establish, and promote habitat connectivity for the Florida panther and the jaguar. Numerous ecosystem and anthropological factors influence panther and jaguar response to wildlife underpasses. These notoriously reclusive felines have complex responses to roads, associated traffic, and human activity (Schwab & Zandbergen, 2011; Colchero et al., 2010; Rabinowitz & Zeller, 2010; Kautz et al., 2006; Foster & Humphrey, 1995; Quigley & Crawshaw, 1992). Ecological changes related to roads and road networks can also greatly impact the way these animals travel across the landscape (Schwab & Zandbergen, 2011; Rabinowitz & Zeller, 2010; Meegan & Maehr, 2002). This paper takes the opportunity to integrate existing theories about environmental impacts, habitat fragmentation, and changes species behavior associated with roads through an interdisciplinary and holistic road ecology approach, in order to examine the feasibility and value of wildlife underpasses to maintain habitat connectivity for jaguars in tropical rainforests.

Studies of the consequences of road network development have not typically taken comprehensive approaches. Historically, transportation networks were seen as "required infrastructure for increasing productivity in a region" and necessary structural components for both economic and social progress (Coffin, 2007: 396). Planners gave little thought to their functionality or environmental impact, and studied road networks through a narrow anthropocentric lens with little acknowledgement of the existence or value of alternative road planning or construction strategies to mitigate environmental damages and maintain ecological health Coffin, 2007; Forman et al., 2003a; Forman, 1998). Emphasis was placed solely on transportation networks' role in human expansion and economic development (Coffin, 2007; Forman et al., 2003a; Forman, 1998). Transportation planning focused exclusively on broad-scale anthropocentric engineering, and physical environment issues associated with road development and construction, but ignored direct and indirect ecological effects of road across landscapes (Forman, 1998).

There are, however, many unintended environmental and ecological consequences of roads (Laurance et al., 2009; Coffin, 2007; Forman et al., 2003a). Roads have diverse and wide-ranging environmental impacts, affecting both abiotic and biotic factors of ecosystems (Laurance et al., 2009; Coffin, 2007; Forman et al., 2003a; Seiler, 2001). Roads make major changes to hydrological components within ecosystems, influencing water quality, runoff, barriers to water flow, and peak flow (Coffin, 2007; Forman et al., 2003e). Erosion and sedimentation associated with roads also affects water quality (Laurance et al., 2009; Coffin, 2007; Forman et al., 2003e). Different types of pollution from the use or construction of roads impacts ecosystems, as well. Chemical pollutants and spills connected with road construction and maintenance persist in the environment for long periods of time and affect large areas due to storm runoff (Forman et al., 2003f; Seiler, 2001). Noise pollution from vehicle traffic is particularly detrimental to species that incorporate sound into basic behavior, such as birds, or species that avoid human activity (Coffin, 2007; Forman et al., 2003c). Finally, air pollution from vehicle emissions is “the most significant effect of road related transportation,” as air pollutants and changes in the Earth’s atmosphere affects both humans and environment (Coffin, 2007: 399; Seiler, 2001). In addition to changes in hydrology, erosion, and pollution, microclimatic changes in wind direction and speed, temperature, humidity, and isolation arising from the presence of roads can change ecosystem composition and impact ecological cycles in areas contiguous to, and far away from, roads (Laurance et al., 2009; Coffin, 2007; Forman et al., 2003a).

Biotic affects also change ecosystem structures and functions. Microclimatic changes encourage the spread of generalist and invasive species that exploit highly variable ecological conditions (Laurance et al., 2009; Coffin, 2007). Road networks facilitate the spread of these species across landscapes, which weaken ecosystem structures and components (Laurance et al., 2009; Coffin, 2007; Forman et al., 2003b). Road kill is one of the largest direct effects of roads, and in the United States “road kill… surpasse[s] hunting in its effect on vertebrate mortality” (Coffin, 2007: 399; Forman et al., 2003c; Seiler, 2001). When roads bisect migration routes and home ranges, many species come into contact with roads in search of food and water resources and den sites (Coffin, 2007; Forman et al., 2003c; Seiler, 2001). Roads therefore act as population sinks, as higher levels of animal activity on or along roads increases instances of animal-vehicle collisions (Coffin, 2007; Forman et al., 2003c; Kerley et al., 2001; Foster & Humphrey, 1995). Human activity and socio-economic transformation connected with roads also affects ecosystem health, structure, and function. Stresses associated with roads and human activity often force species to shift temporal patterns of dispersal, hibernation, or foraging to avoid human contact (Forman et al., 2003c; Seiler, 2001). Road and road networks also fragment habitats and create barrier and edge effects, which, combined with land use changes and loss of habitat, impedes movement of animals and separates breeding populations (Coffin, 2007; Forman et al., 2003c; Kerley et al., 2001).

VII. Creating an "Interdisciplinary Umbrella": Road Ecology

Interest in roads and associated impacts continues to grow as scientists, planners, and other interested parties realize and study environmental impacts of road networks and development. Virtually all landscapes include roads and road networks, and impacts of road networks extend over large areas through terrestrial ecosystems (Laurance et al., 2009; Riitters & Wickman, 2003; Coffin, 2007; Forman, 1998). The diversity of road impacts opens the door for different disciplines and techniques to examine a range of applications for this research in varying fields and locations. Until recently, however, there has been no way to unify diverse road studies. In this section, I will define road ecology and outline the history of the approach, before focusing how to incorporate road ecology into analysis of Florida panther and jaguar use of wildlife underpasses.

