Existing knowledge, understudied ecosystems, and rapid human development: Can existing research of the environmental impacts of roads on wetlands be applied in the Pantanal?

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Abstract: Wetlands, diverse habitats with important conservation value, provide habitat for terrestrial and aquatic organisms in addition to numerous ecosystem services for humans. Roads and road networks negatively affect wetlands because they fragment ecosystems and cause physical and biological changes. Knowledge of the environmental impacts of roads on wetlands is lacking for large, intact, and important wetland ecosystems like the Pantanal region in central South America. This study attempts to gather and analyze studies on road ecology in the temperate wetlands of eastern North America in order to apply this knowledge in the understudied Pantanal. Research conducted in temperate wetlands may provide insight regarding the impacts of roads on habitat connectivity, species richness, and biodiversity in the Pantanal. However, local knowledge of the Pantanal regarding species composition and habitat heterogeneity is critical to understanding the effect of roads on the region. More studies using the framework of road ecology are necessary for wetlands threatened by roads.

Keywords: road ecology, Pantanal, wetlands, Brazil, biodiversity, habitat fragmentation, wildlife corridor

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Existing knowledge, understudied ecosystems, and rapid development: The environmental impacts of roads on the wetlands of the Pantanal, South America

Introduction

Wetlands are particularly diverse habitats because they are home to both aquatic and terrestrial flora and fauna. Wetlands are important for conservation because they are often home to many rare and endangered species. For example, in the United States alone, over a third or all rare or endangered species reside in wetlands. Wetlands offer many benefits for both humans and wildlife because they are hydrologic modifiers, wildlife centers, and beneficial for both water quality and nutrient cycling (Forman, et al. 2003). As wildlife centers, wetlands are the most botanically productive habitats on earth and support high abundance and diversity of animal life per surface area. However, wetlands are heavily influenced by the surrounding landscape because they depend upon surrounding habitats for physical and biological exchanges (Mitsch & Gosselink. 2000). Therefore, wetlands and buffer areas around them are important, and policy decisions regarding wetland protection and conservation need to account for buffer zones between core wetland habitat and the surrounding landscape (Findlay & Houlahan. 1997).

Despite the values of wetlands described above, humans drastically modify these wetland ecosystems through agricultural production, urban development, and road construction. Because of their proximity and association with water and abundant natural resources, humans target wetlands for settlement, which is why many of our nation's greatest cities sit on former wetlands. Roads and road networks, whose effects are intense in both highly developed areas and core habitat areas where transportation infrastructure is new, affect biological processes in wetlands because they introduce nutrients and sediments. Wetlands give, receive, and cycle nutrients and energy from their surrounding environments, which can have negative consequences at the edges of roads. The ecological impacts roads have on wetland ecosystems is a topic that merits greater consideration in today's world, where wetlands negatively bear the burden of economic development and nearly every corner of the Earth is affected by human transportation networks.

With this in mind, an important question is whether existing research on the environmental impacts of roads on wetlands can be applied to wetland ecosystems currently threatened by impending economic development and associated road networks. The application of the studies and information gathered in the temperate wetlands of North America, which have been studied using a road ecology framework, would be beneficial in areas where the impacts of roads on wetland communities is poorly understood and/or in wetland areas with impending development. Therefore, the question: to what extent can studies under the theoretical framework of road ecology in temperate wetlands be applied to either understudied, unique, or endangered wetland habitats around the world.

In an attempt to answer this question, I chose to examine the Pantanal, a wetland in South America that represents one of the world's largest wetland biomes (Junk and Cuhna. 2005). The Pantanal provides a unique opportunity for a case study on road ecology in wetlands because the biome is still in pristine condition given the unique characteristics of the wetland historically hindered economic development (Junk and Cuhna. 2005). The only major economic activity in the region, cattle ranching, fosters a sense of communal stewardship over the majority of the Pantanal (Seidl, et al. 2001), and results in minimal environmental impacts (Junk and Cuhna. 2005). However, since the mid 1990s, a changing economic and political climate in Brazil, Bolivia, and Paraguay has increased development pressure in the Pantanal region, as these countries (especially Brazil) want to involve the Pantanal into national economic development and integration strategies (Junk and Cuhna. 2005). Greater connectivity of transportation networks and road construction accompany economic development, and therefore as time progresses the Pantanal biome will experience more intense environmental impacts resulting from roads. In order to quantify and predict these impacts for the Pantanal, existing knowledge must be analyzed from well-studied wetland habitats that experience intense anthropogenic impacts resulting from roads. Studies conducted in wetland habitats in eastern North America provide enough information and evidence to inform predictions on the impacts of roads in the Pantanal region. Therefore, this study attempts to understand and apply existing knowledge on the environmental impacts of roads on wetlands in eastern North America to the Pantanal biome. This information will be important for developers, resource managers, and conservationists working in the region, and will serve to inform conservation strategies designed to help mitigate the negative effects of roads around and within the Pantanal biome.

Background

The Pantanal is one of the world's largest wetland habitats and a growing ecotourist attraction for the three countries that share the Pantanal. Although tourism has recently emerged in the local economy, cattle ranching and fishing are the primary economic activities in the Pantanal (Pott and Pott, 2004). The known and documented impacts of roads through the region are minimal because the only roads in the Pantanal consist of one paved highway (the Miranda – Corumbá highway) in the southern part of the biome and a very low density and number of unpaved roads (Pott and Pott, 2004). The lack of information is due to the absence of environmental impact studies regarding the Pantanal's existing roads. The Pantanal biome is unique because, although its species diversity is large, the wetland does not contain large numbers of wetland-specific or endemic species (Junk et al. 2006). Instead, plants and animals from areas surrounding the biome continue to migrate in and out of the region both randomly and seasonally due to habitat availability, other biological pressures, and human pressures (Junk et al. 2006), This observation highlights the importance of connectivity between Pantanal wetlands and surrounding habitats.

The Pantanal experiences a seasonally wet tropical climate that results in a predictable flooding regime. However, as predictable as the floods may be, they vary significantly over time and space across the region (Junk and Cunha, 2005). Because the effects of flooding and rainfall vary over space and time, weather conditions in one area of the Pantanal have effects in the form of delayed flooding or drought in other areas of the Pantanal. Therefore, in order to understand the effects of roads in a region like the Pantanal, one must take a multi-scalar and multi-dimensional approach to studying the way in which roads affect ecological processes. Because the region is a wetland, and therefore strongly linked both physically and biologically to its surrounding environment, the effects of road building and land change in the areas surrounding the Pantanal should also be taken into account. However, there are very few studies conducted in the Pantanal region from the perspective of either road ecology (Fischer, et al. 2003) or land change science (Seidl, et al. 2001), and this lack of knowledge could potentially lead to misguided policy decisions regarding any development of ranching, tourism, or infrastructure in the region. Because my study explores the potential environmental impacts of road construction and road networks around the Pantanal, a greater understanding of the dynamics of land change within and surrounding the region would be extremely helpful in the development of practical solutions for protecting biodiversity and ecological integrity.