At the 1994 Ecological Society of America conference, only one study's title contained the word "road," and many ecological studies excluded this important environmental factor from analysis (Forman et al., 2003a). As scientists began to question effects of roads on flora, fauna water flows, erosion patterns, and wildlife movements on roads, there was no unifying discipline through which to examine the wide-ranging effects of roads (Forman et al., 2003a). Road ecology, a term coined by Richard T. T. Forman in 1998, "centers on understanding the interactions between road systems and the natural environment" and an interdisciplinary approach is necessary to incorporate the variety and breadth of ecological impacts associated with roads (Beckmann et al., 2010: xv; Coffin, 2007). The road ecology framework serves as an "interdisciplinary scientific umbrella," (Coffin, 2007: 397) and incorporates work from population ecology, stream biology, forestry, engineering, geography, wildlife ecology, conservation biology, landscape architecture, planning, landscape ecology, and civil engineering, as well as ideas of spatial pattern and process, network theory, metapopulation dynamics, stream corridor functions, and landscape change (Beckmann et al., 2010; Coffin, 2007; Forman, 1998).

The history of road ecology, and its inherently interdisciplinary approach, informs they way the discipline deals with the large physical extent of roads and associated ecological impacts. Road impacts do not only affect narrow swaths of land adjacent roads, but also affect ecosystems greater distances from roads (Coffin, 2007). The scalar extent of these impacts ranges from local to landscape, and the thematic extent ranges from urban to rural. Humans are inherently linked to roads, as roads are "both a result of the expanding footprint and a driver of human expansion" (Beckmann et al.3, 2010: xv). Ecosystems structures, processes, and components are changing and shifting in response to roads (Coffin, 2007). The discipline of road ecology makes it possible to incorporate different variables associated with these changes through interdisciplinary work. Different fields with different expertise tackle interconnected elements of the discipline, and inspire change within transportation planning by incorporating and engaging various entities into the planning process (Coffin, 2007; Forman, 1998). New ideas in road ecology aim to "provide for… ecological flows and biodiversity, as well as safe… and efficient mobility" (Forman, 1998: iv). In this way, collaborative research on roads proves useful to the transportation community, highway and road agencies, local governments, public and private forestry operations, parks agencies, non-governmental organizations, and environmental action groups (Forman, 1998).

VIII. Narrowing the Focus: Road Ecology and Wildlife Underpasses

A number of different approaches are necessary to examine the abiotic and biotic impacts of wildlife underpasses, and how these impacts affect Florida panther and jaguar use of these crossing structures. Road ecology provides the interdisciplinary framework necessary to connect and examine these diverse variables. This paper uses a road ecology approach to explore: (1) the importance of habitat connectivity for the Florida panther and the jaguar, and how roads directly affect habitat connectivity; (2) the ecological and anthropogenic impacts associated with roads that affect behavioral responses and use of habitat surrounding roads and wildlife underpasses; (3) structural components and construction techniques vital to promoting wildlife use of underpasses by the Florida panther and the jaguar; and (4) conservation opportunities associated with maintaining habitat connectivity with wildlife underpasses for the Florida panther and jaguar. These factors are important when designing and planning wildlife crossing structures, and a single-minded research approach would not incorporate the many variables that impact and influence Florida panther and jaguar use of wildlife underpasses. A comparative study between the Florida panther and the jaguar offers a useful way to apply the framework of road ecology to the findings of road studies across different landscapes, in order to inform the design and function of road networks and future wildlife underpasses (Coffin, 2007).

IX. Methods

The purpose of this paper is to explore the potential of wildlife underpasses as effective habitat connections in tropical rainforests, using the Florida panther and the jaguar as comparative case studies. To thoroughly approach this research question, however, it is essential to first comprehend the importance of habitat fragmentation, in order to understand how wildlife underpasses may facilitate habitat connectivity. Few studies tackle tropical rainforest habitat fragmentation due to roads, and because of this lack of data and analysis, it is valuable to examine roads, associated habitat fragmentation, and the success of wildlife underpasses in other ecosystems. Studies from different habitats offer insight into the ways tropical rainforest ecosystem processes, structures, and components may react to road network development, habitat fragmentation, and mitigation.

An understanding of road-based fragmentation in tropical rainforests provides a foundation for comparing the Florida panther, and its response to habitat fragmentation and wildlife underpasses to the jaguar's potential response to these factors in the tropical rainforest. While few studies examine jaguars and their response to roads, there is a wealth of information about Florida panthers, and their reaction to roads and wildlife underpasses. This paper will examine how Florida panthers and jaguars exhibit similar behavioral characteristics, occupy similar ecological niches, and have similar ecological requirements, all of which influence how these feline species may respond in similar ways to wildlife underpasses.

X. Cascading Effects of Habitat Fragmentation

Historically, large, wide-ranging carnivore species experience periods of extensive range collapse and high extinction rates (Rabinowitz & Zeller, 2010). Large carnivores are currently in a state of decline worldwide, and the Florida panther and the jaguar represent two species experiencing rapid population downturns (Rabinowitz & Zeller, 2010). These felines need large amounts of habitat to support healthy populations due to their ecological requirements, wide-ranging nature, and low population density (Kautz et al., 2010; Beckmann & Hilty, 2010; Forman et al., 2003c; Sanderson et al., 2002). Roads and associated habitat fragmentation and loss, as shown in **Figure 5**, initiate a number of cascading population, genetic, and environmental impacts on a multitude of scales. In this way, habitat fragmentation and habitat loss are two of the biggest threats to these species.