Despite the region's known conservation value, a value shared by local residents, the government of Brazil, and international environmental organizations, very few studies have examined the Pantanal from the perspective of human environment interactions, and even fewer have used the theoretical framework of road ecology. The Pantanal and the surrounding Cerrado biome represent two of the most heterogeneous and biologically diverse habitats in the world. The connection between the Cerrado and the Pantanal provides a habitat corridor for large mammals and other species between all the biomes of South America, including the Amazon and Atlantic rain forests, and helps maintain the flow of genetic and species diversity between individual species and groups of species across all of central South America (Fischer, et al. 2003). Figure 1 in the appendix highlights the conservation units and protected areas of the Pantanal, while also providing perspective on the geographic proximity and connectivity of the Pantanal, Cerrado, and other major South American biomes (Junk, et al. 2006.) Because the ecosystem remains mostly intact and in good health, and because the population density of the region is very low, sustainable development and wildlife conservation may be achieved in this incredible biome (Junk and Cunha 2005). However, due to private land ownership and regional economic incentives, land use change resulting from agricultural development and cattle ranching around the edges of the Pantanal biome, which includes the construction of dirt roads, continues to deforest higher elevation areas in the region (Seidl, et al. 2001). Although cattle ranching, the main economic activity in the region, has occurred in the Pantanal for two centuries, no major changes have occurred in the vegetative composition of the biome's extensive grasslands (Pott and Pott 2004). This suggests the nearly 3.5 million cattle herded in the region filled a relatively empty ecological niche, and would discourage any hypotheses suggesting the cattle themselves have negative environmental impacts (Pott and Pott 2004). Also, cattle ranching is typically not regarded as an environmental problem in the region. The most serious environmental problem in the Pantanal, which is siltation caused by intense erosion in the highlands surrounding the region, is inextricably tied to variables not commonly associated with cattle ranching taking place within the biome, including seasonal flooding regimes, climate fluctuations, and anthropocentric land use changes surrounding the wetland (Pott and Pott. 2004). Therefore, other factors, such as transportation infrastructure, outside economic pressures, and land use change, should be given greater consideration when exploring environmental change in the region.

Theory and Approach

The main theoretical framework that applies to both my research question and my examination of the interplay between roads and wetland environments is road ecology. Road ecology is an interdisciplinary framework that broadly examines the impacts of roads and road networks on the surrounding environment (Forman, et al. 2003). The field is relatively new, and seeks to quantify the environmental impacts of the ever-expanding network of roads and transportation corridors that accompany anthropocentric development. The global nature of the world's present environmental concerns, combined with the increasing extent of roads and road networks prompted scientists studying ecology and global environmental change to become interested in the cumulative effect of roads on their surrounding environment due to how roads fragment habitats and introduce more intense and profound human-environment impacts into habitats and ecosystems (Forman, et al. 2003). The density, spatial arrangement, and intersections of roads are all variables that road ecologists focus upon to better understand and quantify the environmental impacts of roads (Forman, et al. 2003). At the end of the 20th century, the lack of studies regarding these variables and their ecological effects forced ecologists to ask questions that tried to determine the physical impacts of roads and road construction and the resulting biological changes that roads caused. After the discipline gained notoriety for its examination of road mortality and other small-scale, easily quantifiable variables, scientists began to apply both well-established disciplines, such as physical geography, and newer disciplines, such as landscape ecology, to wider spatial scales to gain a better understanding about how roads effect groups of organisms, entire habitats, ecosystems, and biomes (Forman, et al. 2003). The combination of these established disciplines under a new framework that examines roads represented the birth of road ecology as a theoretical framework through which scientists began the process of understanding how roads altered, and continue to alter, biophysical processes. While most road ecology research has taken place in Europe and the United States, the book, *Road Ecology: Science and Solutions*, indicates the discipline of road ecology is growing and becoming a priority for scientists and conservationists worldwide (Forman, et al. 2003).

For this analysis, an ecologically focused perspective was necessary because, while exploring whether the current knowledge on the environmental impacts of roads and road density could be applied to biomes such as the Pantanal, applied studies using road ecology in wetland ecosystems essentially do not exist. The lack of landscape level studies on wetland ecosystems using road ecology, especially in understudied biomes such as the Pantanal, makes for a dangerous lack of information in both highly and less developed areas of the world. The vast and interconnected nature of current human-environment impacts on wetlands means more information, even if it is applied from studies in other ecosystems, is necessary to inform mitigation and conservation strategies for understudied ecosystems and biomes. These understudied biomes, which include the Pantanal, are at risk to new human development that undermines conservation efforts.

Because my research focuses on case studies that quantify the impacts of roads on wetland ecosystems, it falls almost exclusively within the theoretical framework of road ecology. Most of the studies I am using have an ecological focus, and therefore can be said to be biocentric. These studies examine the biological and ecological responses to anthropogenic changes in the form of road networks, instead of the societal and economic forces responsible for environmental change. Although social and economic forces often drive how decisions are made regarding the location and extent of road construction, socio-economic drivers, considerations, and variables do not directly address or attempt to quantify the ecological impacts that their activities have on the surrounding environment. A potential weakness of road ecology is that although road ecology addresses the ecological impacts of roads specifically, it does not address the societal, cultural, and economic variables that, when added together, provide a much more holistic and complete view of the many variables and processes that lead to road construction and its resulting environmental impacts. Political ecology and land change science are two examples of the types of approaches needed to understand the anthropogenic variables involved with road building and environmental change (Turner II and Robbins, 2008). A closer examination of road ecology indicates that elements of political ecology and land change science would be useful to understand the human processes that shape environmental processes and vice versa.

Since I am conducting my research from a road ecology approach, I will not explicitly analyze and interpret the societal and economic forces shaping the construction of roads through wetland ecosystems. However, this does not mean that land change science, political ecology, and other theoretical approaches that better account for anthropogenic variables do not provide important or related contributions to my literature review and analysis. Studies from a variety of theoretical frameworks exist for the impacts of roads and road density in North American wetlands, while far fewer studies, especially those from a road ecology perspective, exist for the Pantanal biome. Therefore, it would be senseless to ignore the studies conducted using different approaches or frameworks regarding the environmental impacts of roads in the Pantanal. This also means some of the studies that contributed to my research incorporated many different approaches, which included conservation biology, globalization, political economy, and sustainable development (Junk and Cunha 2005, Pott and Pott 2004). These more general overviews provided critical background information about the Pantanal biome, and included detailed accounts of the wetland's history, present state, and future direction. They also added to the information that was analyzed using road ecology theory and practice.

Wetland ecosystems, like all other ecosystems and environments, are affected by physical and chemical alterations that result from human activities. However, wetlands are often indirectly affected by changes in water-use and land-use in areas adjacent to or simply near core wetland habitat (Burbridge, 1994). Knowing that wetland ecosystems are adversely affected by changes in land use directly, indirectly, and at many different spatial scales means that land change science should be considered during any study regarding the impacts that roads exert on wetlands. Because the world we live in today is constantly modified, changed, and affected by human activities, land change science offers objective and scientific data to help ecologists better understand the rates and scales at which habitat loss and alteration is occurring. This information can then be used to inform road ecologists who are examining particular biological or ecological patterns and processes that are modified by the anthropogenic effects of roads. Land change science applies to ecological studies that look at large ecosystems, such as the Pantanal wetland region in Brazil, Bolivia, and Paraguay. This is especially useful for studies using road ecology regarding wetlands, because often times the studies examining local, small-scale effects could benefit from information on the larger scale physical and biological processes affecting the wetland. For example, the land-use patterns around wetlands and the manner in which roads are situated within landscapes may be just as important as the actual size of wetlands (Forman, et al. 2003). Land change science informs road ecology because it tries to identify and model any thresholds in non-linear systems, which include the environmental and organic systems present in the biosphere and ecosphere (Turner and Robbins. 2008). The focus of land change science in the realm of biological systems stresses slight alterations in initial conditions that produce variable outcomes for the physical and biological components of both small and large-scale ecosystems. With respect to road ecology, the slight alterations in initial conditions represent roads and road construction through wetlands, and with the help of land change science, modeling these alterations produces expected outcomes for many ecological variables, such as edge effects, habitat connectivity, and species richness, that can be compared with observed outcomes.

Under the theoretical framework of road ecology, the study of roads and wetlands attempts to understand the ecological effects of roads with respect to the physical structure of the habitat, the connectivity of the wetland to the surrounding landscape, and the resulting changes in ecological structure and biological components present in the wetland (Forman, et al. 2003). The way in which wetland habitats are connected physically and biologically to their surrounding habitat is complex because of the interactions between, and the connectivity of, surface and subsurface water reservoirs (Forman, et al. 2003). The impacts of roads in wetland regions vary from altering the hydrology of watersheds to disrupting the movement patterns of wildlife (Forman, et al. 2003). During my research, I decided to focus on a few aspects of road ecology that are both easily quantifiable and easily applied to other wetland ecosystems. The aspects and variables I focused on during my literature review were population ecology, habitat connectivity, and biodiversity and species richness. Studies from temperate wetlands in Eastern North America are numerous regarding these specific variables (Findlay and Houlahan. 1997; Forman and Deblinger. 2000; Roe, et al. 2006), and therefore any summary or analysis of these studies indicates overarching trends with respect to road ecology and wetlands. Therefore, these studies would help inform any research conducted in a region like the Pantanal where, overall, this information is lacking.

While population ecology is rather narrow and usually deals with individual species or groups of species, it joins habitat connectivity under the same general ecological framework of conservation ecology (biology). The relationship between biodiversity, species richness, and road networks in wetland areas has been studied (Findlay and Houlahan. 1997), but with respect to the extent to which roads affect wetland habitats globally there is very little research regarding how these variables are related. Studies regarding the relationship between road mortality and population ecology (Steen and Gibbs 2004, Beaudry et al. 2008, Forman and Deblinger 2000, Findlay and Houlahan 1997) make important connections between high road density, lower species diversity, and higher local extinction rates. Another important correlation I found during my literature review was the temporal effects of roads on wetland biodiversity found in temperate wetlands (Findlay and Bourdages 2000). The multi-scalar aspect of human environment interactions, along with the lack of research on wetlands across the globe (in particular in important biomes like the Pantanal) supports the importance of using a road ecology approach to my analysis and applications. Also, because of the wealth of knowledge about conservation biology and the number of studies concerned regarding it, the variables that govern conservation biology became the focus of my research under the theoretical framework of road ecology.

For many reasons, road mortality is a major theme of many of the studies I examined (Finder et al. 1999, Gibbs and Shriver 2005, Bernadino Jr. and Dalrymple 1992, Lloyd et al. 2005). Significant literature is devoted to wildlife hot spots (Finder et al. 1999, Lloyd et al. 2005) and trying to find the spatial distribution of these hot spots along major roads. The definition of a wildlife hotspot, according to Lloyd et al. 2005, is a place along a road where high levels of wildlife movement occur due to physical geography and habitat availability, combined with high traffic volumes. Due to the extremely low traffic volumes in the Pantanal (Pott and Pott 2004), and biome's high level of biodiversity, I assumed for the purposes of my research that a lengthy discussion of wildlife hotspots would be both redundant and impractical. Also, the case studies I have from temperate biomes would not lend themselves well for applying knowledge of wildlife hotspots to tropical or subtropical wetlands. The closest correlation I have would be the Florida Everglades (Bernadino Jr. and Dalrymple 1991), and even in this case I do not feel confident using knowledge of wildlife hotspots in the Everglades as a proxy for hotspots in the Pantanal. Although an analysis of wildlife hotspots was impractical, road mortality became a central focus of my study due to an existing inventory of road kill that exists for the Pantanal and Cerrado biomes from the early 2000s (Fischer, et al. 2003). This inventory provided the base upon which the framework of road ecology was applied with the goal of trying to quantify the effects of roads in the Pantanal. Using this study in coordination with studies from temperate wetlands facilitated the applied nature of my analysis while adhering with the theoretical base that comprised both the idea and motivation for the study.

The approach to my paper is applied and exploratory because through my research I try to identify or quantify the possible impacts of roads through the Pantanal, a wetland where roads and their environmental impacts have not been studied. Therefore, the impact of roads in these areas is either unknown or speculated. Applied research is speculative in its own right, but it is also backed by both empirical data and observational evidence. Studies of both small and large-scale ecological phenomenon are important for applied research on wetlands because observations of the interactions of variables at different spatial scales are much more informative than observations at one particular scale. The case studies guiding my understanding of the environmental impacts of roads on wetland ecosystems take the approach of road ecology and attempt to illustrate the landscape-level effects of roads on wetland biodiversity, species richness, and habitat connectivity (Forman, et al. 2003).

Methodology

I will be using a specific set of case studies from Canadian wetlands that examined the spatial and temporal aspects of the effects of existing road networks on species richness and biodiversity for multiple different groups of organisms (Findlay and Houlahan, 1997; Findlay and Bourdages, 2000). These studies demonstrate how roads influence ecosystem biology in temperate wetlands over both space and time. Other case studies that study road effects on population ecology and habitat connectivity in temperate wetlands will both complement and strengthen the studies regarding the impacts of roads on biodiversity (Gibbs and Shriver, 2005; Roe et al, 2006; Steen and Gibbs, 2004). I will then try to apply the conclusions made by these studies to the Pantanal biome, one of the world’s largest, intact wetland ecosystems.

To better understand the Pantanal, I analyzed two studies focused on the ecology and current land use in the Pantanal biome (Junk and Cuhna, 2005; Seidl et al, 2001). I analyzed another two studies in order to understand the biodiversity and conservation history of the region (Pott and Pott. 2004; Junk et al, 2006.) The Pantanal case study I chose to focus most of my attention on provided an inventory of data on animal road mortality along the major highway spanning the southern portion of the Pantanal (Fischer et al, 2003). This study was crucial for my analysis and understanding of road mortality in the region. The data from this study, which is represented with Tables 1 through 4 in the Appendix, helped to connect road mortality to the broader studies concerning biodiversity in the region, and provided a useful tool for comparing the effects of roads in the Pantanal to the effects of roads in other wetlands.

The majority of my analysis explores whether the existing, extensive research on how roads affect the previously mentioned biological variables in the temperate wetlands of eastern North America can be applied to the Pantanal biome, where the impacts of roads on terrestrial and aquatic flora and fauna are understudied. My methodology is useful because it provides knowledge and suggestions under the framework of road ecology for an area (the Pantanal) that lacks this information, is understudied from a road ecology perspective, is incredibly biodiverse, and is subject to the effects of expanding human development. Therefore, any similarities or linkages between the effects of roads on Pantanal and the wetlands of Eastern North America will provide useful information. However, my methodology does not directly account for many of the differences between the two ecosystems I focused upon, which resulted in different suggestions regarding different species and groups of organisms. Although briefly addressed in the analysis, the differences between the Pantanal and the wetlands of Eastern North America are profound, and therefore, the analysis must be narrow in order to focus on broad ecological processes that occur in all biomes (habitat connectivity, population ecology, etc.) The applied aspect of my literature review and analysis allowed for the exploration of possible scenarios and outcomes, but failed to provide the kind of local knowledge on the effects of roads on biodiversity and species richness that extensive research from a road ecology perspective would provide for the Pantanal.

Analysis

Roads in temperate wetlands have quantifiable effects on wildlife. Road density, in particular (Findlay and Houlahan, 1997), has been shown to significantly affect species richness among plants, birds, herptiles and amphibians in temperate wetlands in Canada. Other studies indicate amphibian species richness in particular suffers from increasing urban land-use (Lehtinen, et al, 1999), which includes higher road density, and that the relationship between higher road density and decreasing species richness only strengthens over time (Findlay and Bourdages, 2000). These findings suggest higher road densities affect species across all taxa, and that species highly dependent upon, or specialized for, wetlands, such as amphibians and wetland plants, are some of the most affected.