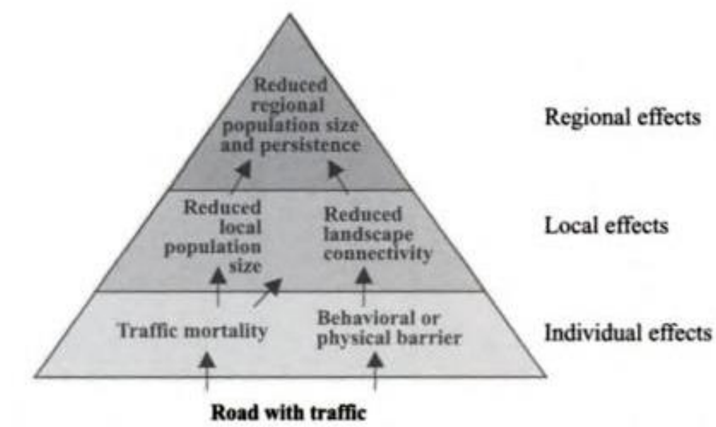

Figure 5. Cascading effects of road system on individual animals and wildlife populations (Forman et al., 2003c).

Connected habitat patches alleviate stochastic pressures, such as demographic, environmental, and genetic uncertainty, and increases the "chance of persistence in small populations" (Rabinowitz & Zeller, 2010: 939; Beckmann & Hilty, 2010; Quigley & Crawshaw, 1992). Conservation of corridors and habitat patches provides basic requirements for "species-persistence-genetic exchange" (Rabinowitz & Zeller, 2010: 939). Connecting species populations increases effective population size, decreases genetic drift and inbreeding, and increases mating ability, female fecundity, and juvenile survival (Rabinowitz & Zeller, 2010; Beckmann & Hilty, 2010; Tewksbury et al., 2002). Habitat connectivity also allows for repopulation of locally extinct areas (Forman et al., 2003c). Strengthening genetic diversity reduces extinction risks and individuals maintain higher fitness, which benefits overall population health (Rabinowitz & Zeller, 2010; Tewksbury et al., 2002). Habitat fragmentation also impacts habitat health, as small, isolated patches do not mature into strong and stable ecosystems (Hooper et al., 2005; Tewksbury et al., 2002). This makes small habitat patches vulnerable to anthropogenic and environmental factors and decreases habitat value to many species (Tewksbury et al., 2002; Meegan & Maher, 2002).

Anthropogenic changes to the landscape and to road networks are a leading cause of habitat fragmentation and habitat loss (Beckmann & Hilty, 2010). Roads "serve as the arteries of [an] ever-expanding human footprint" through population growth, extractive industry growth, and increasing development (Beckmann & Hilty, 2010: 5). Road networks not only destroy existing habitat in their construction, which contributes directly to habitat loss, but also act as physical and biological barriers for many species (Beckmann & Hilty, 2010; Laurance et al., 2009; Coffin, 2007). Edge effects of roads distinctly alter ecosystem composition, structure, and processes in habitat next to roads, and these biological changes can permeate hundreds of meters into adjacent habitat (Beckmann & Hilty, 2010; Coffin 2007). These edge effects may be so distinct that many species of plants and animals are no longer able to persist in edge habitats (Beckmann & Hilty, 2010). Barrier effects therefore hinder movement of species and create isolated metapopulations (Coffin, 2007).

As discussed briefly in the introduction, the impacts of road networks on habitat connectivity and destruction are particularly pronounced in tropical rainforests. Rainforests support many species with unique ecosystem specializations that are extremely vulnerable to environmental change (Laurance et al., 2009). Tropical rainforest ecosystems are especially sensitive to edge effects of roads, as changes in light, temperature, and humidity directly affect forest composition (Laurance et al., 2009). In the Amazon rainforest, for instance, researchers note correlations between "increasing fires and drought conditions, i.e. regional climate change, and the amount of forest fragmentation and deforestation," as well as the construction of roads (Coffin, 2007: 402). Road clearings inhibit faunal movements because many tropical rainforest species' evolutionary features encourage avoidance of edges and clearings (Laruance et al., 2009). Roads also support human invasions by "hunters, miners, colonists, and land speculators" into isolated regions of tropical rainforests, which increases resource exploitation and environmental degradation (Laurance et al., 2009: 662).

XI. Are Underpasses Worth It?

Tropical rainforests' unique responses to roads mean maintaining habitat connectivity in these regions poses many unique challenges. Tropical rainforest ecosystems are inherently complex and interconnected, which makes it difficult to select target species for conservation initiatives (Laurance et al., 2009). Large, wide-ranging, low-density carnivores, such as the jaguar, however, serve good target species for wildlife crossing structures because they occupy a diverse number of habitats on a large spatial scale (Beckmann & Hilty, 2010; Meegan & Maehr, 2002; Sanderson et al., 2002; Clevenger & Waltho, 2000; Quigley & Crawshaw, 1992). Planning wildlife crossing structures around these types of species places importance on developing connectivity between many different types of habitats, and offers protection for a greater amount of land, including entire functioning ecosystems, which will also benefit other species (Beckmann & Hilty, 2010; Meegan & Maehr, 2002; Sanderson et al., 2002; Clevenger & Waltho, 2000; Quigley & Crawshaw, 1992).

Wildlife crossing structures, such as wildlife underpasses, overpasses, and canopy crossings, are relatively new concepts but are championed as a way to mitigate habitat fragmentation in habitats bisected by roads (Clevenger & Ford, 2010; Goosem et al., 2005; Forman et al., 2003d; Foster & Humphrey, 1995). The general function of these structures allows fauna movement safely across roadways in order for species to meet biological needs, such as finding food, cover, or mates (Forman et al., 2003d). These structures help facilitate essential species movements by linking habitats separated by roads and reducing road kill and animal-vehicle collisions (Beckmann & Hilty, 2010b; Corlatti et al., 2009; Goosem et al., 2005; Forman et al., 2003d; Foster & Humphrey, 1995). While observational studies show wildlife crossing structures are used by a variety of species, more research is needed to determine "whether wildlife crossing structures reliably prevent mortality and population fragmentation" in a way that strengthens ecosystem health (Foster & Humphrey, 1995).