While areas of low road density may experience less of the ecological effects caused by roads themselves, the human and non-human activities associated with the road represent the indirect, negative ecological consequences of the road. Cattle ranching in the Pantanal is a good example of how a human activity that benefits from the construction of roads (primarily dirt roads) can lead to ecological changes after road or trail construction. Biodiversity conservation in the Pantanal is interconnected with and dependent upon the behavior and management practices of cattle ranchers (Seidl, et al, 2001).

When comparing the Pantanal and temperate wetlands in eastern North America, it becomes clear that roads contribute to road mortality, affect species richness, and create other environmental impacts differently in the Pantanal than in eastern North America, primarily due to differences in habitat structure, existing biodiversity, and different anthropogenic pressures. The Pantanal is considered a hyperseasonal savannah because it is comprised of multiple different savannah vegetation types and is subject to prolonged periods of flooding (Junk, et al. 2006). The habitat heterogeneity within the Pantanal biome results from the three basic land formations, which are flood free ridges, seasonally flooded plains, and permanent water bodies (Pott and Pott. 2004). Deciduous and semi-deciduous forests, grasslands, and aquatic macrophytes are the dominant plant communities in the three basic land formations respectively (Pott and Pott. 2004). Forests in the Pantanal primarily exist in higher elevations above the mean flood level (Junk, at al. 2006), while wetlands in eastern North America are almost exclusively associated with forested ecosystems (Findlay and Houlahan. 2000). The mosaic of scattered forests within and among large, flooded grassland plains is unique to the Pantanal, and is not typical of the forested wetlands and vernal ponds found in eastern North America (Beaudry, et al. 2008; Gibbs and Shriver, 2005.). Historically, the clearing of forest for agricultural lands affected both ecosystems, and still represents the most impactful human development. The removal of forest on non-flooded ground in the Pantanal for cattle ranching has resulted in 500,000 hectares of deforested land since the 1970s (Seidl, et al. 2001), while the clearing of temperate forests in eastern North America for agricultural purposes has resulted in the loss of 75% of the region's wetlands since colonial settlement (Findlay and Houlahan. 2000). While it is clear both the Pantanal and eastern North American wetlands have many similarities, differences in habitat structure and anthropogenic pressures should be taken into account for any study examining the environmental impacts of roads.

From a more regional perspective, despite their obvious differences in physical structure, habitat availability, and area, the two dominant biomes in southwest Brazil, the Pantanal and the Cerrado, are two interconnected habitats that share many species and represent an important corridor for the movement of animals across all taxonomic groups (Fischer, et al, 2003). For example, the Pantanal itself is not home to many endemic species, largely due to the high frequency of both flooding disturbances on an annual scale and dramatic climactic changes on longer temporal scales, and therefore the biome's current biodiversity depends on its connectivity to other biomes such as the highly biodiverse Cerrado (Junk, et al. 2006). The Cerrado is particularly important for conservation concerns because it represents a convergence area for large mammal species that frequently populate and migrate between the Amazon basin, Atlantic forests, and the Pantanal (Fischer, et al. 2003). The biodiversity present in the Pantanal region is also dependant upon connectivity and migration because the physical habitat does not allow for the year-round existence of many species (Junk, et al. 2005).

Road mortality in the Pantanal, and in between these two biomes, has not been extensively studied. However, one important study that inventories road mortality in the Pantanal indicated wildlife mortality along roads in the region increased by eight times over ten years spanning from 1992 to 2002, and by 33 percent the final three years of the inventory (Fischer, et al, 2003). In wetland habitats like the Pantanal, new habitats and migration corridors associated with new roads may be contributing to increased road mortality (Fischer et al, 2000). Whether this increase can be attributed to better sampling, more comprehensive studies, or unexpected road effects is up for debate and needs to be studied more extensively. One major difference between the Pantanal and North American continental wetlands that probably influences road mortality is the high diversity and density of large mammal populations in the Pantanal. In North America, many of the studies examining the impact of road mortality on mammals focus on large ungulates (Finder et al, 1999; Litvaitis and Tash, 2008; Lloyd et al, 2005). The motivation behind these studies is both anthropocentric (the economic and emergency impacts of deer-vehicle collisions, Floyd et al, 2005) and out of necessity because high biodiversity for large mammalian fauna just does not exist and individual species are of conservation priority. Also, an Ontario study on road density and species richness showed increasing forest cover was strongly associated with higher species richness for mammals, while increasing road density had much less of an influence on this same variable (Findlay and Houlahan, 1997). This study illustrates the motivation for studies on roads in temperate wetlands, and focuses on multiple conservation priorities (forest loss and mammal conservation). In comparison to the Pantanal biome, the diversity of large mammals in North America is markedly less, which therefore minimizes the impact roads or road networks have on populations and mortality of mammalian fauna.

The inventory of animal road mortality for the Pantanal and Cerrado organized road kills into three main groups, which were herptofauna, avifauna, and mastofauna (Table 1, Table 2, and Table 3, Fischer, et al. 2003). According to the data, in the Cerrado and Pantanal regions mammalian road mortality accounted for two thirds of the 15,000 wild animals killed by roads in the year 2002 (Fischer et al, 2003). For reptiles and amphibian roadkills in the Pantanal, 9 of the 29 species surveyed were frequently road killed (Table 1). For mammals, 9 of the 44 species found dead along the road were frequently road killed (Table 3). Certain types of mammals, such as armadillos and anteaters, were killed more by the road than other species. For amphibians, road mortality in the Pantanal was worse in comparison to the Cerrado, while road mortality for mammals was about equal in both biomes (Tables 1 and Table 3). Road mortality for avifauna affected more species in the Pantanal, but exhibited higher intensity in the Cerrado (Table 2).

Trying to interpret this data and what it means for the conservation of biodiversity and habitat integrity in the Pantanal is complicated. Amphibians and reptiles suffer greatly from roads that traverse wetland habitats regardless of their location. Amphibian migration typically involves movement between permanently inundated wetlands and drier upland areas (Trombulak and Frissell. 2000). The habitat fragmentation caused by roads, the physical barrier of the road, and the resulting mortality that occurs on the road can seriously alter the structure and integrity of local populations of these organisms (Steen and Gibbs, 2004; Gibbs and Shriver, 2005). Based upon road mortality data for amphibians and reptiles in the Pantanal, the surveyed road provided a substantial barrier for certain species of snakes, frogs, and large lizards. Specifically, the data for snakes is consistent with data from Indiana that showed mortality of wetland snakes was highest in areas where wetlands existed on both sides of a road (Roe et al, 2006). This implies that the wetland patches or wetland ecosystems interrupted by roads are hotspots for road mortality because they previously fostered the unchallenged movement of these organisms. Another study, which examined the movement and mortality and turtles in upstate New York, found amphibian populations are most affected by roads that bisect wetland habitat patches as opposed to circumventing suitable habitats, and that the life history traits and movement ecology of semi-aquatic herptiles makes their populations vulnerable to road mortality (Beaudry, et al. 2008). The road mortality for herptiles inventories in the Pantanal suggests that the road there may have similar effects upon local populations of these organisms. The habitat heterogeneity introduced by the road introduces novel habitats alongside the road (Fischer et al, 2000), but the limited connectivity that results from the road incurs changes in local population structures for individual species of less mobile organisms, which then impacts the overall biodiversity for groups of these organisms in the region of the road or road network. These novel habitats, and the road itself, introduce a more heterogeneous assemblage of plant and animal communities along the road, but also increase wildlife activity along the road and provide an unsafe habitat for herptiles (Bernadino Jr. and Dalrymple, 1992).