Different fauna species show distinct preferences for various types of wildlife crossing structures and structural components can encourage or deter use of these structures by specific species. It also takes time for species to adapt to crossing structures and learn how to use these habitat connections (Clevenger & Waltho, 2000). Studies in

Banff National Park, Alberta, Canada, show elk, deer, and coyotes prefer overpasses, whereas wolves, cougars, black bears, and grizzly bears are less likely to use exposed wildlife crossing structures (Corlatti et al., 2009). In fact, cougars rarely ever use overpasses and prefer the cover of underpasses (Corlatti et al., 2009). Existing research suggests crossing structures must be properly located in appropriate habitat in order to facilitate species use and should also be located in areas of known target species movement (Jensen et al., 2010; Foster and Humphrey, 1995). Fence installation around wildlife crossing structures is important to funnel fauna to crossing structures and exclude them from the highway right-of-way (Jensen et al., 2010; Foster and Humphrey, 1995). Studies also indicate crossing structures should offer an unobstructed view of habitat on the other side in order to facilitate fauna movement (Jensen et al., 2010). More species-specific research is needed, however, in order to determine what habitat and structural features encourage use of artificial crossings by target species (Jensen et al., 2010).

Dynamics of human activity around wildlife crossing structures, along with landscape characteristics, also play a large role in determining which species use structures (Clevenger & Waltho, 2000). Many large carnivores do not use underpasses in close proximity to human activity, which decreases the effectiveness of crossings as habitat connections (Jensen et al., 2010; Clevenger & Waltho, 2000). It is therefore necessary to limit anthropogenic interference with crossing structures and carefully monitor species use of structures (Jensen et al., 2010). In this way, a diverse number of characteristics and variables must be taken into account when designing crossing structures. There is no “cookie-cutter” technique to structure application or construction, and every conservation case is different depending on location, target species, and intended outcome. This paper will focus on wildlife underpasses, as they are the preferred wildlife crossing structures of large carnivores, such as the Florida panther and the jaguar.

Wildlife underpasses have proven successful in a number of different ecosystems throughout the northern hemisphere, including Banff National Park in Alberta, Canada, throughout Europe, and southern Florida (Corlatti et al., 2009; Forman et al., 2003d; Foster & Humphrey, 1995). Studies of wildlife underpasses show fauna successfully use wildlife underpasses to cross roadways, and animal road mortality rates significantly decrease after implementation (Jensen et al., 2010; Foster & Humphrey, 1995). Although most wildlife underpasses studies take place in temperate regions, research shows underpasses can also be effective in tropical rainforest ecosystems (Goosem et al., 2005; Forman et al., 2003d). Sensitivity of rainforest fauna to road development and edge effects, however, must be taken into account when designing wildlife underpasses in tropical ecosystems. Additional structural components help to mitigate edge effects associated with roads and are encourage use of these crossing structures by rainforest fauna (Goosem et al., 2005). Mature, revegetated corridors between habitat patches and wildlife underpasses direct fauna towards underpass entrances, since many tropical rainforest species avoid edges and clearings and natural floor coverings within underpasses, as well as logs and brush along walls, also make these structures more inviting to forest-dwelling fauna (Goosem et al., 2005: 306, Laurance et al., 2009). If proper planning and consideration is given to placement and structural components of wildlife underpasses, however, these structures can serve as effective habitat connections in tropical rainforests.

XII. Applying Florida Panther Case Studies

Research addresses the effectiveness of wildlife underpasses to facilitate habitat connectivity for only a small number of target species, mostly because a limited number of wildlife underpasses exist worldwide (Forman et al., 2003d). The Florida panther, however, represents a charismatic megafuana whose unique habitat and population issues have sparked extensive study on its response to roads and wildlife underpasses (Schwab & Zandbergen, 2011; Jensen et al., 2010; Kautz et al., 2006; Meegan & Maehr, 2002). In the late 1960s, a highway was constructed across south Florida to create an interstate system between two, growing population centers on the east and west coasts of Florida (Jensen et al., 2010). Nicknamed ‘Alligator Alley,’ hydrologic and transportation restoration motivated the Road 84 highway project (Jensen et al., 2010). Alligator Alley bisected Florida panthers’ habitat ranges and, after construction of the highway, animal-vehicle collisions accounted for about 49 percent of documented Florida panthers’ deaths (**Figure 6**) (Jensen et al., 2010; Foster & Humphrey, 1995).

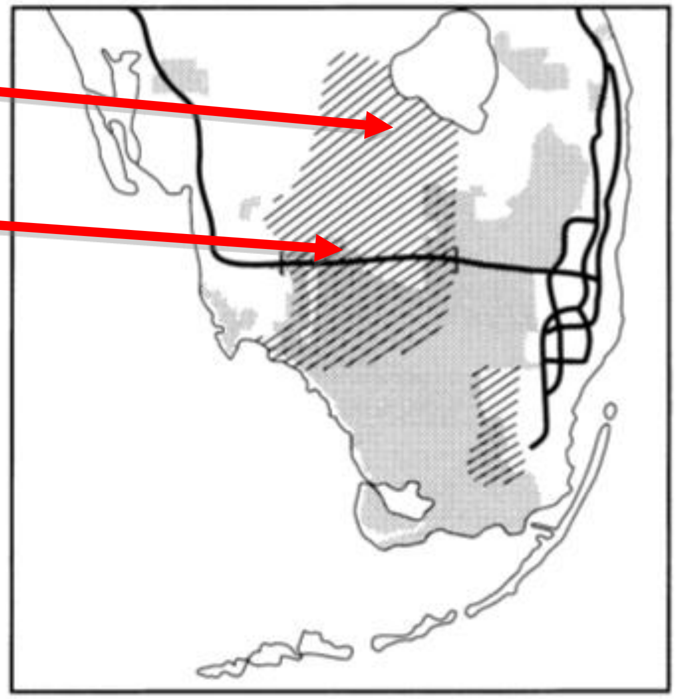

Figure 6. Public lands for conservation (shaded), known Florida panther habitat (diagonal lines), and interstate highways (bold lines) in south Florida. "Twenty-four wildlife underpasses and fencing were installed along the 64-km portion of Interstate 75 marked with brackets" (Foster & Humphrey, 1995: 95).

The Florida panther, however, is a federally listed endangered species under the Endangered Species Preservation Act (Jensen et al., 2010; Foster & Humphrey, 1995). When upgrades for Road 84 were proposed to create four-lane interstate highway I-75, highway construction was stalled because of conflicts with protection of this endangered species (Jensen et al., 2010). Higher speeds and increased traffic were expected to increase hazards for Florida panthers living near the road, and officials were forced to consider wildlife-vehicle collision mitigation measures (Jensen et al., 2010; Foster & Humphrey, 1995). A combination of fencing and wildlife underpasses were put into place to lessen road impacts on the Florida panther (Foster & Humphrey, 1995). Up until that point, most research on wildlife crossing structures had focused on ungulates, so the construction of these wildlife underpasses created a new chance to study how large predators respond to crossing structures (Foster & Humphrey, 1995).

Since the implementation of wildlife underpasses on I-75, a wide variety of research examines Florida panther's behavioral response to roads and crossing structures, as well as how these structures impact habitat connectivity for the species (Schwab & Zandbergen, 2011; Jensen et al., 2010; Kautz et al., 2006; Meegan & Maehr, 2002; Cramer & Portier, 2001; Foster and Humphrey, 1995). In this way, case studies on the

Florida panther offer a wealth of information about how large, wide-ranging, nocturnal, and shy felines respond to roads, wildlife underpasses, and associated anthropogenic activity. In stark contrast to the Florida panther, little is known about jaguars' response to roads and associated habitat fragmentation. While researchers discover more about jaguars every year, "anecdotal accounts by hunters and naturalists" are still the basis for most jaguar literature because of the elusive nature of the species, which makes it difficult to study (Schaller & Crawshaw, 1980: 161). The known similarities between Florida panther and jaguar species, however, make it possible to analyze Florida panther case studies to examine how the jaguar may respond to habitat fragmentation by roads and use wildlife underpasses.

XIII. Importance of Habitat Connectivity for the Florida Panther and Jaguar

Destruction of habitat and habitat fragmentation are two of the biggest threats to Florida panther and jaguar populations (Schwab & Zandbergen, 2011; Rabinowitz & Zeller, 2010; Kautz et al., 2006; Sanderson et al., 2002). Current habitat patches, consisting of five percent of its former range in south Florida, barely support viable breeding populations for Florida panthers (Schwab & Zandbergen, 2011; Kautz et al., 2006). Jaguars similarly have experienced a 54% reduction in their historic range due to habitat fragmentation and reduction (Rabinowitz & Zeller, 2010; Sanderson et al., 2002). The demographic benefits of habitat connectivity are therefore vital components in successful conservation planning for both species (Rabinowitz & Zeller, 2010).

Florida panthers and jaguars are both wide-ranging carnivores. Both male and female Florida panthers require large areas of suitable habitat, between 435 and 650 square kilometers and 193 and 396 square kilometers respectively and can disperse up to 68 kilometers (Schwab & Zandbergen, 2011; Kautz et al., 2006). Jaguars occupy similarly sized home ranges and disperse similar distances, however, the size of home ranges and dispersals are also greatly influenced by suitable habitat availability (Rabinowitz & Zeller, 2010). Florida panther and jaguar home ranges are dynamic and at times overlap (Schwab & Zandbergen, 2011; Quigely & Crawshaw, 1992). In many instances, mothers and daughters of both species may occupy intersecting home ranges, although this is more unlikely in resource-scarce areas (Schwab & Zandbergen, 2011; Quigley & Crawshaw, 1992). Juvenile males of both species, on the other hand, occupy larger home ranges and stray long distances to find adequate habitat (Schwab & Zandbergen, 2011). In this way, young male panthers and jaguars are usually the "trailblazers" of new areas of colonization as they search for their own home ranges (Schwab & Zandbergen, 2011; Colchero et al., 2010; Meegan & Maehr, 2002).

Habitat quality greatly impacts dispersal of Florida panthers and jaguars (Schwab & Zandbergen, 2011; Quigley & Crawshaw, 1992). Forested habitat patches are important diurnal resting places for Florida panthers, and panthers dislike overly wet and swampy habitats (Schwab & Zandbergen, 2011; Meegan & Maehr, 2002). This encourages Florida panther migration northwards instead of south into the swampy Everglades (Meegan & Maehr, 2002). Highways, rivers, and open habitat also act as movement barriers for many adult Florida panthers and they are less likely to move through these exposed landscapes (Meegan & Maehr, 2002). Jaguars are also hesitant to cross man-made boundaries, such as grazing lands or forest cuts. Like Florida panthers, forest cover is also important to jaguars and they generally avoid riparian habitats such as those associated with livestock farms (Quigley & Crawshaw, 1992). In this way, appropriate habitat connectivity and conservation are essential to maintain health Florida panther and jaguar populations. The dangers of road crossings and species avoidance of roads, however, make road networks barriers to species movement. Underpasses offer a way to mitigate these impacts and encourage species dispersal.