Though they are limited in number and density, all the roads that traverse the Pantanal are surrounded on both sides by extensive wetland habitat, and therefore now act as novel barriers to dispersal for amphibians and reptiles. Another factor yet to be studied in the Pantanal is the temporal effect of roads on Pantanal organisms. Based upon studies in temperate regions, the full effect of road construction on wetlands may not be apparent for decades (Findlay and Bourdages, 2000) due to the dynamic nature of population ecology and the lag time between road construction and the onset of local species extinction. This study found this to be especially true for vascular plants, birds, and herptiles, whose species richness values were better explained by past road density (Findlay and Bourdages, 2000). The significant negative effects that past road densities had on these organisms means that higher present road densities will only intensify the impacts roads have on plants, birds, and reptiles in the Ontario wetlands as time goes on. Although the existing road infrastructure in the Pantanal may be having minimal effects, the introduction of new roads associated with the new development of ecotourism and cattle ranching would have multi-dimensional and multi-scalar effects, because they would contribute to the local fragmentation of the wetland while also introducing, over time, increasingly detrimental impacts on the population structures of local species.

The possible implications of these barriers on the populations of these organisms is unclear, but undoubtedly, because of similar patterns of road mortality, the effects of the fragmentation of wetlands in temperate areas can be applied, in many respects, to the Pantanal. How to mitigate these effects is an entirely different issue. For example, wildlife underpasses, road closings, and reduced speed limits are all strategies to combat road mortality for snakes

(Bernadino Jr. and Dalrymple, 1992) and other organisms. However, because of the extent of wetland habitat in the Pantanal, identifying wildlife hotspots and areas to implement mitigation infrastructure would be too extensive to be feasible. The low density of roads and huge expanses of intact habitat also do not incentive conservation and mitigation measures at present.

For mammals, the diversity of fauna in the Pantanal seems to create a much different situation than in the temperate wetlands of North America. A quick overview of the common mammals in temperate wetlands indicates relatively high diversity among small mammals and lower diversity among larger mammals (May, Wildlife Habitat Council. 2001). Large mammals, such as black bears (Larkin et al, 2004), do exist in wetland ecosystems in eastern North America, but, because of the extent, integrity, and connectivity of wetlands in this region, these wetlands do not constitute the primary habitat for most large mammal species. The highly fragmented nature, smaller size (in relation to the Pantanal), harsher climactic conditions, different physical structure, and the intense anthropocentric pressures associated with wetland patches in temperate North America create conditions that are not suitable for large mammals with large area and resource requirements. Therefore, regarding habitat for large mammals, wetlands in eastern North America fail to compare to the Pantanal.

Although an in depth inventory of the mammal species present in the Pantanal does not exist, 93 species of mammals have been confirmed to exist in the entire floodplain, with estimates ranging from that number to 132 different species (Junk et al, 2006). While the carrying capacity for large ungulates and large grassland adapted mammals is high for the Pantanal, only livestock have occupied this niche for almost 200 years (Junk, et al. 2006). The fact that cattle grazing over this time period did not cause major changes in vegetation types speaks to the Pantanal grassland's relatively empty niche, high potential carrying capacity for large mammals, and high diversity of existing and migratory mammals (Pott and Pott. 2004). Large, native herbivorous animals do not characterize the Pantanal, and Pantanal diversity of native ungulates and other large mammals is relatively low compared to other tropical environments. However, the number (of different species) and size of mammals that suffer from road mortality in the biome are both greater in the Pantanal than in temperate North American wetlands (Junk et al, 2006). For example, in eastern North America the white-tailed deer is the only large ungulate that experiences significant road mortality (Finder et al, 1999). In the Pantanal, six ungulates, the marsh deer, red deer, grey deer, field deer, white-lipped peccary, and collard peccary all experience low to moderate road mortality (Fischer et al, 2003). This is evidence that, despite the fact that mammal diversity in the Pantanal is relatively low compared with Sub-Saharan Africa or even its surrounding biomes, the number of species that experience road mortality are many times greater than in the temperate wetlands. This finding questions whether on road mortality for large mammals conducted in temperate regions can be applied to the Pantanal. The structure and diversity of mammal populations in the Pantanal cannot be compared to regions outside of the tropics. Also, the enormity of the Pantanal biome cannot be compared to any of the case studies I examined from eastern North America. The Everglades are similar to the Pantanal in that they share a similar climate characterized by a wet and dry season, and that the organisms living in both of these wetlands are adapted to the seasonal changes in the physical environment (Bernadino Jr. and Dalrymple, 1992). However, the Everglades lack the Pantanal's mammalian diversity, especially among larger species.

The most important way to conserve biodiversity in the Pantanal may be to approach biodiversity conservation from multiple perspectives relating to the type of organism. Wetland dependent species, such as amphibians, should be prioritized. Studies regarding the effects of roads on wetlands in other areas of the world could easily inform conservation strategies for amphibians and reptiles in the Pantanal. The Pantanal contains few endemic species (Junk and Cuhna, 2005), and many species and populations of particular species migrate in and out of the Pantanal seasonally. Therefore, large-scale habitat integrity and connectivity is particularly important between the Pantanal and its surrounding biomes, including the Cerrado, where many of the mammal species found in the Pantanal have source populations (Junk et al, 2006). Maintaining large areas of intact habitat would also benefit smaller wetland organisms, which are more affected by roads and road networks that bisect and highly fragment suitable habitat (Beaudry, et al. 2008). For large mammals in the Pantanal that have large habitat requirements and migrate over larger territories, maintaining regional connectivity between the Pantanal and Cerrado while simultaneously minimizing the effects of road mortality for roads in the region would be an acceptable and effective conservation strategy. For smaller organisms, the more local impacts of roads tend to also be very intense, and can lead to severely reduced habitat connectivity (Beaudry et al, 2008), biodiversity (Lehtinen, 1999), local population extinctions (Gibbs and Shriver, 2005), and unexpected road related effects (Bernadino Jr. and Dalrymple, 1992) such as new potential habitats in vulnerable areas next to the road. These findings stress a multi-dimensional and multi-scalar approach is necessary to mitigate the effects of roads in wetland regions. It also stresses the importance of incorporating local conditions, species assemblages, and physical geography when applying research conducted in wetlands from one biome to wetlands in another biome. Without local knowledge, the process of applying studies from one area to another can be both complicated and frustrating.

One similarity between the Pantanal and temperate wetlands in eastern North America is that they are both primarily privately owned, with 95% and 75% of the Pantanal (Seidl et al, 2001) and US wetlands (EPA) under private ownership respectively. The interest in wetlands conservation for wildlife in the eastern United States is primarily focused on ecosystem services (Noss, et al. USGS) and waterfowl, fish, other aquatic species. Large mammal conservation does not appear to be a priority in the wetlands of temperate North America. For the Pantanal biome, based upon the diversity of large mammalian fauna, I suggest conservation strategies focus upon large mammals. Interestingly enough, the only public lands in the Pantanal exist along the major roads, including the federally owned South Pantanal road where Fischer et al. inventoried road kill data in 2003. In an area where so much of the land is privately owned, conservation strategies might be implemented more easily along the roads. Facilitating the connectivity of habitat for large herbivorous and carnivorous mammals requires large infrastructure that allows for wildlife to cross roads. Providing wildlife crossings for large mammals in the Pantanal would hopefully also facilitate the movement of smaller terrestrial animals, such as amphibians and reptiles, whose slower movement, attraction to roadside, human-influenced wetlands, and overland migrations leaves them particularly vulnerable to vehicle related road mortality (Gibbs and Shriver. 2005). Since wildlife mortality is dramatically increasing for the South Pantanal (Fischer et al, 2003), probably due to higher traffic volumes associated with human development in the region, conservation measures to mitigate these impacts should be implemented as soon as possible. The pro-development economic and political situation in the region, and in Brazil as a country, is only adding to the anthropogenic pressures on the Pantanal wetlands (Junk et al, 2005). Recognizing that the effects from roads on surrounding ecosystems intensify over time (Findlay and Bourdages, 2000) only adds to the impetus to implement conservation strategies to minimize the effects that Pantanal roads have on the region's biodiversity.