XIV. Wildlife Underpasses for Florida Panther and Jaguar

The wildlife underpasses implemented on I-75 are considered a success—"they reduce road-kills, maintain habitat connectivity, enable genetic interchange to continue, and allow for dispersal and recolonization" by Florida panthers (Jensen et al., 2010: 217; Foster & Humphrey, 1995). The use of these structures continues to increase as Florida panthers learn to use these habitat connections and more panthers move to habitat on the other side of the wildlife underpasses (Jensen et al., 2010; Foster & Humphrey, 1995). Wildlife underpass use by Florida panthers shows that wide-ranging predators do in fact take advantage of wildlife crossing structures, even though they are reluctant to approach forest clearings and human activity (Meegan & Maehr, 2002). This evidence supports the potential effectiveness of wildlife underpass use by the similarly shy jaguar.

In order to be effective, however, wildlife underpasses must be sited and constructed properly in order to encourage species use. Wildlife underpasses should be built in areas of known animal movement (Jensen et al., 2010; Foster & Humphrey, 1995). Studying patterns of animal-vehicle collisions expose road-crossing hotspots, as well as heavily used habitat patches and corridors that are important for maintaining greater habitat connectivity (Schwab & Zandbergen, 2011). For example, as Florida panthers move north from areas like the Florida Panther National Wildlife Refuge (FPNWR) and Big Cypress National Preserve, they generally cross the Caloosahatchee River within a four-kilometer section (**Figure 7**) (Kauzt et al., 2006; Meegan & Maehr, 2002). This knowledge can be used to site underpasses within Florida panther movement corridors in order to encourage panther dispersal northwards. While studies have estimated important habitat patches and corridors for the jaguar, jaguar tracking could inform researchers of important movement corridors and resting habitat patches for jaguars and highlight areas where underpasses could provide crucial habitat connectivity (Rabinowitz & Zeller, 2010, Sandersen et al., 2002).

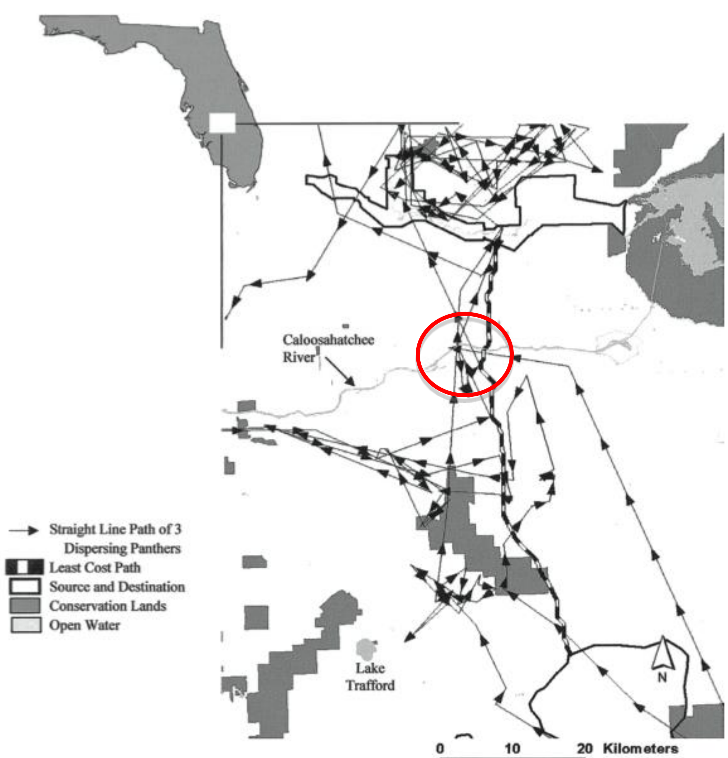

Figure 7. Florida panther crossings of the Caloosahatchee River occur within a four-kilometer section (red circle). Tracking Florida panther movements helps researchers determine the most heavily traveled corridors (Meegan & Maehr, 2002).

Fauna behavioral responses to underpasses, however, greatly influences underpass effectiveness as movement corridors. Research shows Florida panther use of underpasses is deterred by territoriality (Schwab & Zandbergen, 2011). Territoriality of home ranges prevents use of underpasses by more than one individual, which isolates adults and diminishes reproductive success (Schwab & Zandbergen, 2011). Jaguars are also very territorial animals, which may affect underpass use by this species (Quigley & Crawshaw, 1992). Human activity associated with wildlife underpasses impacts their use, as well. Routine maintenance of fencing and underpasses brings humans close to underpasses, and humans also use wildlife underpasses to move livestock and farming equipment (Jensen et al., 2010). Studies show the Florida panther and the jaguar both generally avoid human activity and development, and in this way, human activity necessary for wildlife underpasses development obstructs Florida panther and jaguar use of these structures (Jensen et al., 2010; Quigley & Crawshaw, 1992).

In tropical rainforests, effective implementation of wildlife underpasses will be tricky. Structural components, such as revegetated corridors leading from edges of forest patches to mouths of wildlife underpasses, and planted corridors can mitigate some of the stark barrier effects of road clearings, however, jaguars may still hesitant to approach these man-made structures (Goosem et al., 2005). During the rainy season, wildlife underpasses may be unusable because of flooding (Jensen et al., 2010; Foster & Humphrey, 1995). The effects of flooding and underpass washouts, however, will lessen with improved engineering, design, and construction of wildlife crossing structures. Important lessons can be learned from Florida panther use of wildlife underpasses in south Florida. In order to facilitate jaguar movement, underpasses should be located in known movement areas that are important for larger habitat connectivity. Tracking, both observational and with radio collars, would be a good way to establish these important jaguar habitat and corridors, as well as established home ranges. Fencing should be installed and maintained to prevent jaguars, and other animals, from entering roadways. In this way, proper planning, siting, and construction can vastly improve the probability that jaguars will use wildlife underpasses and these structures viable means for maintaining habitat connectivity in landscapes fragmented by roads.

XV. Landscape-Scale Conservation and Wildlife Underpasses

"Human population growth, habitat loss and fragmentation, agricultural conversions, and transportation planning" continue to stress Florida panther and jaguar habitat (Kautz et al., 2006: 133; Quigely & Crawshaw, 1992). Integration of wildlife underpasses into larger landscape planning and protection of dispersal zones, however, will facilitate recolonization and mitigate habitat fragmentation for both species (Kautz et al., 2006). For the Florida panther, many researchers believe the best way to increase population size is to conserve land north of existing panther habitat and facilitate Florida panther dispersal (Kautz et al., 2006; Meegan & Maehr, 2002). This would open new habitat for Florida panther expansion and allow for population growth. The Florida Wildlife Corridor project is a statewide conservation vision which hopes to connect "remaining natural lands, waters, working farms, and ranches from the Everglades to Georgia" in order to protect a functional ecological corridor, especially "habitat and migration corridors" essential to Florida panthers (**Figure 8**) (Florida Wildlife Corridor, 2012). This project introduces the idea of a landscape-scale conservation plan to aid in the dispersal of Florida panthers throughout the state. The I-75 underpasses play an important role in maintaining connectivity through the corridor, connecting crucial Florida panther habitat and conservation lands in the south to the rest of the state.

Figure 8. Florida Wildlife Corridor would connect natural lands from Georgia to the Everglades, potentially facilitating Florida panther dispersal (Florida Wildlife Corridor, 2012).

While expansion and protection of the Florida panther's range is important, this corridor would also bring the Florida panther population into greater contact with human populations. This could increase the chance of panther-vehicle collisions throughout the state, as well as other negative human-panther interactions, such as potentially dangerous interactions on hiking trails or killing of livestock and pets. While there is currently popular support for Florida panther conservation and dispersal, public opinion may change once Florida panthers start becoming a hazard to more Floridians.

The Florida panther's constriction to five percent of its original home range is a harsh example of how habitat fragmentation and destruction can threaten wide-ranging carnivore populations (Meegan & Maehr, 2002). Studies indicate 78% of historic jaguar home range "still holds potential for jaguar dispersal and movement," but development throughout Central and South America threatens to fragment jaguar breeding populations (Rabinowitz & Zeller, 2010: 939; Sandersen et al., 2002). Informed conservation decisions must be made in order to protect and conserve habitat that is most important to maintaining genetic diversity within jaguar populations (Rabinowitz & Zeller, 2010; Sandersen et al., 2002). Using limited knowledge and sightings of jaguars, researchers identified important jaguar habitat patches and movement corridors (Rabinowitz & Zeller, 2010; Sandersen et al., 2002). More financial support of tracking programs, however, could help establish a better idea of current jaguar home ranges and how these felines move across the landscape. This kind of detailed information about essential jaguar habitat and movement patterns could inform a targeted and efficient conservation network of natural lands.

Based on current information about jaguar habitat, however, an interconnected system of habitat and movement corridors is threatened by expansive human and transportation development. Current and future roads fragment landscapes and provide access for settlers and hunters to previously isolated habitats. In areas with human settlements, direct killings of jaguars in response to livestock killings and habitat degradation are often directly responsible for jaguar population declines. In this way, road development increases chances of human-jaguar interactions as colonizers further fragment habitats by converting intact rainforest into farms. Road network development, however, is important as South and Central American countries look to further economic development through resource extraction. The Initiative for the Integration of the Regional Infrastructure in South America (IIRSA) aims to promote "the development of energy and communication infrastructure to strengthen… territorial development" through intergovernmental actions (Inter-American Development Bank, 2010). Many countries with important jaguar habitat are therefore looking to expand and improve their road networks in order to facilitate development. The Interoceanic Highway is one example of new road construction that crosses both Peru and Brazil. Although at a much larger scale, the highway will connect east and west coasts of South America much as I-75 connects east and west coasts of Florida, and the highway associated development will fragment some of the most important jaguar habitat patches and movement corridors, just as I-75 split Florida panther habitat (**Figure 9**). In order to ensure the jaguar does not become a threatened species like Florida panthers, targeted conservation measures are needed to map and protect vital jaguar habitat and movement corridors, and wildlife underpasses are a viable way to help maintain habitat connectivity throughout a larger jaguar conservation network.