Conclusion

Trying to apply research from one geographical region to another for similar habitats and ecosystems is challenging, but necessary for habitats facing increased pressure from economic development. Roads and transportation networks often accompany economic development in frontier regions, and this results in increased fragmentation and decreased connectivity for the habitats that these roads bisect. After analyzing the numerous studies focused upon road ecology in the wetlands of the eastern United States, some aspects of this research can apply to other wetland ecosystems. The Pantanal provides an excellent case study to test whether research in other wetland habitats can be applied to an understudied and ecologically unique environment threatened by future economic development.

Local knowledge is the most important information when developing conservation strategies to mitigate the effects of roads on wetlands. The lack of knowledge on road ecology studies in the Pantanal is due to both a lack of a comprehensive, complete understanding of the biome's ecology and biodiversity, and the present low-density of major roads in the region. With that said, scientists are beginning to understand the obvious environmental impacts of roads in the region through inventories of road mortality (Fischer, et al. 2003). These studies provide developers and conservationists with recommendations that include reconnecting and maintaining important ecological corridors bisected by roads, facilitating fauna passages, and encouraging partnerships between local communities and conservation organizations (Fischer, et al. 2003). However, analyzing research from the temperate wetlands of North America suggests mitigation strategies need to account for different types of organisms, different spatial scales, and physical habitat structure. Wetland habitats, regardless of geographic location, experience the effects of roads on broad ecological phenomenon, such as habitat connectivity, species richness, and biodiversity (Findlay and Houlahan. 1997; Fischer, et al. 2003). However, the effects of roads on wetlands differ between types of organisms, and when two separate, distinct biomes exhibit differences in species richness for these types of organisms, conservation strategies must acknowledge these differences. For instance, conservation strategies in the Pantanal must prioritize the protection of larger mammals more so than wetlands in eastern North America because the biodiversity of large mammals is greater. In eastern North America, the relatively isolated and fragmented nature of suitable wetland habitats (in comparison to the Pantanal) means that herptiles warrant greater conservation consideration than large mammals for the protection of biodiversity. Therefore, the main conclusion from this analysis is the effects of roads on broader, less-defined ecological phenomenon can be applied to all wetlands if more specific, localized ecological knowledge of species composition and habitat structure is understood for a particular area.

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Appendix

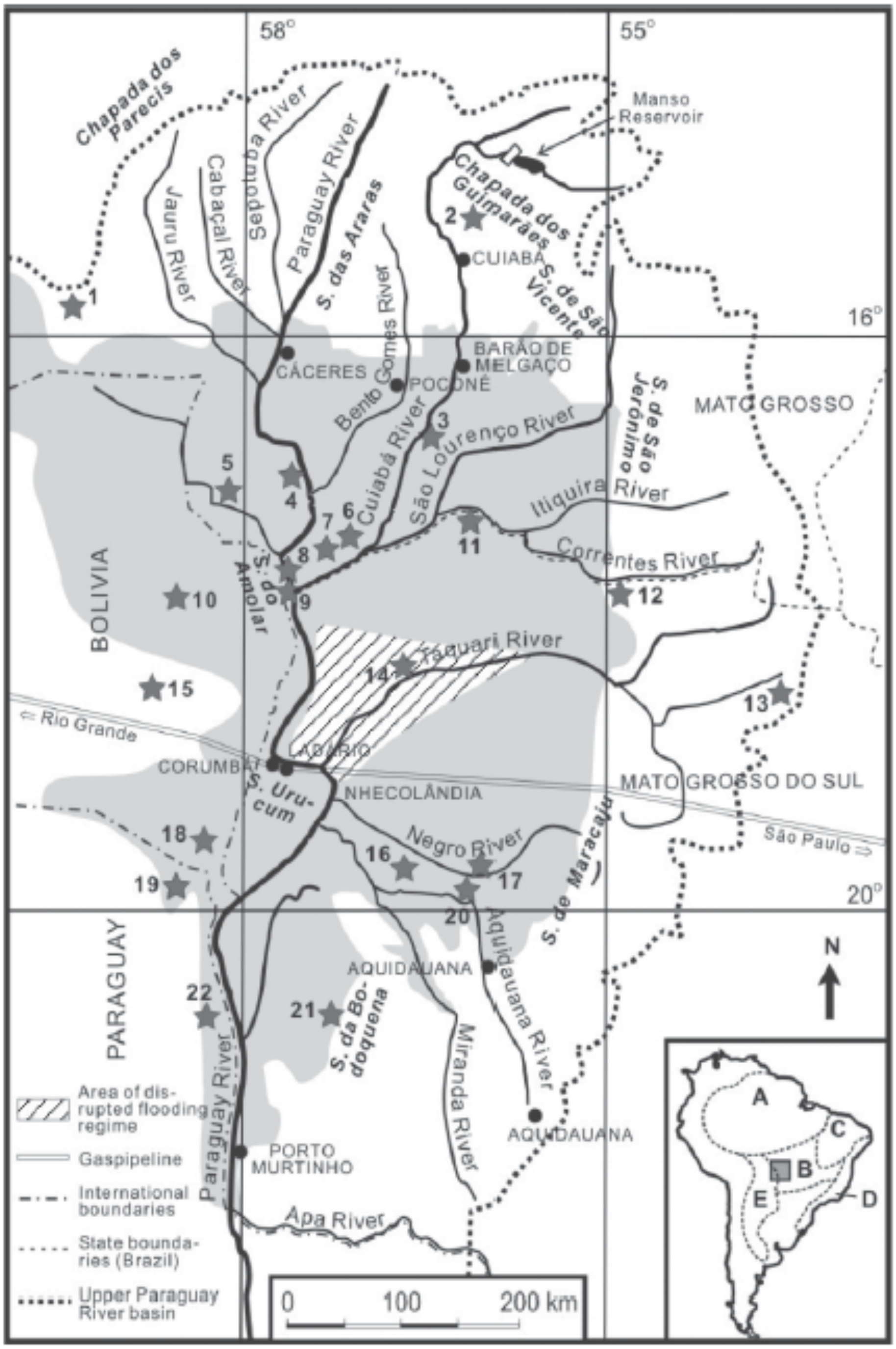

Figure 1. Map of the Pantanal and its catchment area and position of protected areas. 1 = Serra de Ricardo Franco State Park, 2 = Chapada dos Guimarães National Park, 3 = Serviço Social do Comércio Pantanal Private Reserve, 4 = Ecological Station Taiamã, 5 = Guira State Park, 6 = Private Reserve Dorochê, 7 = Pantanal National Park, 8 = Private Reserve Acurizal, 9 = Private Reserve Penha, 10 = National Reserve of Integrated Management San Matias, 11 = Fazenda Poleiro Grande Private Reserve, 12 = Serra de Sonora State Park, 13 = Nascentes do Rio Taquari State Park, 14 = Fazenda Nhumirim Private Reserve, 15 = Reserva Municipal del Valle de Tucavaca, 16 = Complex of the Pantanal do Rio Negro State Park and the Private Reserves Fazendinha and Santa Sofia, 17 = Fazenda Rio Negro Private Reserve, 18 = National Park and National Reserve of Integrated Management Otuquis, 19 = Rio Negro National Park, 20 = Dona Aracy Private Reserve, 21 = Serra da Bodoquena National Park, 22 = Fazenda Rancho Seguro and Tupaciara Private Reserves. For details see chapter 6. The hatched area around Nr. 14 indicates the area affected by the the hydrological changes at the lower Taquari River. The small map indicates the position of the Pantanal in South America and the biomes indicated in the text. A = Amazon forest, B = Cerrado, C = Caatinga, D = Atlantic forest, E = Chaco.