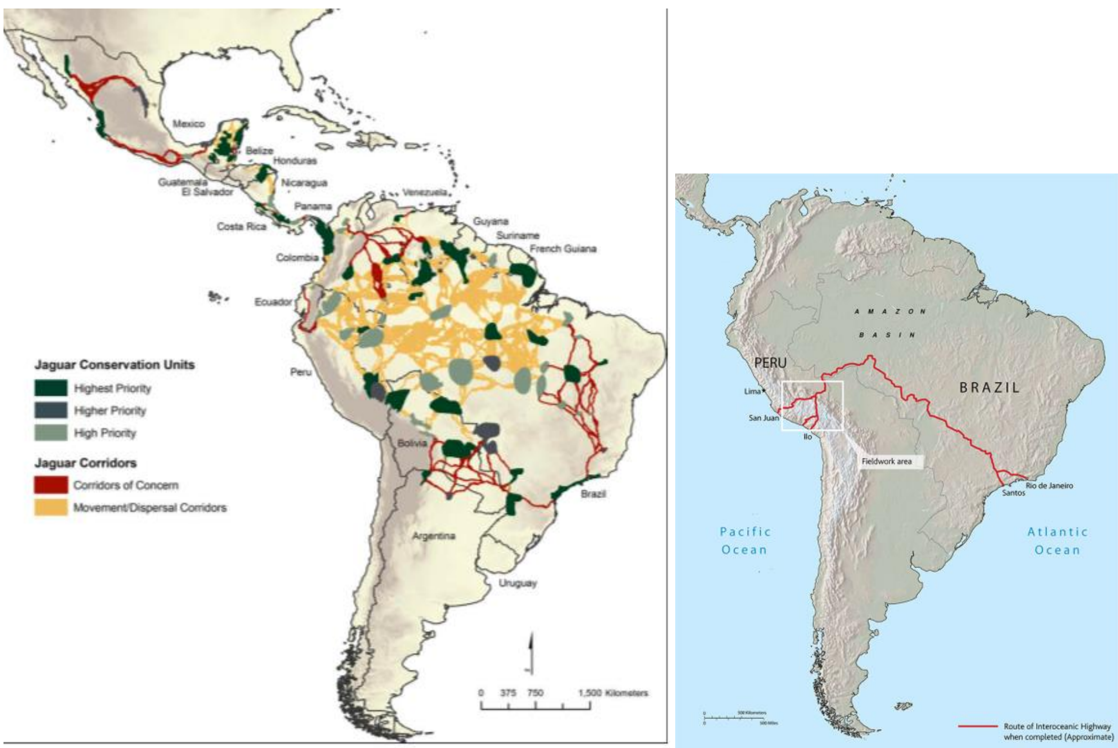

Figure 9. The Interoceanic Highway and associated development threatens habitat connectivity between important jaguar habitat patches and corridors (Rabinowitz & Zeller, 2011; MacQuarrie, 2007).

XVI. Conclusion

Although little research exists on jaguars' response to roads, associated habitat fragmentation, and wildlife crossing structures, important lessons can be learned from the case of the Florida panther and the I-75 wildlife underpasses. Habitat fragmentation and habitat destruction decreased Florida panthers' range to five percent of its historic territory (Meegan & Maehr, 2002). Found only in 10,000 square kilometers in southern Florida, the Florida panther faces demographic, stochastic, and anthropogenic challenges in this small amount of territory (Schwab & Zandbergen, 2011; Kautz et al., 2006). The I-75 wildlife underpasses, constructed on an experimental basis, have proved very successful in mitigating some of these pressures (Jensen et al., 2010; Foster & Humphrey, 1995). These crossing structures "reduce wildlife road kills, maintain habitat connectivity, enable genetic interchange to continue, and allow for dispersal and recoloinization" by Florida panthers (Jensen et al., 2010: 217). In this way, wildlife underpasses already serve as a way to strengthen current Florida panther populations by maintaining habitat connectivity between suitable habitats.

The success of the I-75 underpasses shows how wildlife crossing structures are effective ways to maintain habitat connectivity for wide-ranging carnivores. Without proper conservation planning, however, jaguar populations may also become threatened to the point of extinction by roads, habitat fragmentation, and habitat loss. As transportation development continues to extend into intact jaguar habitat, a greater effort should be made to maintain habitat connectivity for the species. Although there is little direct research on jaguars' response to roads and associated habitat fragmentation, proactive acknowledgement of ecological issues associated with roads and incorporation of wildlife crossing structures into transportation plans throughout the jaguar's range could mitigate some of the same long-term genetic and demographic effects seen in the habitat-constrained Florida panther population. Wildlife underpasses prove to be an effective way to maintain habitat connectivity in tropical rainforests, however additional structural components are needed to facilitate broader tropical rainforest species use (Goosem et al., 2005). The wide-ranging, low-density nature of jaguars' means conservation efforts focused on these felines will conserve larger, functioning ecosystems, and will in turn will also provide protection and habitat connectivity for many other flora and fauna species (Quigley & Crawshaw, 1992).

Financial and political backing of conservation initiatives, however, is vital to the success of these kind of infrastructural conservation programs. Effective, but expensive, tracking of jaguars with detailed observational studies and radio collars determines important habitat patches and corridors for targeted conservation and establishes important road crossing for wildlife underpass placement. The construction of wildlife underpasses must be followed by detailed studies to determine the success of the crossing structures, as well as possible improvements to expand these structures effectiveness as habitat connections. The construction of wildlife underpasses is also very expensive. In south Florida, two wildlife underpasses were completed with a total project cost of $3.8 million dollars in 2007 (Jensen et al., 2010). Most of the jaguar's current range exists in developing countries, where most economic resources are put towards natural resource extraction and colonization. There is little economic incentive to establish these kinds of infrastructural habitat connections, especially for species like the reclusive, and often times problematic jaguar that may interrupt livestock operations.

The expensive nature of wildlife underpasses means many localities may not be able to afford planning, construction, monitoring, and maintenance of these structures. For this reason, it is important to examine alternative solutions to facilitate habitat connectivity by making roads safer for wildlife crossings. Speed bumps, a low-cost alternative, reduce traffic speed and minimize instances of road kill, which allows species to safely cross roads (Schutt, 2008). Other types of traffic management, such as restricting road use during key times of species movement or reducing the number of highway lands, may also make roads safer for species to cross. While wildlife crossings are expensive, Florida panther studies indicate that a combination of fencing, wildlife underpasses, and other traffic management techniques offers the most comprehensive solution for allowing rare, wide-ranging, low-density species movement across highways (Foster & Humphrey, 1995). In this way, proactive integration of this type of wildlife crossing infrastructure and transportation management could also play an important role in maintaining habitat connectivity throughout the world's larger conservation networks.

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