Table 1.
Herpetofauna road killed species in Cerrado and Pantanal transportation network, Brazil. (+)=rarely road killed; (++)=eventually road killed; (+++)=frequently road killed.

TAXA	**Family**	Species	**Vulgar Name**	**Cerrado**	**Pantanal**
AMPHIBIA					
Anura	Bufonidae	***Bufo spp.***	**Toad**	+++	+++
	Hylidae	*Hyla spp.*	Tree-frog		+++
	Leptodactylidae	*Leptodactylus spp.*	Rana	+	+
		Physalaemus sp.	Rana	+	
	Pseudidae	*Pseudis paradoxa*	Paradox-frog		++
REPTILE					
Chelonia	Chelidae	*Phrynops sp.*	Toad-headed-turtle		+
		Acanthochelis sp.	Turtle		+
	Testudinidae	*Geochelone carbonaria*	Red-foot-tortoise		
Crocodylia	Alligatoridae	***Caiman crocodilus yacare***	**Yacare-caiman**	+	+++
		Caiman latirostris	Broad-nosed-yacare		
Squamata					
Sauria	Iguanidae	*Iguana iguana*	Green-iguana		+
	Teiidae	***Ameiva ameiva***	**Green-ameiva**	+++	+++
		Tupinambis spp.	**Tegu**	++	+++
		Dracaena paraguayensis	Paraguay-caiman-lizard		+
	Tropiduridae	***Tropidurus spp.***	**Lizard**	++	++
Ofidia	Boidae	***Boa constrictor***	**Common-boa**	+	++
		Eunectes spp.	**Anaconda**		+++
	Colubridae	*Apostolepis sp.*	Ground-snake		
		Chironius spp.	Tree-snake		+
		Clelia occipitolutea	Musuranna	+	+
		Dipsas sp.	Slug-eating-snake		
		Drymarchon corais	Indigo-snake		++
		Erythrolamprus sp.	False-coral	+	
		Helicops leopardinus	False-water-snake		++
		Hydrodynastes gigas	**False-water-cobra**		+++
		Leptodeira annulata	Cat-eyed-snake		+
		Liophis spp.	Liophis		++
		Mastigodrias bifossatus	**Water-snake**	+	+++
		Oxyrhopus sp.	False-coral	+	+
		Philodryas spp.	Mato-grosso-racer		++
		Pseudoboa sp.	False-coral	+	
		Spilotes pullatus	**Tiger-ratsnake**	++	++
		Thamnodynastes strigilis	Brazilian-snake		+
		Waglaerophis merremi	**Brazilian-boipeva**	++	+++
	Elapidae	*Micrurus sp.*	Coral-snake		
	Leptotyphlopidae	*Leptotyphlops sp.*	Blindsnake		+
	Viperidae	***Bothrops spp.***	**Viper**	++	++
		Crotalus durissus	Rattlesnake	+	

*In bold, the most threatened species in both biomes.

Table 2.
Avifauna road-killed species in the Cerrado and Pantanal transportation network, Brazil. (+)=rarely road killed; (++)=eventually road killed; (+++)=frequently road killed; @=Brazilian red list species (MMA 2003).

Order	**Family**	*Species*	**Vulgar Name**	**Cerrado**	**Pantanal**
Rheiformes	Rheidae	***Rhea americana***	**Greater-rhea**	+++	++
Tinamiformes	Tinamidae	***Nothura spp.***	**Nothura @**	+++	++
		Tinamus spp.	Tinamou		+
		Crypturellus spp.	**Tinamou @**	+	+
		Rhynchotus rufescens	Red-winged-tinamou	++	
Pelicaniformes	Phalacocoracidae	*Phalacrocorax olivaceus*	Neotropic-cormorant		
Ciconiiformes	Ardeidae	*Ardea cocoi*	White-necked-heron		+
		Botaurus pinnatus	Pinnated-bittern		+
		Bubulcus ibis	Cattle-egret		+
		Butorides striatus	Striated-heron		+
		Casmerodius albus	Great-egret		+
		Egretta thula	Snowy-egret		+
		Tigrisoma lineatum	Rufescent-tiger-heron		+
	Ciconiidae	*Euxenura maguari*	Maguari-stork		+
		Jabiru mycteria	Jabiru		++
	Threskionithidae	*Ajaia ajaja*	Roseate-spoonbill		+
		Phimosus infuscatus	Bare-faced-ibis		+
		Theristicus caudatus	Buff-necked-ibis	++	+
Falconiformes	Accipitridae	*Accipiter striatus*	Sharp-shinned-hawk		
		Bursarellus nigricollis	Black-collared-hawk		+
		Buteo albicaudatus	White-tailed-hawk		
		Buteo brachyurus	Short-tailed-hawk		
		Buteo magnirostris	Roadside-hawk		+
		Buteogallus urubitinga	Great-black-hawk		+
		Elanus leucurus	White-tailed-kite		
		Harpyaliaetus coronatus	Crowned-eagle @		
		Heterospizias meridionalis	**Savanna-hawk**	++	++
		Milvago chimachima	Yellow-head-caracara		++
		Parabuteo unicinctus	Harri´s-hawk		
	Cathartidae	*Cathartes aura*	Turkey-vulture		++
		Cathartes burrovianus	Yellow-headed-vulture		+
		Coragyps atratus	**Black-vulture**	+++	+++
		Sarcoramphus papa	King-vulture		+
	Falconidae	*Falco sparverius*	Sparrow-hawk		++
		Micrastur gilvicollis	Lined-forest-falcon		
		Micrastur ruficollis	Barred-forest-falcon		
		Polyborus plancus	**Crested-caracara**	+++	+++
Anseriformes	Anatidae	*Anas spp.*	Pintail		
		Mergus octosetaceus	Brazilian-merganser @		
		Netta erythrophthalma	Pochard		
		Sarkidiornis melanotos	Comb-duck		
Galliformes	Cracidae	***Crax fasciolata***	**Curassow @**	+	+
		Penelope spp.	**Guan @**	++	++
Charadriiformes	Charadriidae	*Charadrius collaris*	Plover		
		Vanellus cayanus	Lapwing		
		Vanellus chilensis	Lapwing		
	Jacanidae	*Jacana jacana*	Jaçanã		+
Gruiformes	Aramidae	*Aramus guarauna*	Limpkin		+
	Cariamidae	***Cariama cristata***	**Seriema**	+++	+++
	Rallidae	*Aramides sp.*	Rail		++
		Rallus sp.	Rail		++
Columbiformes	Columbidae	*Columba spp.*	Pigeon		++
		Columbina spp.	Dove		++
		Geotrygon sp.	Dove		
		Scardafella squammata	Scaled-dove		
		Zenaida auriculata	Eared-dove	+	+

*In bold, the most threatened species in both biomes.

Table 2.
Continuation.

Order	Family	Species	Vulgar Name	Cerrado	Pantanal
Psittaciformes	Psittacidae	*Amazona sp.*	Parrot		+
		Anodorhincus hyacinthinus	Blue-macaw @		+
		Ara ararauna	Blue-and-yellow-macaw		
		Ara maracana	Blue-winged-macaw		
		Aratinga sp.	Parakeet		++
		Brotogeris chiriri	Parakeet		
		Nandayus nenday	Black-hooded-parakeet		++
		Pionus maximiliani	Parrot		+
		Pyrrhura sp.	Parakeet		+
Cuculiformes	Cuculidae	***Crotophaga ani***	**Smooth-billed-ani**	+++	+++
		Crotophaga major	Greater-ani		
		Guira guira	**Guira-cuckoo**	+++	+++
		Piaya cayana	Squirrel-cuckoo		
Strigiformes	Strigidae	***Athene cunicularia***	**Burrowing-owl**	++	+++
		Bubo virginianus	Great-horned-owl		+
		Glaucidium brasilianum	Ferruginous-pigmy-owl		
		Glaucidium minutissimum	Least-pigmy-owl		
		Rhinoptynx clamator	**Striped-owl**	+	++
		Pulsatrix perspicillata	**Spectacled-owl**	+	++
	Tytonidae	*Tyto alba*	Barn-owl	+	
Caprimulgiforme	Caprimulgidae	***Caprimulgus spp.***	**Nightjar**	++	++
	Nyctibiidae	*Nyctibius spp.*	Potoo	+	
Apodiformes	Apodidae	*Cypseloides senex*	Great-dusky-swift		
		Reinarda squamata	Palm-swift		
	Trochilidae	*Colibri semirrostris*	Violetear		
		Glaucis hirsuta	Hermit		
		Heliothryx aurita	Fairy		
		Phaetornis spp.	Hermit		
		Thalurania furcata	Violetear		
Coraciiformes	Alcedinidae	*Ceryle torquata*	Ringed-kingfisher		
		Chloroceryle americana	Green-kingfisher		
Trogoniformes	Trogonidae	*Trogon sp.*	Trogon		
Piciformes	Bucconidae	*Nonnula sp.*	Nunlet		
	Galbulidae	*Galbula sp.*	Jacamar		
	Picidae	*Celeus flavescens*	Blond-crest-woodpecker		
		Colaptes campestris	Campo-flicker	++	
		Picoides mixtus	Checkered-woodpecker		
		Veniliornis sp.	Woodpecker		
	Ramphastidae	***Ramphastos toco***	**Toco-toucan**	++	++
Passeriformes	Corvidae	*Cyanocorax spp.*	Jay		+
	Fringilidae	***Paroaria spp.***	**Cardinal**	++	++
	Furnariidae	*Furnarius rufus*	Rufous-hornero		
	Hirundinidae	*Notiochelidon cyanoleuca*	Blue-white-swallow		+
		Riparia riparia	Bank-swallow		
		Tachycineta albiventer	White-winged-swallow		
	Icteridae	***Gnorimopsar chopi***	**Blackbird**	++	++
	Mimidae	*Mimus saturninus*	Mocking-bird	++	
	Ploceidae	*Passer domesticus*	House-sparrow		
	Thraupidae	*Ammodramus humeralis*	Grassland-sparrow	+	
		Sporophila spp.	Seedeater		
		Thraupis sayaca	Tanager		+
		Volatinia jacarina	Grassquit	++	
		Zonotrichia capensis	Rufous-collared-sparrow		
	Trogloditidae	*Cistophorus platensis*	Grass-wren		
	Turdidae	*Turdus rufiventris*	Rufous-bellied-trush		
		Turdus amaurochalinus	Creamy-bellied-trush		
	Tyrannidae	*Myiozetetes cayanenis*	Flycatcher		
		Pitangus sulphuratus	Great-kiskadee		

Table 3.
Mastofauna road-killed species in the Cerrado and Pantanal transportation network, Brazil. (+)=rarely road killed; (++)=eventually road killed; (+++)=frequently road killed; @=Brazilian red list species (MMA 2003).

Order	Family	Species	Vulgar Name	Cerrado	
Rodentia	Agoutidae	*Agouti paca*	Paca		
	Caviidae	***Cavia aperea***	**Preá**	++	++
	Dasyproctidae	*Dasyprocta azarae*	Agouti		
	Erethizontidae	*Coendou prehensilis*	Porcupine	+	+
	Hydrochaeridae	***Hydrochaeris hydrochaeris***	**Capybara**	++	+++
	Muridae	*Holochilus brasiliensis*	Marsh-rat		
		Nectomys sp.	Water-rat	+	+
		Oecmys spp.	Rice-rat	+	+
		Oryzomys spp.	Rice-rat	+	+
Marsupialia	Didelphidae	*Caluromys philander*	Wooly opossum	+	+
		Didelphis spp.	**Common-opossum**	++	+++
		Micoureus cinereus	Mouse-opossum	+	+
Artiodactyla	Cervidae	***Blastocerus dichotomus***	**Marsh-deer @**		++
		Mazama americana	**Red-deer**	+	++
		Mazama goazoubira	**Gray-deer**	++	++
		Ozotocerus bezoarticus	**Field-deer**	++	+
	Tayassuidae	***Tayassu pecari***	**White-lipped-peccary**	++	+
		Tayassu tajacu	**Collared-pecary**	++	+
		Sus scropha	Wild pig		+
Perissodatyla	Tapiridae	***Tapirus terrestris***	**Tapir**	++	++
Edentata	Bradypodidae	*Bradypus variegatus*	Sloth	+	
	Dasypodidae	***Cabassous unicinctus***	**Naked-tailed-armadillo**	+	++
		Dasypus novencinctus	**Common-armadillo**	++	+++
		Euphractus sexcinctus	**Yellow-armadillo**	+++	+++
		Priodontes maximus	**Giant-armadillo @**	++	
	Myrmecophagidae	***Myrmecophaga tridactyla***	**Giant-anteater @**	+++	+++
		Tamandua tetradactyla	**Collared-anteater**	+++	+++
Lagomorfa	Leporidae	***Sylvilagus brasiliensis***	**Brazilian-rabbit**	+	++
Primata	Atelidae	***Alouatta caraya***	**Black-howler-monkey**	+	+
		Alouatta fusca	Red-howler-monkey		
	Callitrichidae	*Callithrix penicillata*	Marmoset	+	
	Cebidae	***Cebus apella***	**Brown-capuchin-monkey**	+	++
Carnivora	Canidae	***Cerdocyon thous***	**Crab-eating-fox**	+++	+++
		Chrysocyon brachyurus	**Manned-wolf @**	++	++
		Pseudalopex vetulus	**Brazilian-field-fox @**	+++	+++
		Speothos venaticus	**Bush-dog @**	+	+
	Felidae	***Herpailurus yagouarondi***	**Jaguarundi**	++	++
		Leopardus pardalis	**Ocelot @**	+	++
		Leopardus tigrina	**Oncilla @**	+	+
		Leopardus wiedii	**Margay @**	+	+
		Oncifelis colocolo	**Grass-wild-cat @**	++	++
		Panthera onca	**Jaguar @**	+	+
		Puma concolor	**Puma @**	++	++
	Mustelidae	*Conepatus semistriatus*	Skunk	+++	
		Eira bárbara	**Tayra**	++	+
		Galictis cuja	Grison	++	
		Lutra longicaudis	**Common-otter**	++	++
		Pteronura brasiliensis	**Giant-otter @**		+
	Procyonidae	***Nasua nasua***	**Coati**	++	++
		Procyon cancrivorous	**Crab-eating-raccoon**	+++	+++
Chiroptera	Molossidae	*Molossus spp.*	Mastiff-bat	+	+
	Noctilionidae	***Noctilio leporinus***	**Fishing-bat**		++
	Phyllostomidae	*Anoura spp.*	Long-tonged-bat		
		Artibeus spp.	Fruit-eating-bat		
		Carollia spp.	Short-tailed-bat		
		Desmodus rotundus	Common-vampire		
	Vespertilionidae	*Myotis spp.*	Little-brown-bat	+	+

*In bold, the most threatened species in both biomes.